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Refined Ambitions: Exploring Australia's Low Carbon Liquid Fuel Potential

July 2025

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A message from the CEFC

Liquid fuels are vital to Australia's future, whether viewed through the lens of our enduring economic strength, our sovereign fuel security, or our efforts to cut emissions to limit the worst impacts of climate change.

Economically, our massive and diverse land mass underscores our reliance on these energy dense liquid fuels to support heavy and long-distance payloads. Equally, our relatively remote location means we need ready onshore access to substantial physical reserves of these vital fuels. And from an emissions perspective, there is no doubt that achieving net zero emissions by 2050 must include the widespread adoption of low carbon liquid fuels to replace the high emitting fossil fuels currently in use.

Refined ambition: fuelling net zero
As a specialist investor backing our net zero ambitions, the Clean Energy Finance Corporation (CEFC) is all too aware that the undoubted economic benefits of these liquid fuels are not without an emissions cost. And with Australia's growing consumption of these fuels already driving as much as 32 per cent[1] of national emissions, there is increasing awareness of the need for alternative solutions. This report by Deloitte, *Refined Ambitions: Exploring Australia's low carbon liquid fuel potential*, provides a timely discussion of this potential.

Low carbon liquid fuels – LCLFs – can be an essential part of our net zero future, particularly in critical economic sectors where electrification has limitations. LCLFs are also critical to the development of a resilient sovereign energy supply.

Refined ambition: a resilient fuel supply
LCLFs are a form of renewable energy, whether drawn from biogenic feedstocks, such as sugarcane and animal fats, or non-biomass resources, such as captured carbon dioxide and hydrogen.

Global LCLF production has increased by more than 100-fold in the past 20 years, a remarkable rate of growth which shows no signs of halting. Globally, more than 71 BL[2] of additional LCLF capacity is targeting production by 2030.

Australia's liquid fuel demand is materially exposed to these international supply chains. In the 12 months to November 2024, Australia refined only ~20 per cent of its fuel, reflecting a 14-year trend that has seen domestic refining capacity decline from ~75 per cent of national consumption. Key parts of our economy – including heavy industry, freight, mining, tourism and our defence forces – rely on the surety of liquid fuel.[3]

Refined ambition: driving economic growth
LCLFs are compatible with existing infrastructure, including heavy road and mining vehicles and aircraft. They are generally closer to commercialisation than electrification and hydrogen fuel cells in key liquid fuel using sectors.[4]

We commissioned this report from Deloitte to deepen understanding of the potential of LCLFs. It is relevant for the suppliers of these fuels; for the users who will drive the necessary demand; for the policymakers who will establish the building blocks of the industry; and for the investors who will provide the much-needed capital.

This analysis shows that most of the $15 billion domestic feedstock opportunity required by 2050 to underpin domestic refiners will be supplied by Australia's agricultural sector. This would support a total domestic LCLF market valued at more than $36 billion in today's dollars. The potential emissions benefits are also substantial, representing a cumulative reduction of as much as 230 Mt-CO_2-e by 2050.[5]

The CEFC has a long track record of helping build the new energy sources and economic opportunities of our net zero future. This report demonstrates our commitment to bringing this deep sector experience to the LCLF sector. Our ambition is to play a leading role in our LCLF future, providing flexible finance and collaborating with investors, innovators and industry leaders.

Yours sincerely,

Ian Learmonth
Chief Executive Officer, CEFC

Rupert Maloney
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[1] DCCEEW and Australian National Greenhouse Accounts Factors
[2] Deloitte LCLF Project Database
[3] Refer chapter on Market Context
[4] Refer chapter on Market Context
[5] Refer chapter on Market Development

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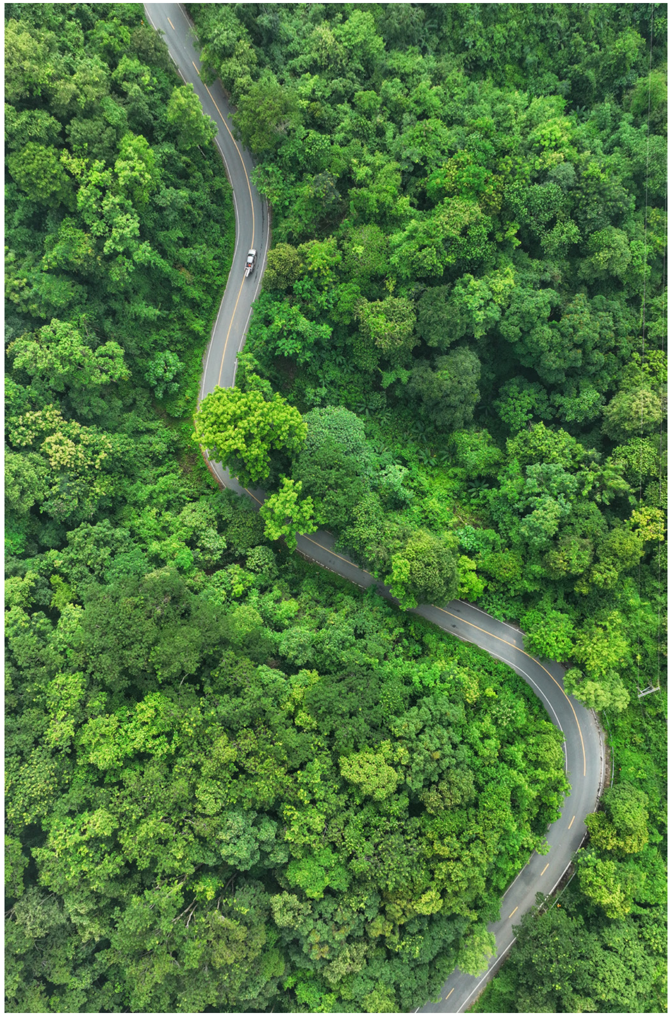

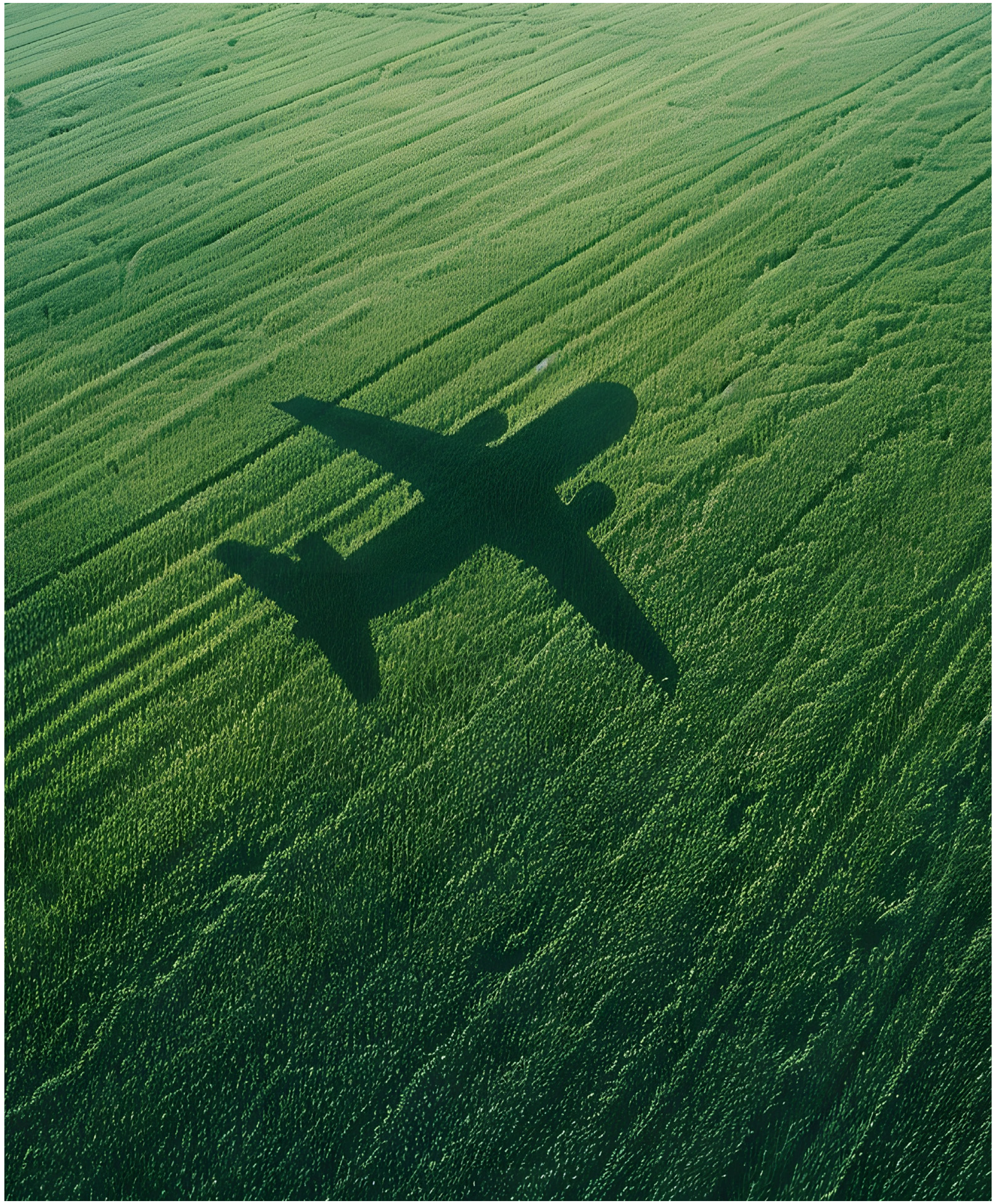

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ACCU	Australian Carbon Credit Unit
APAC	Asia-Pacific
ASTM	American Society of Testing and Materials
AtJ	Alcohol-to-Jet
BL	Billion Litre
CCA	Climate Change Authority
CCS	Carbon capture and storage
CO_2-e	Carbon Dioxide Equivalent
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
dLUC	Direct Land Use Change
DOE	Department of Energy
EMEA	Europe, Middle East, and Africa
EPC	Engineering, Procurement and Construction
ETS	Emissions Trading System
EU	European Union
FID	Final Investment Decision
FT	Fischer-Tropsch
FTC	Fuel Tax Credit
GO	Guarantee of Origin
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Technologies
HEFA	Hydroprocessed Esters and Fatty Acids
HVO	Hydrotreated Vegetable Oil
IEA	International Energy Agency
ILUC	Indirect Land Use Change
ISCC	International Sustainability and Carbon Certification
LCA	Life Cycle Assessment
LCLF	Low Carbon Liquid Fuel

MJ	Megajoule
ML	Megalitre
Mt	Megatonne
MSW	Municipal Solid Waste
NBS	Nature Based Solutions
NSW	New South Wales
OEM	Original Equipment Manufacturer
PJ	Petajoule
PtL	Power-to-Liquids
QLD	Queensland
RD	Renewable Diesel
R&D	Research and Development
REDD	Reducing emissions from deforestation and forest degradation in developing countries
RFS	Renewable Fuel Standard
RIN	Renewable Identification Number
RSB	Roundtable on Sustainable Biomaterials
SA	South Australia
SAF	Sustainable Aviation Fuel
SOC	Soil Organic Carbon
TAS	Tasmania
TRL	Technology Readiness Level
UCO	Used Cooking Oil
US	United States
VIC	Victoria
WA	Western Australia
WTP	Willingness to Pay

Executive Summary

Executive Summary

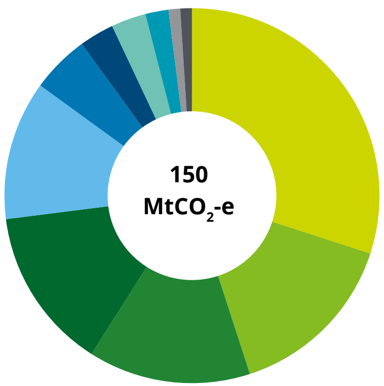
Australia is a major user of liquid fuels, consuming over 56 BL annually

Liquid fuels are central to the energy demands of 11 major sectors of the Australian economy. As the world decarbonises, ongoing dependence on imported liquid fuels will leave these crucial sectors exposed to international volatility.

Low carbon liquid fuels (LCLFs) have a critical role to play in maintaining the competitiveness of Australian liquid fuel users in a decarbonising world

Today, liquid fuel use accounts for ~32 per cent of national emissions. The road transport sector (consisting of passenger cars, light commercial vehicles and heavy freight) is the biggest fuel user. But key pillars of our economy – mining and aviation – collectively represent another 29 per cent of fuel demand.

Figure A: 2022–23 Emissions by fuel use sector[1]



The pace of electrification is increasing markedly as battery prices continue to fall and new models enter the passenger, light commercial, and haulage segments. However, a significant share of Australia's liquid fuel demand is hard-to-electrify, meaning net zero targets could be at risk without other decarbonisation options.

The development of an Australian LCLF industry can deliver the decarbonisation of Australia's hard-to-electrify sectors, with up to a cumulative 290 $MtCO_2$-e abated to 2050 in an Accelerated Scenario. Our economy is characterised by significant reliance on long-distance transport and remote operations. Most of our aviation and long-haul freight travel sufficient distances such that payload and energy density make electrification challenging. Similarly, remote locations and the practicalities of new generation, transmission and distribution assets suggest that our miners will prioritise electrification of newer assets where costs can be spread across a significant asset life. LCLFs offer a promising avenue for these sectors to decarbonise in both the medium and long-term.

Australia's fuel security challenges have been worsening over time, with 80 per cent of liquid fuels imported, costing ~$50.7 billion in 2023

Australian refining capacity has declined by 70 per cent over the past two decades, with 90 per cent of the country's imported liquid fuels coming from Asia.[1] Remaining refinery capacity in Australia is anticipated to face these competitive pressures going forward. Further, even if electrification trends continue, hard-to-abate sectors will remain exposed to this fuel security threat.

This is particularly pertinent for the Australian Defence Force (ADF) which is reliant on liquid fuels for operations.

LCLFs offer an avenue for developing sovereign liquid fuel capacity to mitigate our import exposure

An LCLF industry would facilitate the enhancement of Australian domestic fuel security by developing sovereign capability and resilience. In a decarbonised world, Australia is anticipated to still require 30 BL of liquid fuels, predominantly in the mining, aviation and long-haul freight sectors. Sovereign capacity in LCLF production is critical to ensuring the long-term competitiveness of these industries and the economic security of 375,000 workers highly dependent on these industries.[2]

The production of LCLFs can boost Australia's economic prosperity, with benefits flowing directly to regional communities

An LCLF industry can also deliver a significant economic benefit to Australian farmers and fuel producers. This analysis shows that most of the $15 billion domestic feedstock opportunity required by 2050 to underpin domestic refiners will be supplied by Australia's agricultural sector. This would support a total domestic LCLF market valued at more than $36 billion in today's dollars.[3] With feedstock comprising up to 70 per cent of production costs, this represents a significant economic opportunity for Australia's agricultural sector to diversify income streams for farmers and regional communities.

Furthermore, the development of sovereign production capacity offers a pathway for onshoring greater value-added production.

Sources: 1. Liquid fuel demand and emissions calculated using liquid fuel demand by sector in accordance with Australian Government (DCCEEW), applying scope 1 emission intensity values from Table 8 of the Australian National Greenhouse Accounts Factors. 2. Bioenergy Australia, 2025. 3. CSIRO, 2025.

Advancing economies are embracing LCLFs, with 10 regions having implemented or announced LCLF mandates, and global supply reaching 33 BL as of 2024

LCLF demand has been rising steadily in recent years, driven by government policy. Several countries including in Europe and across Asia Pacific have announced mandates for uptake – largely in aviation. In parallel, supportive supply-side policies have seen global production capacity grow 4x in the decade from 2014 to 2024.

The Australian agriculture sector has a competitive advantage with our abundant feedstock resources to supply the global LCLF market

Australian tallow and canola are major feedstocks for LCLF production. These feedstocks are exported to Europe and Asia where they are transformed into LCLFs for use in those markets.

In the future, Australia can leverage this comparative advantage in feedstocks to play a greater role in global trade, at great benefit to regional communities.

Major investors across the liquid fuel supply chain are vying to develop domestic LCLF production capacity, with over two billion litres of capacity in the project pipeline

Investors are seeing demand signals from potential LCLF end users as well as Australia's feedstock comparative advantage as a lucrative opportunity to invest in domestic LCLF production capacity.

Australia is positioned to be a significant regional market producer, with emerging LCLF production capacity similar to our larger neighbours. Current project pipelines show Australia with ~2,000 ML of capacity, comparable to other emerging regional players like South Korea (2,300 ML) and Japan (2,100 ML).

The Australian state and federal governments are positioning policy to support investment to unlock the LCLF opportunity for the agricultural, fuels and end use sectors.

State and federal government support for the development of an Australian industry is clear, with announced policies offering the green shoots for investment opportunities. Key recent announcements include:

- **Federal:** consideration of supply and demand side support under the Future Made in Australia policy package, with $250 million allotted for LCLF supply chains.
- **State:** The development of a NSW Renewable Fuels Strategy and funding announcements from the NSW, QLD and WA governments.

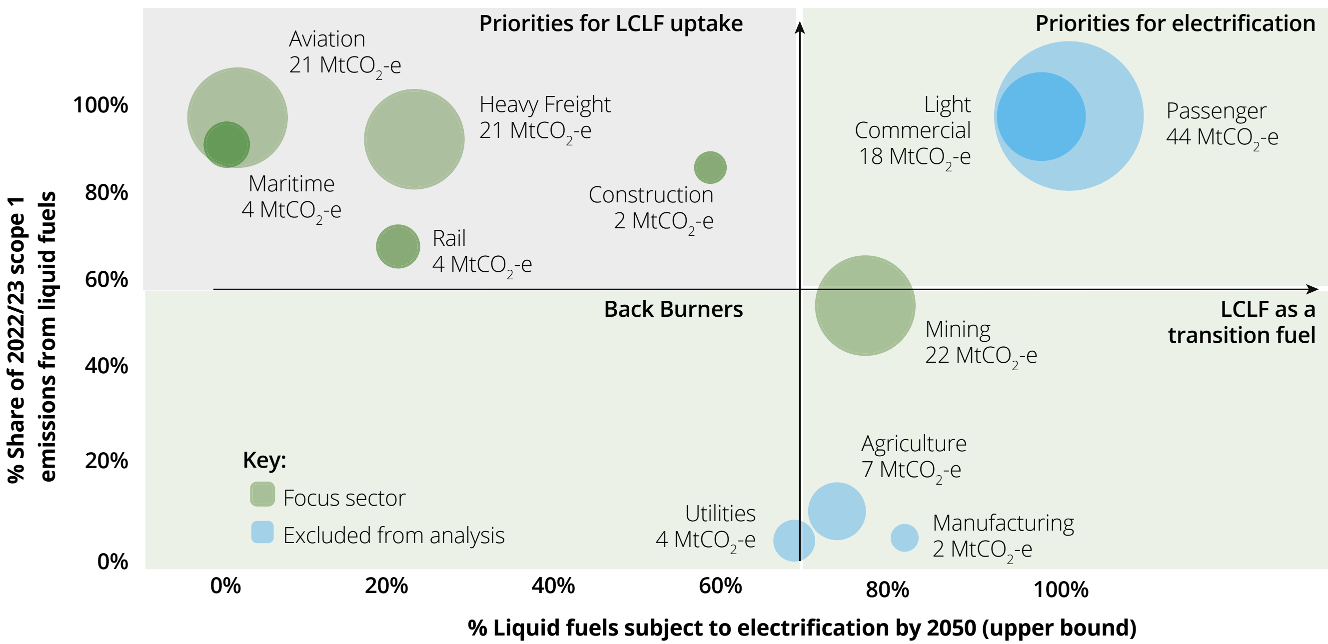
Cooperation with our regional trade partners around energy security will support investment in the domestic industry

A thriving LCLF industry provides an opportunity for our trading partners to invest in Australian agriculture feedstock supply and LCLF production projects to ensure their energy supply security, similar to existing investment within the natural gas sector. Getting buy-in from our regional trading partners is critical to future green statecraft conversations, particularly as Australia becomes less reliant on international supply of liquid fuels.

Development of an Australian LCLF sector will accelerate the decarbonisation of six hard-to-electrify sectors which are vital to Australia's economic interests and key to Australian decarbonisation goals

Australia's hard-to-electrify challenge is concentrated in six priority sectors: aviation, mining, rail, maritime, heavy freight and construction. If we do not decarbonise these sectors, Australia will struggle to deliver on net zero targets. In addition, fuel demand is rising in more than half of these sectors, which could see their emissions rise rather than fall.

Figure B: Identifying priority sectors for LCLF uptake



LCLFs are a unique decarbonisation pathway as they can serve as a direct drop in solution in existing infrastructure for hard-to-electrify fuel use cases. Furthermore, LCLFs are closer to commercialisation than electrification and direct hydrogen use for hard-to-electrify sectors and meet the high gravimetric and volumetric energy density needs of these end use applications.

Fuel users in priority sectors are willing to purchase fuel on an abatement cost basis but face a material cost gap relative to traditional liquid fuels

Interviews with market participants in the priority sectors for LCLF uptake highlight that:

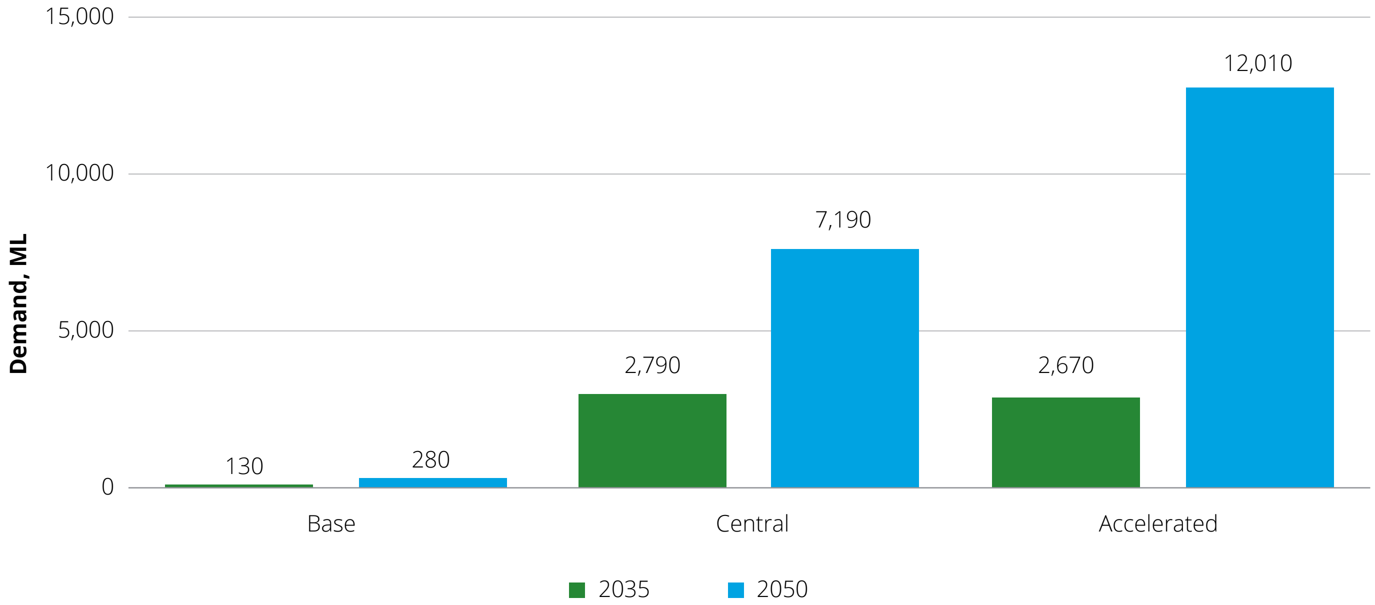
- Fuel users intend to purchase on an abatement cost basis, rather than a flat $/L basis.
- A cost gap is present for all fuel users, although this is more pronounced for sectors where traditional liquid fuels are cheaper (e.g. mining inclusive of the fuel tax credit or the cost of jet fuel).
- On abatement cost terms, LCLFs similarly face a large cost gap to other abatement solutions such as offsets which trade below $40/tCO$_2$-e. However, reaching net zero across Australia's economy by 2050 will require greater investment in direct abatement by these industries.
- Mining and aviation are likely to be the biggest potential user segments. The aviation sector has demonstrated the ability to convert some demand into viable cost premiums.
- LCLFs are one of the only material abatement pathways for rail freight and maritime fuel users. LCLFs are available to these sectors as a drop in solution today.
- Road freight and construction are fragmented sectors but have the opportunity for large companies to be offtakers for LCLF.

LCLF demand could reach between 130-2,790 ML in 2035, with the speed and scale of demand determined by policy settings

Market participants have consistently expressed a view that Australia's demand outlook for LCLFs is unclear, and that demand is a necessary precondition for market formation. Three *hypothetical* scenarios were developed to quantify this:

- **Base Scenario (Market-led Transition):** Economy wide carbon costs remain too low to drive significant LCLF uptake across most sectors. Demand for LCLF is driven by a small subset of end customers willing to pay significant amounts to reduce their scope 3 emissions.
- **Central Scenario (Offset Constrained Transition):**[1] Firms are more focused on direct on-site decarbonisation initiatives to meet their transition to a lower carbon economy. This outcome is achieved through adapting the Safeguard Mechanism and/or voluntarily by participants by adopting a minimum 70 per cent direct on-site decarbonisation as opposed to utilising the majority of offsets in the Base Scenario. They achieve this direct on-site decarbonisation in a rational manner – prioritising lower abatement cost initiatives over higher ones.
- **Accelerated Scenario (Highly Regulated Demand):**[1] Policy intervention mandates LCLF uptake in a manner identical to the ReFuelEU policy on the aviation and maritime sectors. Demand for other sectors as consistent with the Central Scenario.

Figure C: Demand scenarios for 2035 and 2050



Notes: 1. The policy assumptions driving demand in the Central and Accelerated Scenarios are not announced government policy or included as optimal policy interventions. They have been included to illustrate how market dynamics could react to different types of policy intervention.

Australia's biogenic feedstock endowments could be processed into 12.8 BL of LCLF potential by 2050[1]

It is clear Australia has significant biogenic feedstock potential which could enable a scaled LCLF industry. The most recent estimates from CSIRO suggest that Australia's biomass and renewable potential could theoretically convert into 7.2 BL of fuel in 2030, rising to 12.8 BL by 2050.[1] This is comparable to the estimates within this work, as illustrated within Figure D. For feedstocks which are not currently collected and processed, additional investment will be required.

Australia remains the lucky country, producing significant quantities of feedstock for commercially proven technology pathways

Australia produces significant quantities of feedstocks ideally suited to the most commercially proven Hydroprocessed Esters and Fatty Acids (HEFA) LCLF technology (Figure D). This agricultural advantage is likely to grow for HEFA given Australia's ability to expand production of canola and other novel oilseeds.

Australia is endowed with the feedstocks which will feed the next generation production pathways

Australia is a major producer of sugar and carbohydrate-based feedstocks (e.g. sugar, sorghum and wheat) which are key to LCLF production through the Alcohol-to-Jet (AtJ) pathway. Additionally, Australia has an abundance of agricultural residues and wastes which are well suited to the Fischer-Tropsch (FT) production pathway.

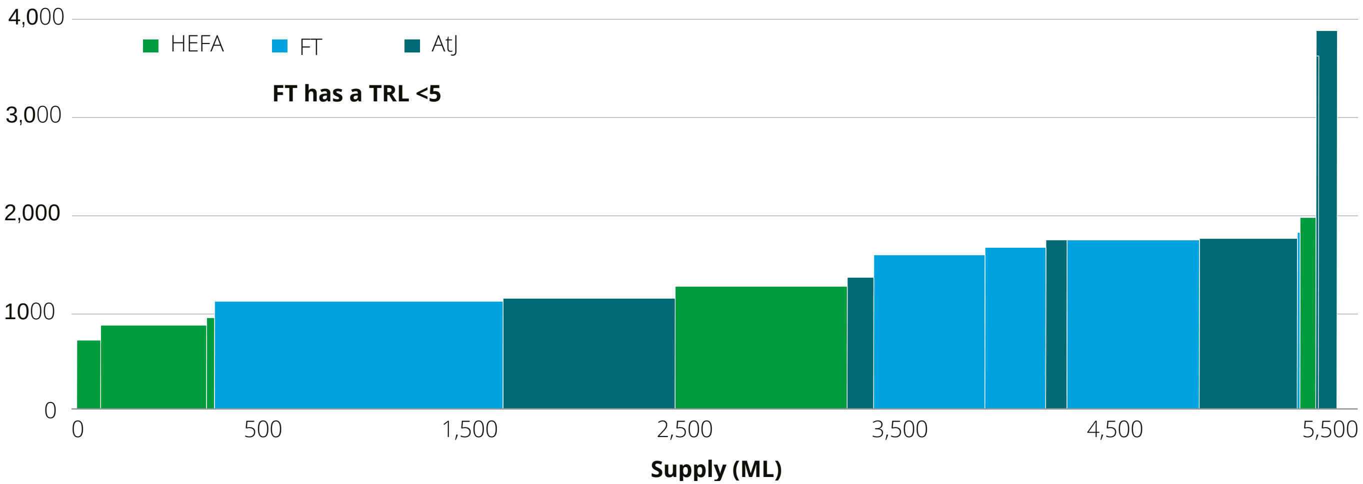
Australia's comparative advantage in agriculture and renewable energy could be unleashed to accelerate domestic and international decarbonisation.

Australia can further boost our supply of key biogenic and domestic feedstocks through dedicated supply methods (e.g. short rotation trees and crop rotations). Additionally, Australia's endowment of renewable energy positions us well to benefit from declining electricity and hydrogen costs to further supply Power-to-Liquids (PtL) based fuels.

From a fuel supply perspective, Australia is rich with potential

As illustrated in Figure D, domestic production of over 5,000 ML of sustainable aviation fuel (SAF) by 2030 is possible. While the abatement cost for this production remains substantial—it represents a crucial investment in establishing a sustainable industry, essential for Australia's decarbonisation efforts.

Figure D: 2030 Australian LCLF supply curve , $/tCO_2$-e for SAF



Notes: 1. CSIRO, 2025.

Beyond HEFA, alternative production technologies could deliver structural price declines in the mid to long-term

While the HEFA pathway is expected to experience learning rates and refining cost efficiencies over time, due to the feedstock cost being an outsized contribution to the LCLF cost stack, future price reductions will be less than newer pathways.

Newer pathways, including AtJ and FT, are being explored by prospective producers. These less mature technologies should experience more significant learning rates.

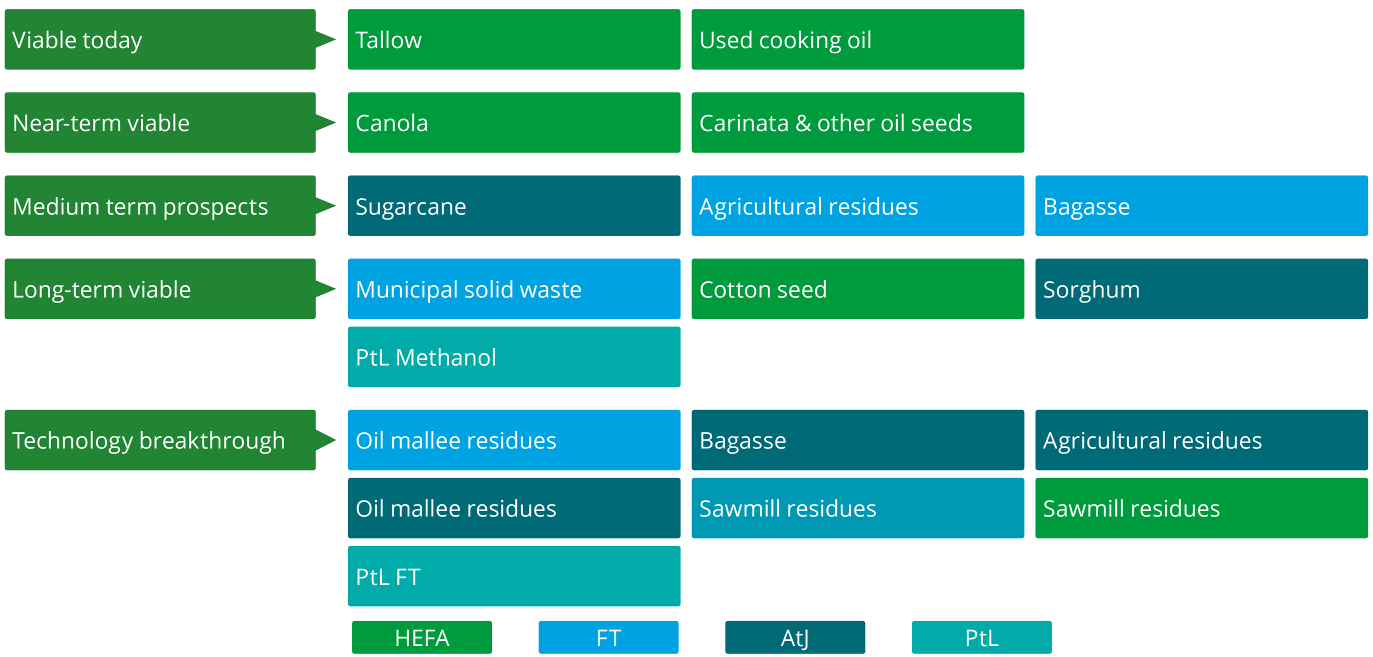
The PtL pathway will experience the largest learning rates (driven by learning rates for renewables and electrolysis technologies), which is expected to result in structural price declines in the mid to long-term.

As a result of these dynamics, several technology–feedstock combinations become more attractive on an abatement cost basis over time.

In the current market context, a relative hierarchy of feedstocks is emerging

A range of factors contribute to the choice of feedstock for a biorefinery. These include costs and emissions intensity, ease of aggregation, and competition from alternative use cases. An interrogation of these factors can inform a subset of feedstocks which are viable today or near-term viable. Similarly, it can highlight where feedstocks may rely on a technology breakthrough for future competitiveness.

Figure E: 2025 LCLF Feedstock Ladder



Continued innovation is needed to deliver structural price declines for all production pathways

The Feedstock Ladder (refer to Figure E) and cost modelling makes clear that innovation is the primary pathway to materially improve the cost competitiveness of LCLFs. Three pathways should be R&D and commercialisation priorities:

1. **Feedstock Cost Reductions:** Current work to reduce feedstock costs include increasing feedstock crop yields (e.g. lifting oilseed yields), utilisation of cover crops to improve land productivity, improving the efficiency of collection and sourcing networks, and economies of scale for pre-treatment.
2. **Yield Improvements:** Processing yield improvements have a multiplier effect on cost reductions. This can include optimising the syngas ratio using hydrogen injection in FT and improving sugar extraction for AtJ, through process change.
3. **Carbon Intensity Improvements:** Reducing the carbon intensity of feedstocks can be delivered either on farm or via Carbon Capture and Storage (CCS) for intermediate processing.

The development of an Australian LCLF industry is contingent upon our approach to several market challenges

The development of Australia's LCLF market is still emerging and key dynamics including value of emissions abatement, decarbonisation targets, and the shape of the supply curve will determine commercial outcomes. Domestic production and re-gional trade demand evolution will be driven by:

- How fuel security is prioritised in the Australian context;
- The abatement contributions LCLF can realise and how marginal abatement costs evolve;
- How demand evolves across sectors, and whether sectors remain more reliant on LCLFs or offsets to meet commitments;
- Which production technologies and feedstocks are needed to service demand, and when; and
- The scale of feedstock demand (crops, wastes, hydrogen) and how market share evolves between feedstocks.

A Market-led Transition Scenario could see Australia emerge as a significant feedstock player

Australia is a winner from the emergence of LCLF demand globally through our comparative advantage in feedstocks. In this scenario, Australia may also be able to stand up a HEFA facility on an export basis due to competitive local feedstocks, but local demand for LCLFs is unlikely to be material without policy intervention, with limited on-site decarbonisation achieved.

In a Highly Regulated Demand Scenario mirroring Europe's mandates, a sizeable LCLF market is achieved, but risks higher costs

Introduction of a comparable mandate to ReFuelEU would drive significant LCLF activity in the 2030s. Supply would need to grow significantly to exceed 5,500 ML by 2040. HEFA and FT will dominate, conditional on FT overcoming its low Technology Readiness Level (TRL) (FT TRL is currently <5). AtJ also enters the market, but only via first generation ethanol. The dynamic then changes materially in the 2040s as less competitive lignocellulosic feedstocks are displaced by PtL.

The mandate drives significant abatement across liquid fuel sectors, with up to 35 $MtCO_2$-e p.a. abated by 2050. The biggest challenge for mandated demand is the increasing marginal cost of abatement with the penetration of PtL to meet demand. In 2040, the average abatement cost for a HEFA/FT dominated market is estimated as $547/$tCO_2$-e. By 2050, this rises to over $1,056/$tCO_2$-e as a result of PtL crowding in.[1]

An Offset Constrained Transition Scenario can balance demand regulation and drive fuel supply competition

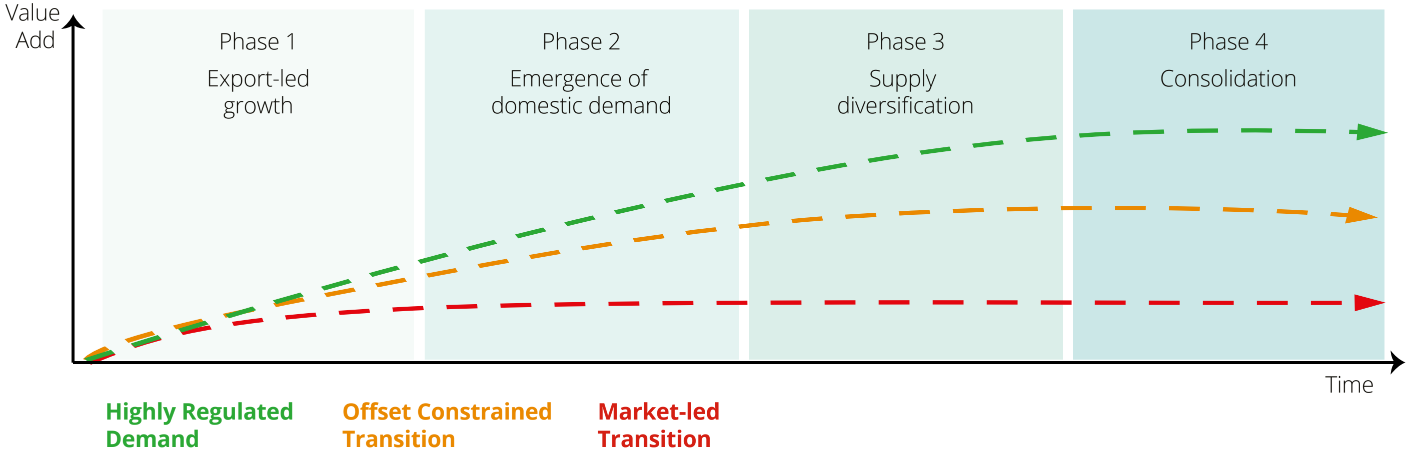
Firms preferencing on-site emissions reduction through either voluntary adoption or the Safeguard Mechanism would drive the development of an LCLF market and free up ACCUs for use in sectors which cannot achieve on-site decarbonisation due to technical challenges. By 2050, 36 facilities at an assumed scale of 200 ML each would be required, representing a significant advancement relative to an unguided transition.

Importantly, the emergence of scaled demand triggers a positive supply-side response, driving significant technology deployment and competition between pathways and feedstocks. Relative to a market-led transition, production costs fall faster, and feedstock collection improves, increasing availability of biogenic feedstocks. This delivers sustained reductions in marginal abatement costs for fuel users.

Four structural dynamics are evident across the scenarios

1. Competition between production pathways is a prerequisite to lower abatement costs over the long run and to driving step change reductions in abatement costs.
2. The speed of cost reductions will determine the timing of biogenic and synthetic fuel competition in the market.
3. Efficient market pricing will be key to manage the co-evolution of SAF and Renewable Diesel (RD) demand. Policy settings that distort price signals could have unintended consequences.
4. Policy will ultimately determine how quickly LCLF demand emerges, the complexity of domestic value chains, and market competition dynamics. But the early investments will likely have an export focus.

Figure F: Expected phases of market development



Investors face five interrelated risks which currently inhibit private investment and industry scale up

Investors recognise Australia's LCLF production potential, and the growing pipeline of feedstock and refinery projects. But five related investment risks currently make capital allocation challenging in the Australian market. Risks include: (i) the unpredictability of demand, (ii) price risk, (iii) feedstock risks, (iv) immature technology deployment ecosystems and (v) policy uncertainty.

Without resolution of these risks, a competitive, efficient, and lowest abatement cost LCLF market will not develop in Australia. International markets have overcome these barriers, and progressed to real transactions, live projects, and on-site abatement.

These risks have been recognised by the Australian Government. Grants available under the Future Made in Australia Innovation Fund and the establishment of the Australian Jet Zero Council, in conjunction with the CEFC's concessional finance, are all working to help alleviate these risks.

Sources: 1. Please see page 65 for the analysis of all three scenarios.

Investment challenges manifest differently depending on the stage of market development

Each sequential phase of market development will require different mitigants to unlock. Unlocking export-led growth will require a focus on access to export markets and scaling Australian feedstocks. Transitioning to domestic demand will require a significant pivot.

Seven accelerators can scale up the Australian LCLF market, with specific actions determined by the stage of market development

There are a broad range of potential actions which actors across the LCLF value chain can take to manage investment risks and scale the market. These have been summarised in Figure G which outlines potential accelerators for Australia's LCLF market.

Coordinated near-term action can leverage Asian mandates to lay the foundation for an Australian value chain

To capture a growing share of Asian LCLF demand, Australia will need to prioritise market access and speed. Feedstock exports and processing infrastructure remain the immediate opportunity. A coordinated approach will be needed from Australian projects and policymakers to facilitate partnerships – primarily focused on ensuring market access and recognition of Australian farming practices. In parallel, market actors can invest today in initiatives that are demand agnostic – primarily in innovation and market transparency.

If Australia can manage the transition from export-led production to delivering domestic decarbonisation, it can harness the fuel security and economic benefits

Domestic emissions reductions can only be realised via domestic demand. Importantly, when domestic demand emerges, it will be coupled to global prices from day one, as it will need to divert feedstock or fuel from existing customers.

A credible demand signal will be needed to begin the managed transition from an export-oriented market, coupled with actions to reduce the cost gap. Accelerating the transition to scale will be critical at this point, with price discovery and increasing feedstock supply essential. Only with these ingredients can market forces and private capital drive outcomes.

Ensuring a competitive market in the future will require near-term decisions to be balanced with the enablers of long-term efficiency

Consumers would be disadvantaged by a market with limited competition. Abatement costs for consumers reduce if competition between production pathways eventuates and drives innovation. However, investment risks are more substantial for newer production pathways than for HEFA.

Enabling competition requires reduction of information asymmetry and mitigants for risk.

A scaled LCLF market can deliver an economic, security and climate dividend for Australia, but will require coordination across the value chain to realise

Figure G: Potential market accelerators

01	**Increase market access**	Increasing Australia's market access to LCLF offtakers, new markets for feedstocks, and access to tech suppliers and EPCs
02	**Increase available risk mitigants**	Offering new risk mitigants for financing challenge: including concessional finance, grant programs, insurance products, and revenue certainty mechanisms
03	**Reduce transaction frictions**	Reducing market frictions by levelling the playing field for technologies and standardising contract terms
04	**Send a credible demand signal**	Underwrite initial demand volumes, including via longer term offtake agreement or through regulation
05	**Reduce information asymmetry between market participants**	Reducing information asymmetry by developing benchmarks, publishing forward expectations of demand, supply, and feedstocks
06	**Leverage innovation to spur cost reductions**	Leveraging innovation to put downward pressure on costs, largely through feedstocks and by increasing fuel yields
07	**Align interests across the value chain**	Supporting alignment of interests through commercial models, vertical integration and partnerships

1: How can LCLF support Australia's decarbonisation journey?

Australia consumes over 56 BL of liquid fossil fuels each year across 11 major sectors of the economy. This liquid fuel use accounted for nearly 150 $MtCO_2$-e in 2022–23; ~32 per cent of domestic emissions. LCLFs have a large role to play in decarbonisation of liquid fuels when no viable alternative low-carbon technology exists.

In global markets, LCLF production is scaling rapidly due to supportive climate and economic policies, with global supply reaching 33 BL as of 2024. Australia plays an important role in these markets by exporting a range of feedstocks which are upgraded into fuel. Momentum for a new generation of production is growing, with 12 advanced LCLF projects in various stages of development across the country.

Noting the evidence gaps that operate to inhibit market activation, this study seeks to develop an updated analysis of the commercialisation economics for domestic LCLF supply and end-use applications to provide market participants with new insights and an evidence base to advance their consideration of LCLFs as a decarbonisation option.

Australia consumes over 56 BL of liquid fossil fuels each year; 44 per cent consumed off road

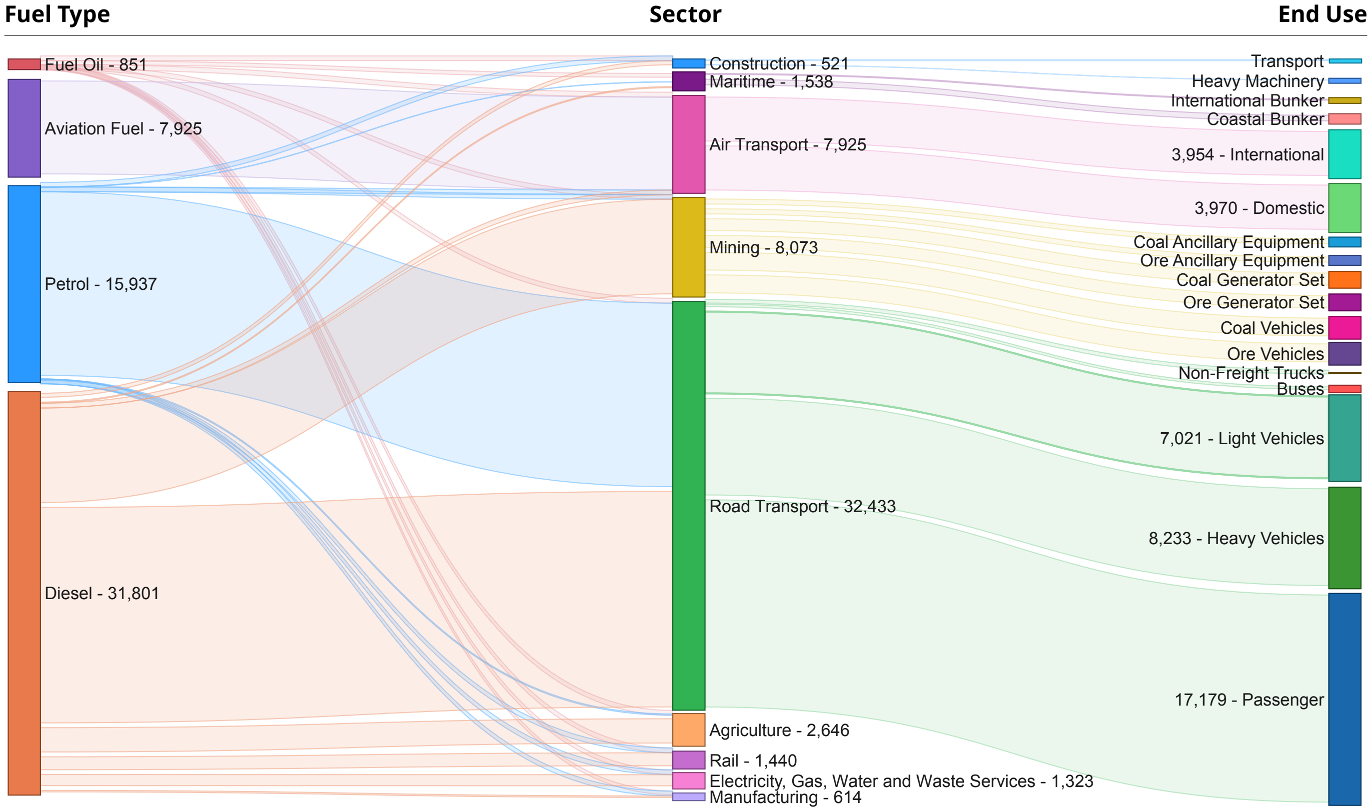
Australia's liquid fuel consumption extends across 11 primary economic sectors, and accounts for more than half of the nation's final energy demand.** In 2022–23, liquid fuel use exceeded 56 BL, with collective consumption across the transport and mining sectors representing more than 90 per cent of domestic demand.

Diesel represents more than half Australia's liquid fuel use – accounting for 56 per cent of use. Petrol primarily for passenger and light commercial vehicles is the next largest fuel segment at 28 per cent. Aviation fuel and fuel oil round out fuel types.

In 2022–23, 49 per cent of consumption was concentrated in sectors for which displacing the majority of liquid fuel use with alternative clean technologies such as electrification is challenging. These users, including the aviation, mining, rail, maritime, construction and heavy road freight industries, will remain dependent to some degree on liquid fuel use in either their transition period to novel decarbonisation technologies or in their long-term future state. This presents a compelling opportunity for LCLFs.

Estimates in Figure 1 are inclusive of Defence fuel use in peacetime. Total Defence fuel use was estimated at 310 ML in 2020–21, approximately 0.6 per cent of domestic liquid fuel use.[6]

Figure 1: National liquid fuel consumption (ML) by industry and subset – 2022–23[1,2,3,4,5 *]



Notes: *Maritime fuel consumption uses data from the Australian Energy Update 2022 report as proxy figures, given the 2023 report did not contain associated maritime data. ** Road transport sector is broken down into passenger, light commercial and heavy freight.

Sources: 1. Australian Government (DCCEEW), 2024. 2. Australian Government (DCCEEW), 2022. 3. Australian Bureau of Statistics, 2020. 4. Australian Government (DITRDCA), 2023. 5. Australian Petroleum Statistics, 2024.
6. Joint Standing Committee on Foreign Affairs, Defence and Trade, 2021.

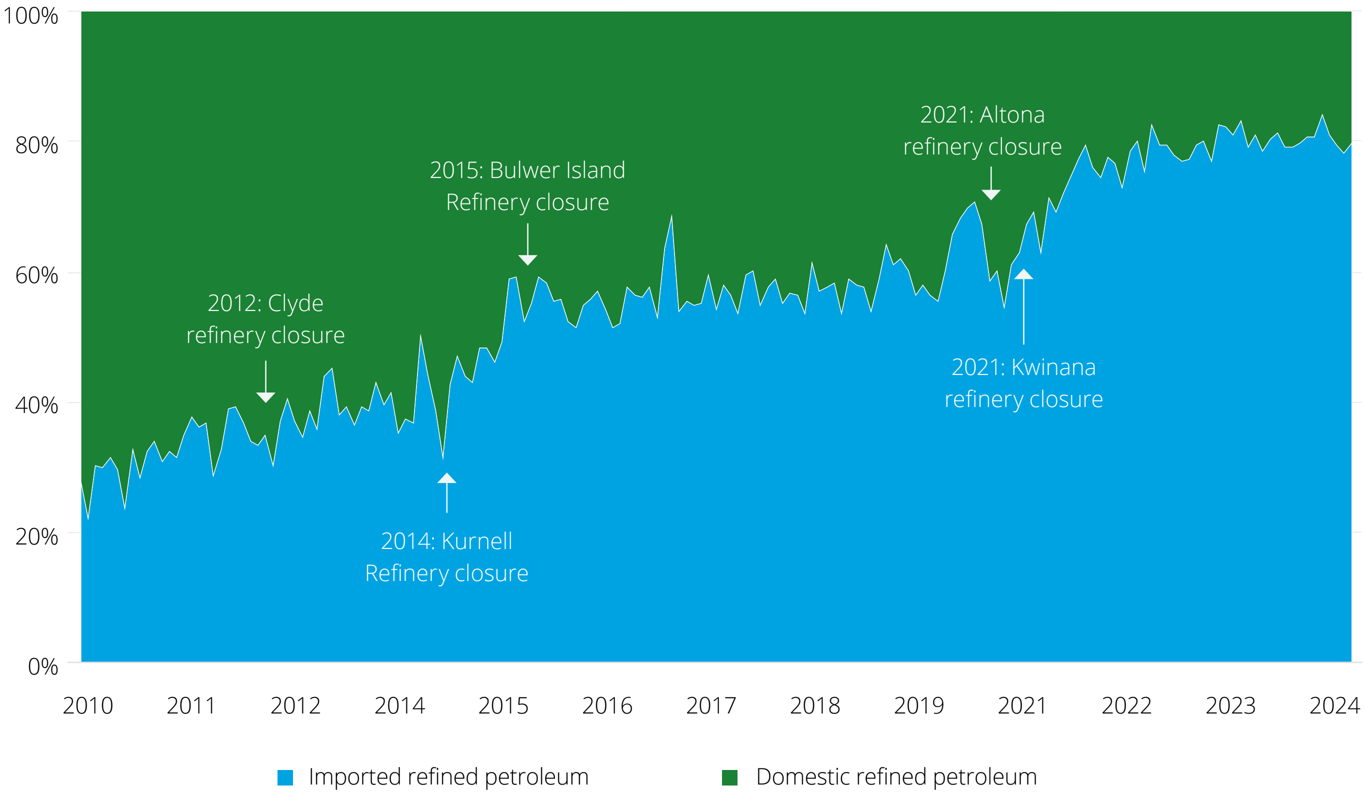
Australia has increasingly relied on imports to meet domestic liquid fuel demand, presenting strategic risks to the economy

Australia's liquid fuel demand is materially exposed to international supply chains. In the 12 months to November 2024, Australia produced ~20 per cent of its key fuel group demand, reflective of a 14-year trend that has seen domestic refining capacity decline from ~75 per cent of national consumption. This contraction reflects the closure of five key refineries over the past 12 years, with domestic producers citing tighter margins, excess global supply and the expansion of cost-efficient capacity in Asia as key drivers. Collectively, the five refineries represented 31,660 ML of production capacity.[2]

Since the turn of the century, Australia's increasing reliance on international fuel products has begun to represent a considerable share of the import bill. As depicted in Figure 3, the national fuel bill has grown to represent ~11 per cent of the total value of all imported goods in 2024, up from two per cent in 2000. Australia's fuel volumes reached an all-time high in 2024, driven by diesel consumption.[3] Australian imports of liquid fuels represent a significant cost, exceeding ~$50.7 billion in 2023.[4]

Today, over 90 per cent of imported petroleum products are sourced from Asian refineries, leaving Australia's economic and national security vulnerable to global supply interruptions. This risk is most acute for diesel and aviation fuel; in 2024, 65 per cent of diesel imports were sourced from just three countries (South Korea, Malaysia and Singapore), with 70 per cent of aviation fuel imports purchased from China, Malaysia and Singapore.[5] This clustering of supply exposes Australia to fundamental strategic vulnerabilities should supply from international sources be disrupted, especially given Australia's Geelong and Lytton refineries are approaching end of life.

Figure 2: Domestic refinery production versus imports since 2010 (automotive gasoline, diesel oil, fuel oil and aviation turbine fuel)[1]

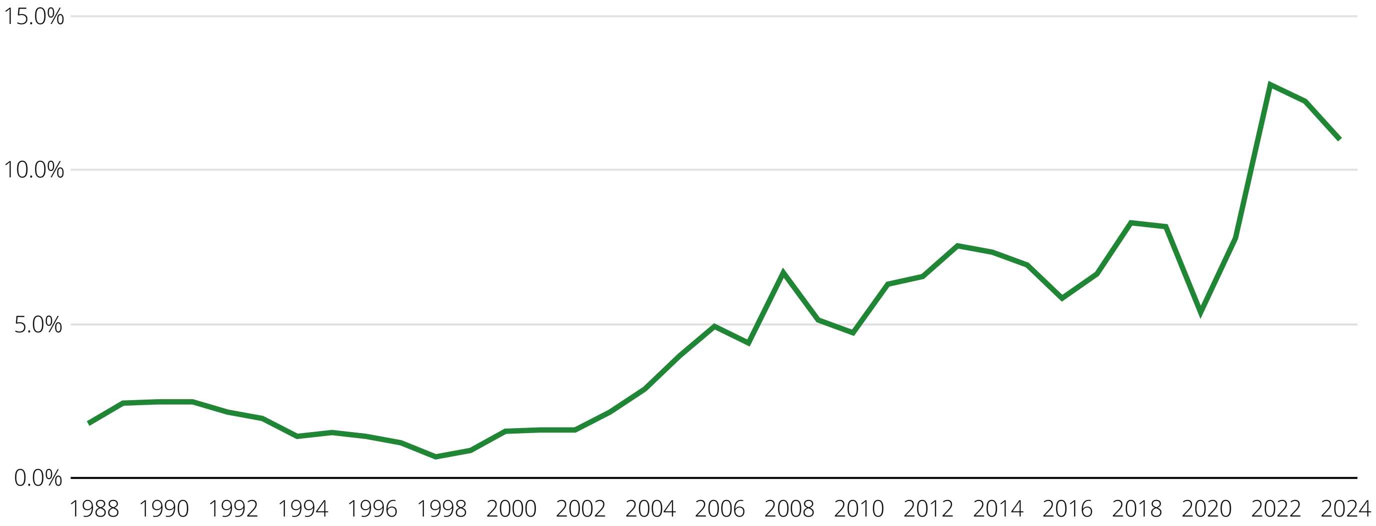


Sources: 1. DCCEEW, 2024. 2. Parliament of Australia, 2020. 3. Ampol, 2025, Full Year Results. 4. Bioenergy Australia, 2025.
5. Based on analysis of DCCEEW, Australian Petroleum Statistics, 2024.

The most notable implications of these fuel security risks are to:

- **Sovereign economic security:** Australia's heavy industry, freight, mining and tourism sectors are significant economic contributors which rely on surety of liquid fuel supply to operate productively. Supply impacts would catalyse cascading disruptions to regional economies which are underpinned by these industries, with implications for domestic employment and GDP.
- **National security and defence capability:** The ADF consumed ~310 ML of liquid fuel in 2020–21.[1] Any disruption to secure and resilient energy supply is likely to be synchronous with increased demand from the ADF and would impact its ability to deploy domestically or project force abroad.

Figure 3: Australian fuel imports as a share of all imports by value[2]



Sources: 1 ASPI, 2022. 2. ABS, 2024.

Australian liquid fuel use accounted for nearly 150 $MtCO_2$-e in 2022–23; ~32 per cent of domestic emissions

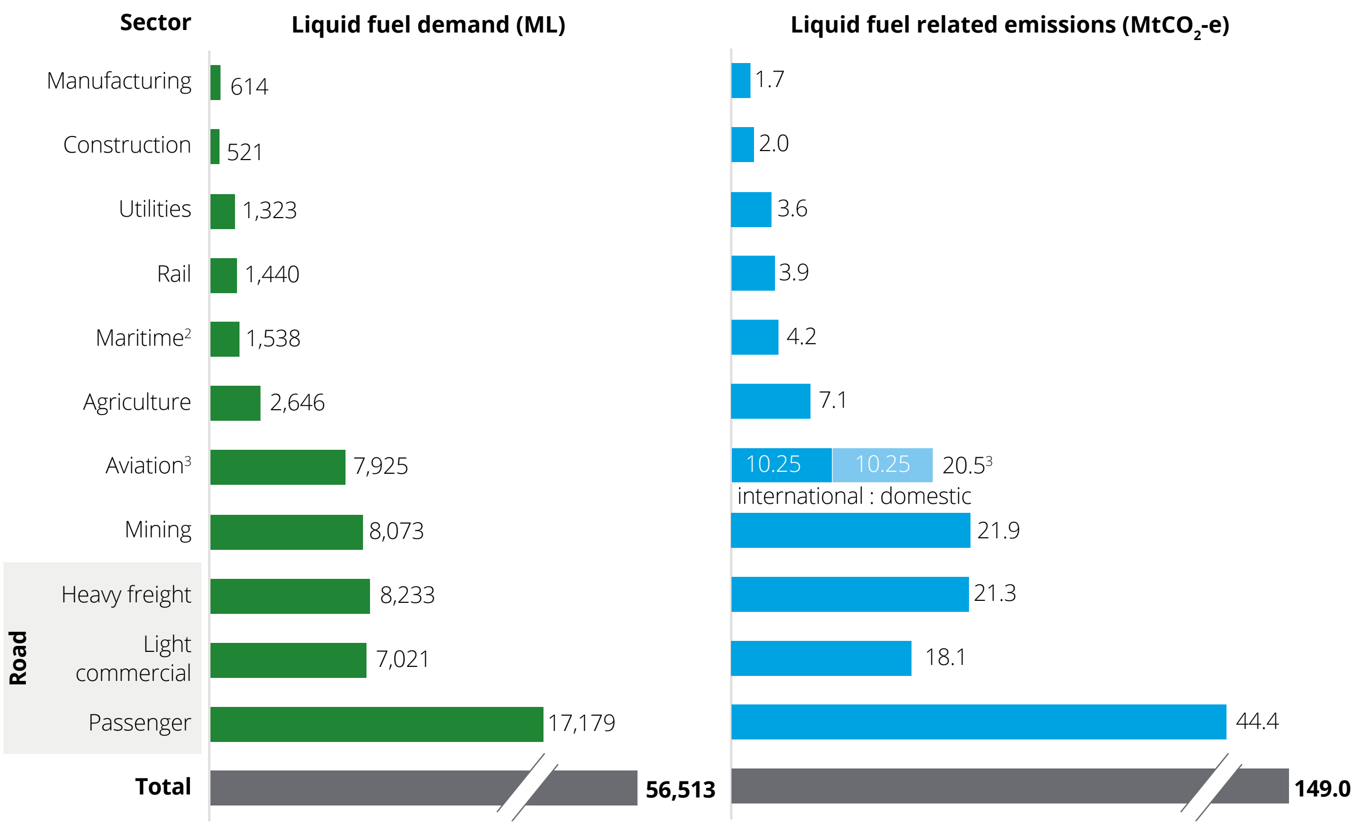
Liquid fuel use is a dominant source of Australia's carbon footprint, accounting for 32 per cent of Australia's total 465.2 $MtCO_2$-e in 2022–23.[4] Recovery from the COVID-19 pandemic has seen emissions from liquid fuels grow steadily in recent years, driven primarily by the transport sector (the dominant user of liquid fuels) which grew 1.9 per cent between 2022–23 and 2023–24.[5]

This growth was driven by a 6.7 per cent increase in emissions from domestic jet fuel consumption and a 2.7 per cent increase in emissions from road diesel consumption over the year to June 2024. Emissions from road petrol consumption were relatively flat over the same period, increasing 0.1 per cent.[6] This is reflective of a longer-term trend that has seen Australia's diesel consumption increase by 93 per cent since 2014, while petrol vehicle stocks have increased by only five per cent.[7]

Without intervention, the transport sector is projected to represent Australia's largest source of sectoral emissions by 2030.[8] Unlike petrol use-cases, which have seen some growth in hybrid and electric options, the absence of a commercially viable alternative for the majority of diesel and jet fuel use cases, combined with a lack of incentives for fuel switching, risks seeing domestic liquid fuel emissions continue to climb in the coming years.

It should be noted that Defence's peacetime fuel use is included across several sector categories in this analysis. This may increase in response to operational circumstances.

Figure 4: Crude awakening: 2022–23 sectoral liquid fuel demand and emissions[1,2,3]



Sources: 1. Liquid fuel demand and emissions calculated using liquid fuel demand by sector in accordance with Australian Government (DCCEEW), applying scope 1 emission intensity values from Table 8 of the Australian National Greenhouse Accounts Factors. 2. Maritime only considers coastal and domestic shipping; however, some estimates suggest that maritime emissions associated with Australia's international trade account for 39.2 $MtCO_2$-e. 3. Aviation fuel use accounts for 20.5 $MtCO_2$-e emissions, however, only domestic aviation is counted in Australia's emissions targets. 4. National Greenhouse Gas Inventory Quarterly Update: June 2023. 5. Quarterly Update of Australia's National Greenhouse Gas Inventory: June 2024, 2024. 6. Ibid. 7. Ibid. 8. Australia's emissions projections 2024, 2024.

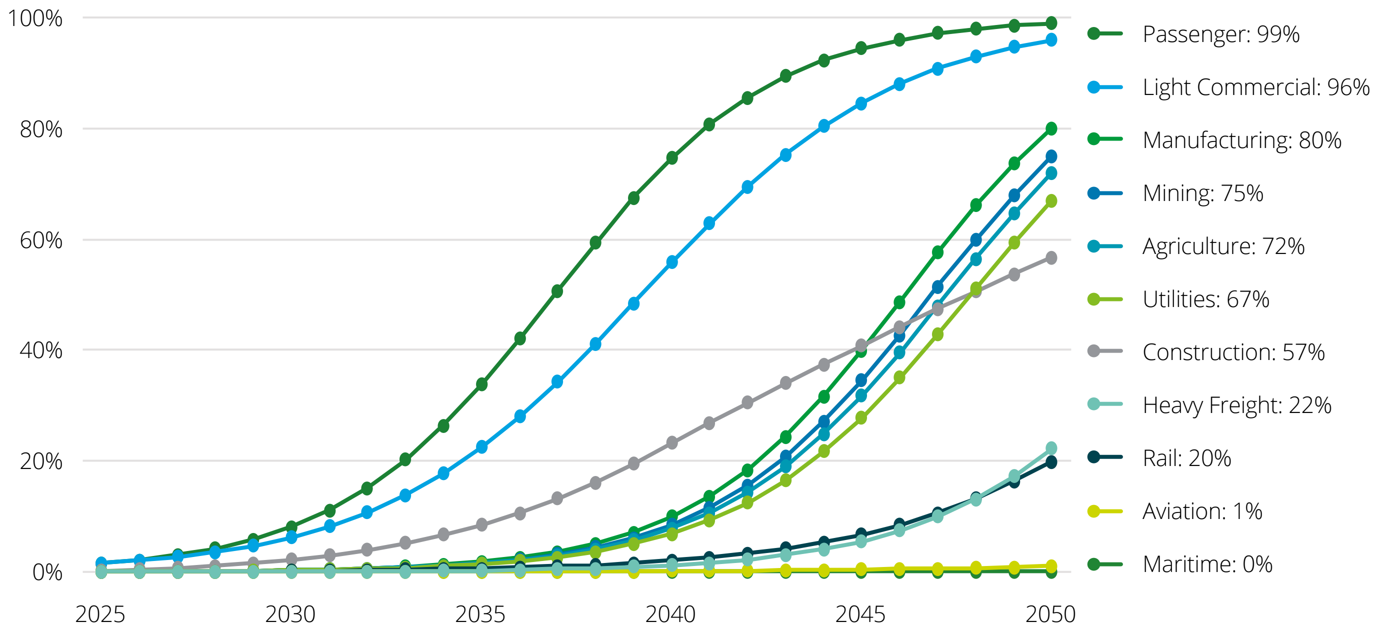
Some fuel users can readily electrify, with electrification potentially able to reduce 2050 liquid fuel demand by 57 per cent

There are significant tailwinds for electrification of passenger and light commercial vehicles globally. Battery prices have fallen by 85 per cent over the past decade.[2] The number of electric vehicles available to purchase in the Australian market increased by 50 per cent alone in 2024 in part driven by new fuel efficiency standards, as the number of fast chargers continues to grow.[3]

CSIRO estimate that by the 2040s electric vehicles make up almost all sales of new passenger cars and light commercial vehicles. This ensures that by 2050, 99 per cent of the passenger fleet and 96 per cent of the light commercial fleet have electrifed.[4] In contrast, the Mission Possible Partnership only estimate that 85 per cent of heavy freight vehicle sales will be electric by 2050.[5] Combined with long asset cycles, this could limit the electrified share of long-haul vehicles to ~22 per cent by 2050.

Electrification rates for other sectors vary materially. Interviews with mining companies and their public statements indicates a high degree of confidence in electrification by 2050 but note that these are contingent on the build out of renewable electricity infrastructure. Rates are near zero for maritime and aviation.

Figure 5: Fuel sector electrification fitted to simple adoption curves[1]



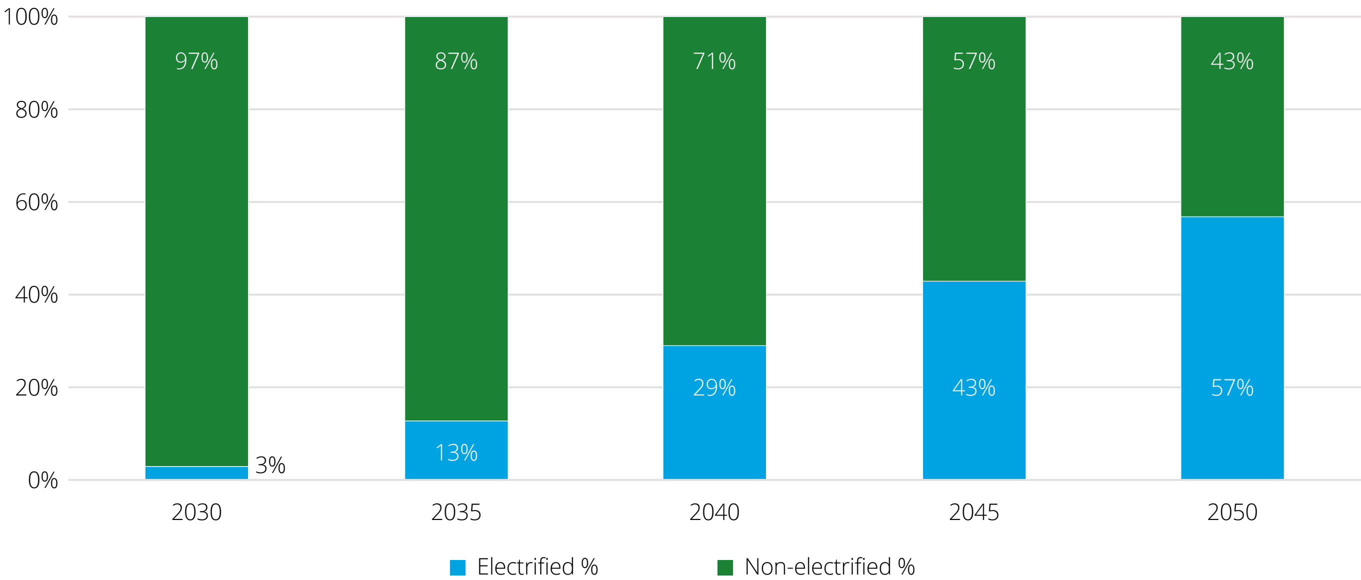
Source: 1. Deloitte analysis. See inputs and assumptions in Appendix A. 2. BNEF 2024. 3. Electric Vehicle Council 2024. 4. CSIRO, 2023. 5. Mission Possible Partnership, 2023.

The impact of the electrification uptake assumptions in Figure 5 is to drive a steep reduction in liquid fuel demand from the 2040s onwards. Figure 6 suggests that electrification could reduce fuel demand by 29 per cent by 2040 and 57 per cent by 2050.[2] This could see Australia's liquid fuel demand fall to around 30 BL in 2050. This could reduce the economy's reliance on fuel imports but would require investment in charging and electricity infrastructure to facilitate.

The consequence of the different electrification uptake profiles across liquid fuel sectors is that there are increasingly fewer sectors making up the majority of Australia's residual liquid fuel demand. In 2024, aviation, heavy freight and mining made up 42 per cent of national liquid fuel demand. By 2040, this is tracking to be 64 per cent, and 80 per cent by 2050.

Delays to electrification could undermine Australia's fuel security in the absence of sovereign fuel production capacity. Any delay in the rate at which Australian liquid fuel users electrify will have a significant impact on our future fuel requirements. For example, if electrification slows down by 20 per cent, we may need to import an additional 7.7 BL of fuel in 2050 – equivalent to the entire output of Viva Energy's Geelong refinery.

Figure 6: Implied electrification of the fuel mix to 2050[1]



Source: 1. Deloitte analysis. See inputs and assumptions in Appendix A. 2. Note that rising population and economic growth would see fuel demand increase to 2050 even with expected efficiency gains. Electrification countervails this - reducing total liquid fuel demand, but underlying activity will continue to increase.

Key liquid fuel use cases are hard-to-electrify and will need alternative abatement options

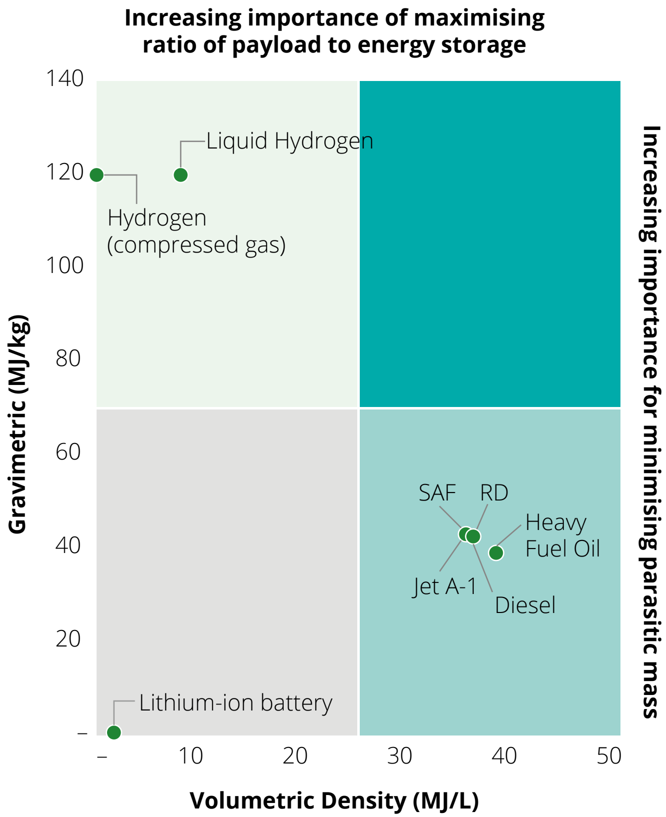
High energy density remains a critical advantage of liquid fuels that electric systems have yet to match. Liquid fuels like diesel and aviation fuel offer relatively high energy content per unit mass and volume, which is why sectors such as aviation, heavy road freight and maritime have historically depended on them. Aircraft require fuels that provide high thrust-to-weight ratios for long flights, while ships, trucks and heavy mining equipment rely on the compact, energy-dense characteristics of liquid fuels to sustain long-distance and high-load operations. Current battery technologies, even as they improve, cannot yet deliver comparable energy density without significantly increasing weight and reducing payload efficiency.

Long replacement cycles for liquid-fuel compatible assets further impede a rapid shift away from liquid fuels. Many critical sectors—including aviation, rail, and long-haul road freight—operate on equipment with life spans that extend well beyond typical consumer vehicles and are not easily retrofitted with electric technologies. Aircraft, locomotives, and heavy trucks are capital-intensive assets designed for up to 60 years of service, meaning fleets are not regularly refreshed. This turnover rate creates a significant inertia; even when novel, low-emission electric alternatives become available, scaled adoption will be constrained by the need to amortise investments over long replacement cycles, making it challenging to rapidly phase out established liquid fuel technologies.

The Australian context of extended routes and remote operating environments exacerbate electrification challenges. Long-haul freight, remote rail freight lines, and off-grid mining operations face severe infrastructure limitations that hinder the deployment of electric power. Electrification requires a dense network of generation, distribution and charging or power-supply stations—a condition difficult to satisfy on isolated routes or on remote mine sites across many parts of Australia, where capital costs, enabling infrastructure deficiencies and labour shortages are exacerbated. Additionally, the business case behind a brownfield site with a relatively short remaining asset life and exposure to fluctuating commodity prices (e.g. an existing mine) may be unable to support the new assets needed for electrification.

Sector-specific operational demands underscore why liquid fuels will remain indispensable in many applications. Beyond the inherent technical issues of energy density and infrastructure availability, each liquid-fuel use case presents unique challenges. In aviation, stringent safety and performance regulations demand long-duration, high-energy output; in rail freight and road freight, intermittent electrification and network compatibility on remote routes persist; and in both mining and linear construction equipment, operations in remote terrains make regular charging impractical. These inherent characteristics mean that, until breakthroughs occur in energy storage and implementation, liquid fuels will continue to power critical heavy-duty and long-distance applications.

Figure 7: Energy densities of comparable energy storage[1,2,3]



Sources: 1. DCCEEW, 2024. 2. US Department of Energy. 3. Bioenergy Australia.

LCLFs will be an essential decarbonisation solution for hard-to-electrify sectors

LCLFs offer a pathway to abatement where electrification is not possible or commercially mature. While electrification is expected to displace 57 per cent of 2050 fuel demand, alternative decarbonisation pathways will be required to address not just the residual 43 per cent, but to ensure hard-to-electrify sectors can deliver upon net zero commitments.

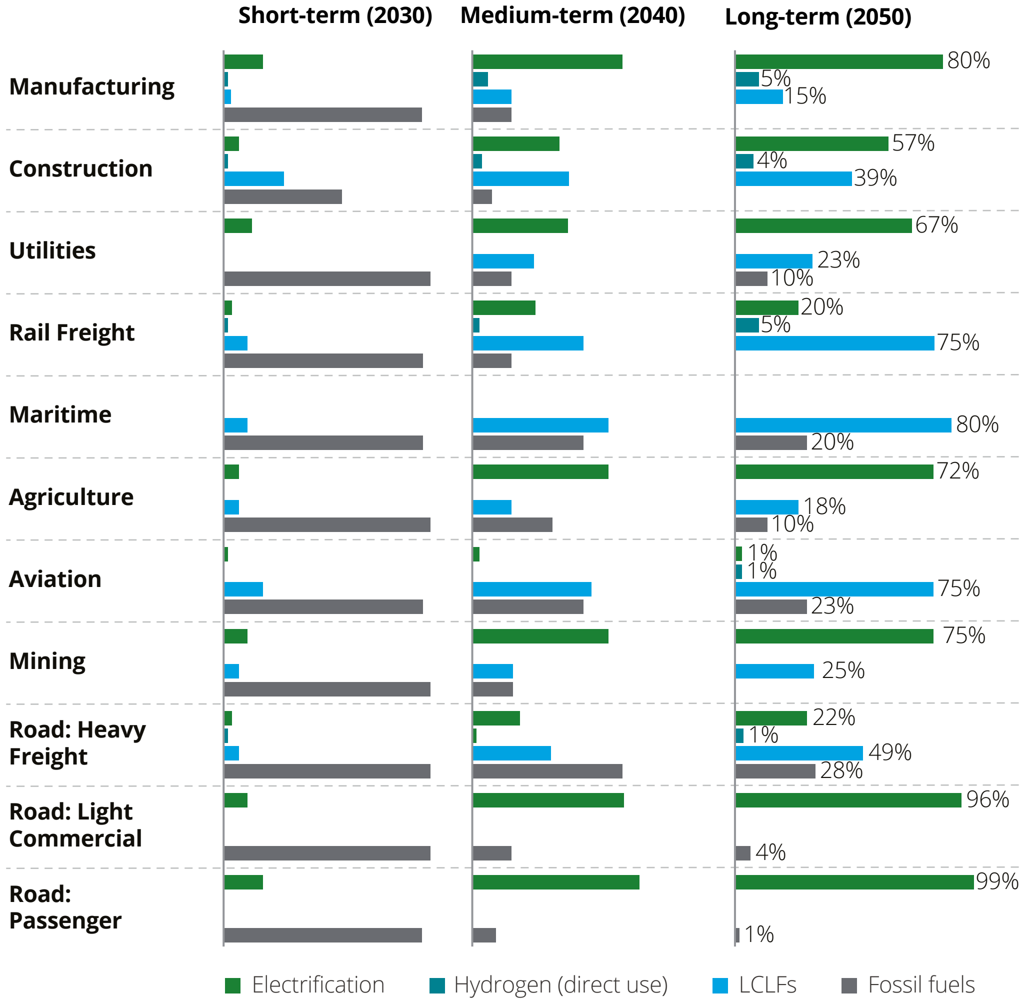
LCLFs are low emissions drop in alternatives to conventional fossil fuels. LCLFs can be made from biogenic feedstocks (e.g. oilseeds, wastes, and biomass), or from non-biomass resources through chemical processes (e.g. combining hydrogen and captured carbon dioxide). Depending on the feedstock, different conversion pathways are used to convert feedstocks into LCLFs. For the purpose of this study, LCLFs include **SAF, RD and synthetic fuels** such as e-methanol and e-fuels which can be derived from hydrogen.

Compared to conventional fossil fuels, LCLF feedstocks can absorb carbon dioxide during their growth cycle and/or displace emissions from landfill, effectively closing the carbon loop and reducing lifecycle emissions. When combusted, LCLFs can also reduce other pollutants like particulates and sulphur by up to 100 per cent relative to fossil fuels.

In the short to medium term, LCLFs can offer a transition pathway for assets reliant on decarbonisation innovation. For industries heavily reliant on diesel, such as mining, LCLFs like RD provide immediate emissions reductions utilising existing equipment. This is crucial while alternate technologies, like electric powered machinery, progress toward commercial viability.

However, sectors such as aviation, maritime, long-haul rail, and heavy road freight are unlikely to electrify at scale, emphasising the need for LCLFs. While some scope exists for electrifying shorter aviation or freight routes, these sectors predominantly require high energy density fuels for longer distances. In addition, sectors like rail freight face challenges due to the long asset lifecycles and significant costs associated with replacing existing diesel locomotives and infrastructure to facilitate full electrification. Even if technological barriers related to electrifying longer routes and replacing incumbent assets are surpassed, stringent industry safety standards, particularly in aviation, are anticipated to impede large-scale electrification. This reinforces the importance of LCLFs as the primary decarbonisation lever.

Figure 8: Decarbonisation pathways for liquid fuel sectors[1]



Sources: 1. Deloitte analysis. See inputs and assumptions in Appendix A.

LCLFs have key advantages as a drop in decarbonisation solution for liquid fuel users, with global investment beginning to scale

The International Energy Agency (IEA) estimates that in 2024, annual investment in LCLFs will reach USD ~$13 billion, more than double the 2015 to 2021 average.[1] LCLFs are gaining traction as a decarbonisation pathway for key economic sectors, both as a transitionary solution while alternative technologies are developed, and as a primary decarbonisation lever. The key advantages of LCLFs are:

- **'Drop in' characteristics** – LCLFs are compatible with existing infrastructure, including heavy road and mining vehicles and aircraft (up to approved blend limits). Second generation LCLFs enjoy superior blending rates in unmodified engines over first generation LCLFs, a dynamic that inhibited scaled uptake of ethanol and biodiesel. This nullifies the need for capital investment in novel decarbonisation equipment and supporting infrastructure prior to existing asset lifecycles expiring.
- **Higher degree of technical readiness** – Despite variance by production pathway and end-use, LCLFs are generally closer to commercialisation than electrification and hydrogen fuel cells in key liquid fuel using sectors.
- **Higher energy density** – Mass and volume are critical metrics for determining an appropriate energy source for hard-to-abate applications. The higher volumetric and gravimetric density of biofuels such as SAF and RD makes them highly suitable as an energy storage solution over current lithium-ion battery technology. While technological advancements are expected, the current energy density of batteries required to power large-scale mining and road freight vehicles are posing a challenge to uptake in the near-term.

Taxonomy of LCLFs[2]

LCLFs are generally categorised as generation one or two based on the feedstocks used and production process employed, which dictate significant variances in the properties of the final fuel output. Synthetic fuels are not classified strictly within the traditional generations of LCLF but offer a promising long-term production pathway.

1

First Generation:

Ethanol and biodiesel produced from edible food sources and waste oils using established production processes to convert oils, sugars and starches into fuel. Blends of up to 20 per cent can be used on unmodified engines to deliver carbon abatement ranging from ~20 to 40 per cent.

2

Second Generation:

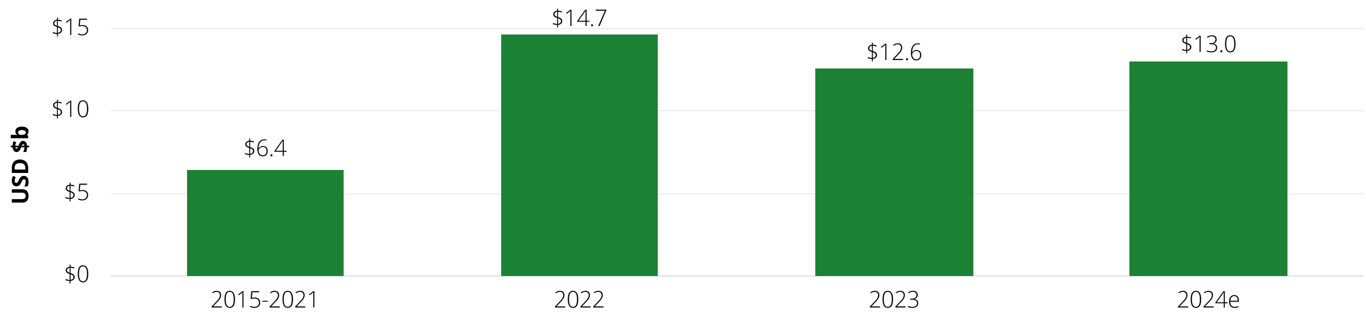
Drop in fuels such as RD and SAF, produced by converting waste-based feedstocks into fuel.[3] These fuels can drive scaled carbon abatement of up to 85 per cent, and can be used in unmodified engines as blends or in 100 per cent neat form.

3

Synthetic Fuels:

Also known as PtL, converts green hydrogen from electrolysis and captured CO_2 into jet fuel and other hydrocarbon products. Capable of achieving up to 100 per cent emissions reduction, but commercialisation will turn on cost reductions in green hydrogen and CCS.

Figure 9: Average annual global investment in LCLFs[4]



Sources: 1. IEA World Energy Investment 2024, 2024. 2. Cavelius, P et al, 2023. 3. Alternative Fuels Data Center. 4. NREL SAF: Decarbonising American Aviation Through Agriculture, 2024.

This study provides a state of Australia's LCLF market, and aims to develop an evidence base to advance consideration of LCLF adoption and production in Australia

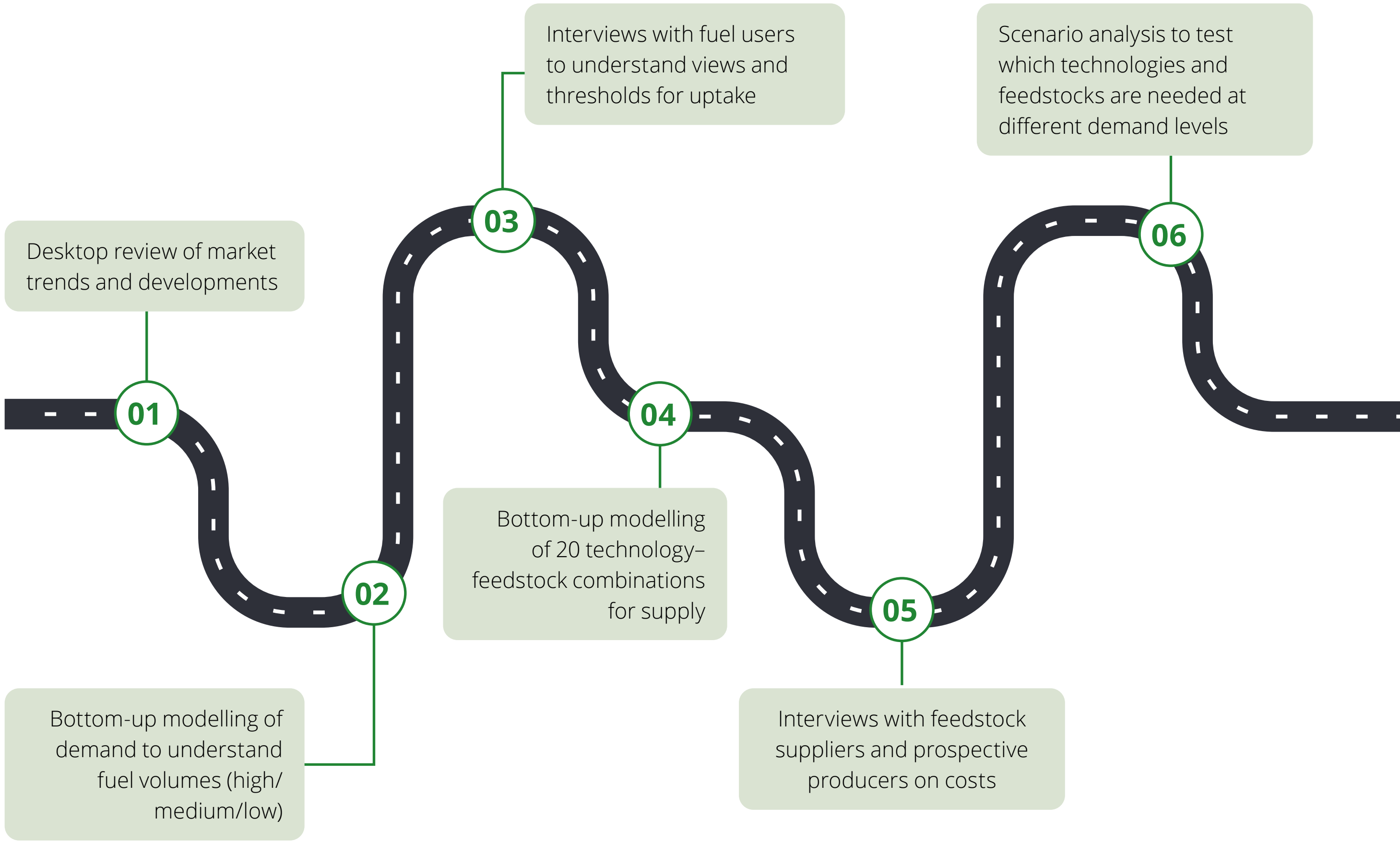
A domestic LCLF sector can provide an essential transition pathway for hard-to-abate segments across the whole economy, while driving economic complexity and diversification across Australia's regions. Domestic production capabilities can be scaled if barriers including future demand uncertainty and potential volatility in end users' willingness to pay (WTP) is overcome.

Noting the evidence gaps that operate to inhibit market activation, this study seeks to develop an updated analysis of the commercialisation economics for domestic LCLF supply and end-use applications. Key focus areas include:

- The **current state of the LCLF market** globally and Australia's current and historical involvement, explored in Chapter 2.
- The quantum and timing of **domestic market demand** for LCLFs, explored in Chapter 3.
- The evolution of **production costs** for different LCLF feedstocks and technology combinations over time, as explored in Chapter 4.
- A scenario analysis focused on the **evolution of an Australian LCLF market** to understand how supply and demand may interact over time, explored in Chapter 5.
- Key **investment risks and barriers to investment,** explored in Chapter 6.
- Potential **market accelerators**, explored in Chapter 7.

Providing this insight intends to inform commercialisation sequencing for the LCLF market and feed into industry and government investment and policy considerations.

Approach to the market study analysis:



The following considerations are excluded from the scope of this study:
- Competition between sectors for fuel or feedstock (either for price or inputs);
- Fuel trade flows or an import/export balance; and
- Total or net economic outcomes.

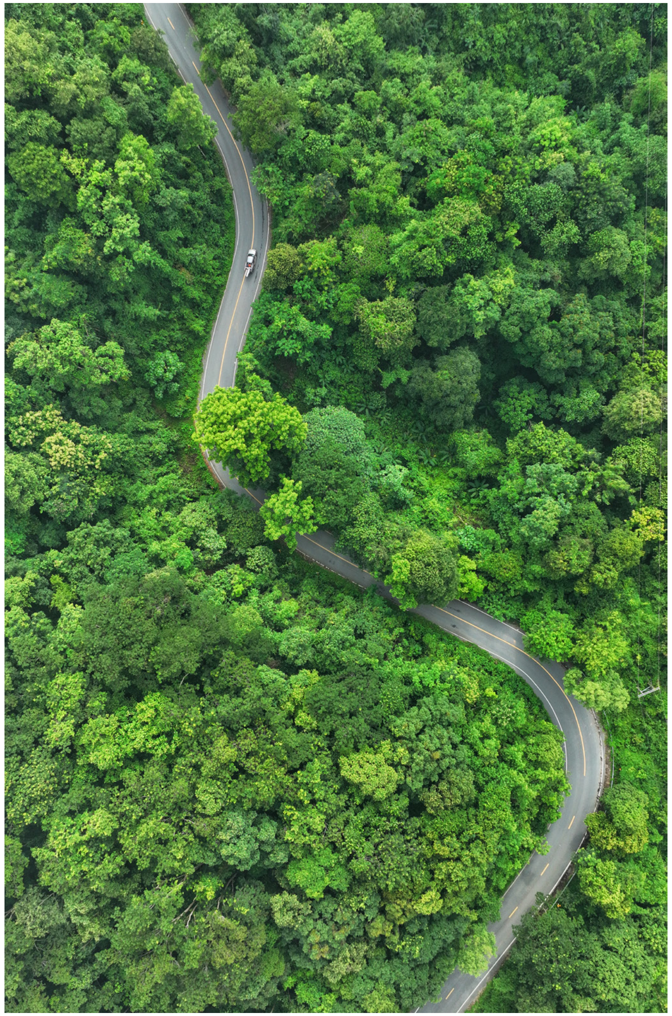
2: How has the LCLF market developed globally and in Australia?

Globally, the LCLF market is at an inflection point. Supply has quadrupled since 2014 and there are nearly 200 announced projects in the global pipeline. The supply-side is responding to strong government action, with more than 10 countries announcing or implementing LCLF mandates.

Australia already plays in the LCLF market, primarily through $3.9 billion in feedstock exports to refineries in the US and Singapore. Momentum is growing for a new generation of LCLF projects in Australia – with 12 announced biogenic and 4 e-fuels projects representing ~2,000 ML of announced capacity.

Australia's pipeline and feedstock industries are regionally significant. There is clear evidence that establishing domestic LCLF value chains could deliver on economic, security and climate objectives, with large benefits flowing directly to regional Australia.

LCLF demand has been rising strongly due to government action and mandates



Global demand for LCLFs is experiencing significant growth, driven by demand-side intervention from governments around the world, including the implementation of mandates and fuel standards. LCLFs are increasingly being recognised as a key lever in the global decarbonisation effort. This trend is particularly evident in the aviation sector, where uptake of SAF is being catalysed by government regulation. Currently, eight countries/regions are expected to implement SAF mandates in the next few years,[1] with several other countries discussing proposals for mandates. **However, only the European Union (EU) and the United Kingdom (UK) have firm mandates for SAF beginning in 2025.**

In the EU, mandates are putting a floor under LCLF demand. The ReFuelEU aviation and FuelEU maritime initiatives are forcing demand for LCLFs by regulating early adoption and driving producers to compete. Specifically, the ReFuelEU aviation initiative mandates that fuel producers provide a minimum share of biogenic SAF from 2025 and synthetic fuel from 2030 to EU aircraft operators.

The establishment of renewable fuel standards in the US have been instrumental in supporting growth in the consumption of LCLFs, which has grown by ~520 per cent since 2011.[2] The US Federal Renewable Fuel Standard (RFS) mandates that transportation fuel contain a minimum volume of renewable fuel annually, with robust regulation to ensure that the lifecycle emissions footprint of these fuels is demonstrably lower than that of conventional fossil fuels.

The Asia-Pacific (APAC) region is also witnessing a rise in mandated LCLF uptake. Jurisdictions including Japan, Singapore and Malaysia are moving to regulate scaled uptake of SAF in the coming decade.

More is needed to help scale up demand globally. Key challenges include limited production capacity given the nascency of the sector and pressures on fuel users and end consumers with limited capacity to pay the current cost premium that exists between fossil fuels and unsubsidised LCLFs.

Sources: 1. Policies obtained from T&E, ICAO and eFuel Alliance, 2024. 2. USDA, 2025.

Figure 10: LCLF (SAF) policies by country / region

Country /Region	Jet fuel consumption 2022 (MLpa)[1]	Policy[2]	Description
EU	50.3	EU Emissions Trading System (ETS) – Increased cost of fossil fuel	Phase out free allowances for the aviation sector by 2026, accelerating the implementation of the polluter pays principle. 20 million SAF allowances granted for free until 2030
		ReFuel EU Aviation Initiative – SAF Mandate	Sets minimum share of SAF available at EU airports: 2 per cent in 2025, 6 per cent in 2030, 20 per cent in 2035, 34 per cent in 2040, 42 per cent in 2045, 70 per cent in 2050, with sub-targets for PtL
UK	12.0	RTFO – Renewable Transport Fuel Obligation - SAF Mandate	Sets minimum share of jet fuel to be made from sustainable sources: 2 per cent in 2025, 10 per cent by 2030, 75 per cent by 2050. Incentivised via greenhouse gas (GHG) credit scheme
Indonesia	3.3	SAF Mandate	Blending mandate for international flights to be implemented from 2027: 1 per cent in 2027, 2.5 per cent in 2030, 12.5 per cent in 2040, 30 per cent in 2050
Malaysia	1.5	SAF Mandate	SAF blending mandate to be implemented from 2027: 1 per cent in 2027, 47 per cent by 2050
Singapore	8.5	Singapore Sustainable Air Hub Blueprint – SAF Mandate	1 per cent SAF uplift target in 2026 that could be raised to 3–5 per cent by 2030
India	7.7	SAF Mandate	Indicative SAF blending targets for international flights: 1 per cent by 2027, 2 per cent by 2028 and 5 per cent by 2030
Japan	9.0	Energy Supply Structure Upgrading Law – SAF Mandate	SAF mandate to replace 10 per cent of jet fuel consumption by 2030
South Korea	6.4	SAF Mandate	SAF blending mandate: 1 per cent SAF for international flights by 2027
US	90.5	Federal Renewable Fuel Standard (RFS – Fuel Standard)	Oil refiners and fuel importers required to blend annually increasing quantities of renewable fuel into transport sector. Compliance tracked through renewable identification number system
		California LCFS (Subnational) – Fuel Standard	Applies a system carbon intensity reduction to put a value on carbon reduction generated from renewable fuels. SAF producers can voluntarily opt in to produce credits
Brazil	5.9	ProBioQAV – SAF Mandate	SAF mandate for domestic flights to be implemented from 2027 to reduce Brazil's airline emissions by 1 per cent in 2027, increasing to 10 per cent in 2037
Australia	6.2	Future Made in Australia – Supply/ Demand Side Support	Supply and demand side support under the Future Made in Australia policy package, with $250 million allotted for LCLF supply chains
		State-based Initiatives and Funding	Development of a NSW Renewables Fuels Strategy and funding announcements from the NSW, QLD and WA governments

Sources: 1. Estimations based on data from U.S. Energy Information Administration. 2. Policies obtained from T&E, ICAO and eFuel Alliance, 2024.
Note: Fuel demand was depressed by COVID and had not returned to pre-pandemic levels in 2022.

Supply of LCLFs has grown by ~4x since 2014 and continues its rapid global expansion, underpinned by supportive economic and climate policies

The growth in global LCLF production capacity is tightly coupled to supportive demand and supply-side intervention. As can be seen in Figure 11, policy signals to underwrite demand or bridge the supply cost gap are catalysts for new production capacity.

In the US, policy settings have been accretive over time, beginning with the establishment of the Renewable Fuel Standard in 2005 and building to include carbon intensity mandates and supply-side tax credits. As illustrated in Figure 12, the 'stackability' of these supply-side incentives significantly reduces the cost premium of LCLFs, reducing both the $/L and abatement cost differential between fossil fuels and renewable alternatives.

Marginal incentives have determined the balance of production. Due to energy density and emissions accounting rules, RD has historically been advantaged by US policy settings relative to SAF. This is because of RD's flexible, less capital-intensive production process, which yields a higher fuel output from a variety of feedstocks, thereby reducing the cost per ton of CO_2 emissions avoided compared to SAF. This has seen producers over index RD production to the detriment of SAF. However, the Inflation Reduction Act (IRA) has redressed the balance, with the value stack for SAF production now outweighing RD in places, which is expected to bring significant new volumes of SAF onto the market.*

Figure 11: The steady rise of LCLF supply globally[1]

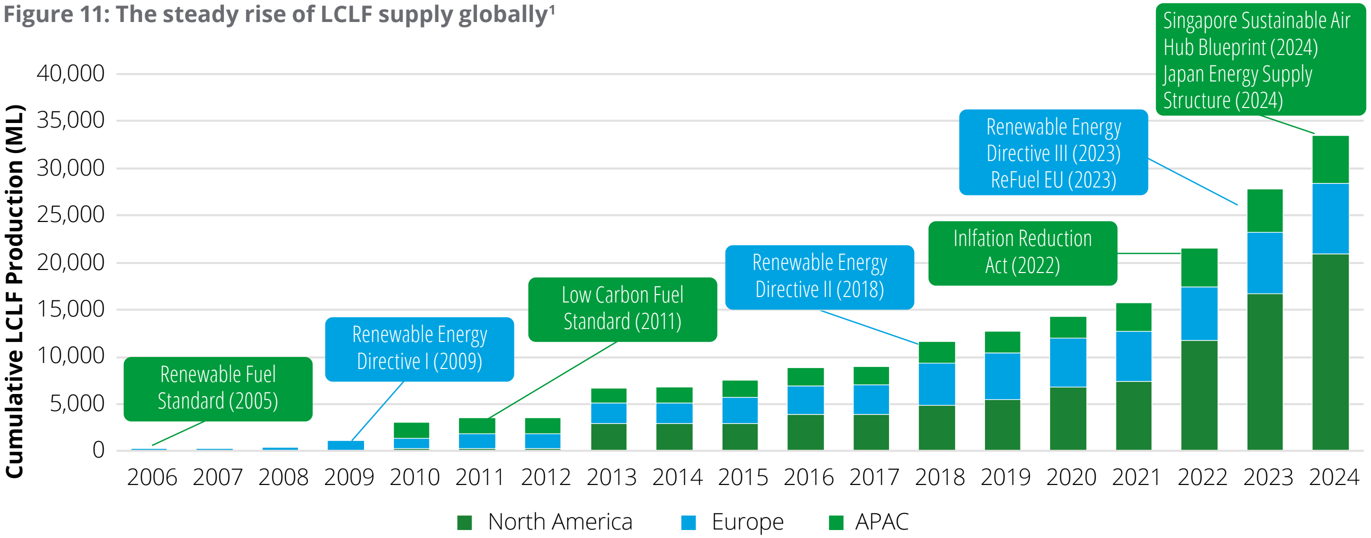
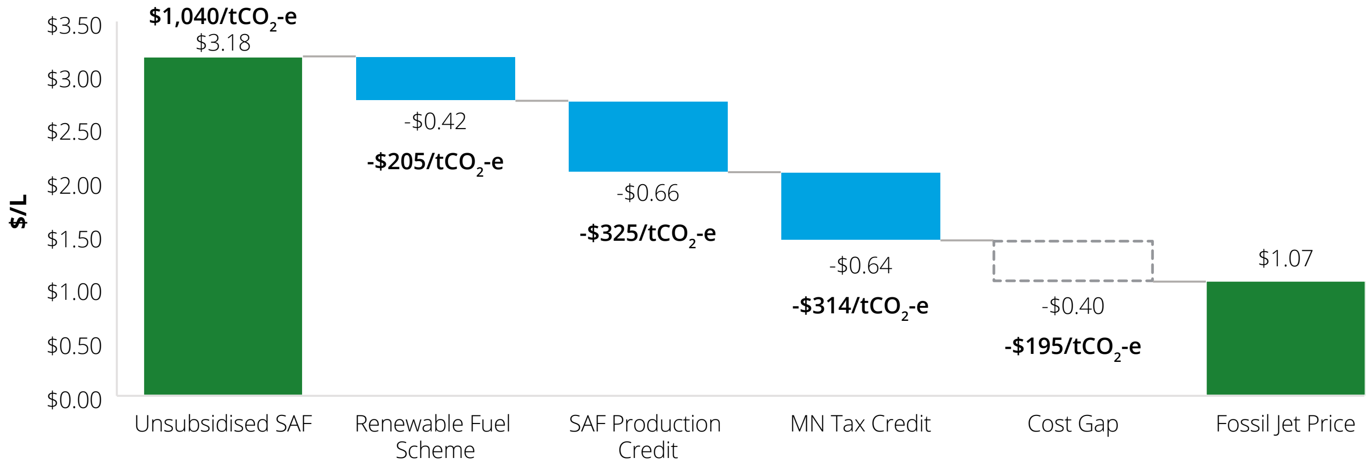


Figure 12: The impact of stacked policy support on US West Coast SAF cost and abatement cost in US state of Minnesota[2]



Sources: 1. Deloitte LCLF Project Database. 2. Based on DOE SAF Liftoff Report, assuming 80 per cent abatement from SAF.
Notes: * It is unclear whether the support for LCLFs under the IRA will continue under the new US Federal administration.

There is over 71 BL of announced LCLF capacity targeting production by 2030, but headwinds are constraining market development

The Americas and EMEA account for over 80 per cent of announced capacity, off the back of anticipated demand from mandates and supply-side support. In comparison, Australia accounts for just over two per cent.

However, 2024 formed a turning point for the global industry, with over two-thirds of capacity slated to enter the market either delayed or cancelled. There have been significant setbacks, with proponents such as Neste citing refining margin compression, rising feedstock costs, capital cost escalations of up to 30 per cent and a drop in the value of US credits as the key drivers.[2] In response to these market dynamics, Neste shares have fallen ~70 per cent over the past two years, with cancelled dividends and reports of up to 600 job losses also announced.[3]

Oil majors also faced significant headwinds for projects in 2024, culminating in delayed investment decisions, abandoned projects, and considerable financial impairments. Selected examples include:

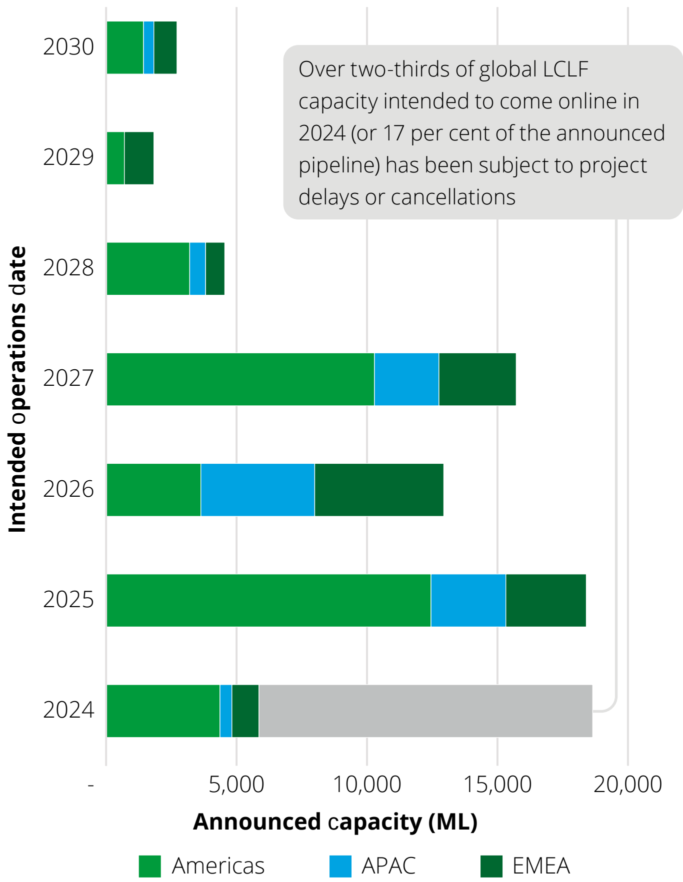
- Shell pausing construction on its flagship biorefinery in Rotterdam (on which it had taken FID in 2021) writing off between $600 million to $1 billion in value.[4]
- BP pausing planning on two biorefineries at existing sites.[5]
- World Energy halving its 2030 goal for SAF production and delaying the timeline of its Texas project.[6]
- Velocys reporting repeated funding challenges leading to delays at the Bayou facility in Mississippi, despite a 15-year offtake agreement with Southwest Airlines.[7]
- Domestically, in early 2025 BP stood down construction and design contractors from its Kwinana Renewables Fuel project.[8]

Operational facilities were also not immune. Most notable of these project failures has been Enerkem's decision to shutter its Edmonton waste-to-ethanol project 11 years ahead of schedule after ongoing technical challenges.[9] Fulcrum Bioenergy and Vertex – both with operational facilities – have also filed for bankruptcy.[10,11]

Headwinds have been driven by compression of refining margins. Three dynamics are at play. First, normalisation of oil prices from recent highs (which increases the cost premium of LCLFs), has put downward pressure on LCLF prices. Second, weakening policy supports (particularly in the US where LCFS and Renewable Identification Number (RIN) credits declined materially in 2024) has undercut an important source of revenue for refiners. Third, rising feedstock prices have increased costs as LCLF prices have declined, squeezing margins.

Margin compression is expected to normalise over the coming years as demand matures. Over the medium term, the demand response from mandates should support LCLF prices. At the same time, feedstock prices may moderate as new supply enters the market. For example, Canada is expected to bring 5.7 Mt of new canola crush capacity online by 2028.[12] Together, these factors should restore refining margins.

Figure 13: Global pipeline of announced SAF and RD projects by region[1]



Sources: 1. Deloitte LCLF Project Database. 2. Neste's Financial Statements Release 2024. 3. Neste hits 2016 low after loss, dividend policy cancellation. 4. Shell expects hit of up to $1b on stalled biofuel plant. 5. Refocusing plans': bp pauses work on SAF plants. 6. World Energy delays Houston SAF project timeline, halves 2030 target. 7. Investor consortium in late bid to save cash-strapped SAF technology developer Velocys. 8. BP puts its $600m Perth clean fuel refinery plans on ice. 9. Waste-to-ethanol biofuels plant in Edmonton closes 11 years ahead of schedule. 10. Fulcrum BioEnergy files for bankruptcy protection. 11. Vertex files for bankruptcy, considers sale of Alabama facility. 12. Grain Brokers Australia, 2024.

Australia has had a mixed experience with first generation LCLFs, with demand struggling to be unlocked and remaining facilities operating at between 20-40 per cent capacity

The domestic first generation LCLF industry arose out of a desire to reduce reliance on fossil fuels and imported petroleum products. Domestic production of biodiesel and ethanol grew from nearly zero in the early 2000s to 365 ML in 2013, with the first production facility established in 2003.[3]

Despite an abundant feedstock base, the absence of a comprehensive government policy has proven to be a roadblock for scaled demand, as depicted in Figure 14 and 15. Prior to 1 July 2015, domestically produced ethanol and biodiesel products did not attract an excise tax, incentivising early uptake. From this date on, the excise tax rate has increased annually, until it reaches its maximum in 2030. Further, there is evidence to suggest that NSW's and QLD's respective six per cent and four per cent ethanol fuel mandates have not been met, resulting in lower market uptake. The United States Department of Agriculture estimated that, with exceptions, in 2021 the levels were around two per cent for bioethanol petrol in NSW, and 1.6 per cent in QLD.[4]

The industry has also been hampered by considerable consumer distrust and scepticism. Many consumers have concerns that first generation biofuels could damage existing assets, with a lack of original equipment manufacturer (OEM) clarity on warranty cover exasperating this dynamic.

These headwinds have resulted in cascading contraction of the domestic production landscape, with facility closures and underutilisation reigning supreme. Figure 14 and 15 indicate that in 2021, Australia's two operating ethanol and biodiesel refineries were operating at 40 per cent and 20 per cent of their respective combined capacity. This, combined with the closure of large-scale facilities such as United Petroleum's Dalby biorefinery, has seen domestic production collapse since 2016–17.

Figure 14: Australian ethanol production over time[1]

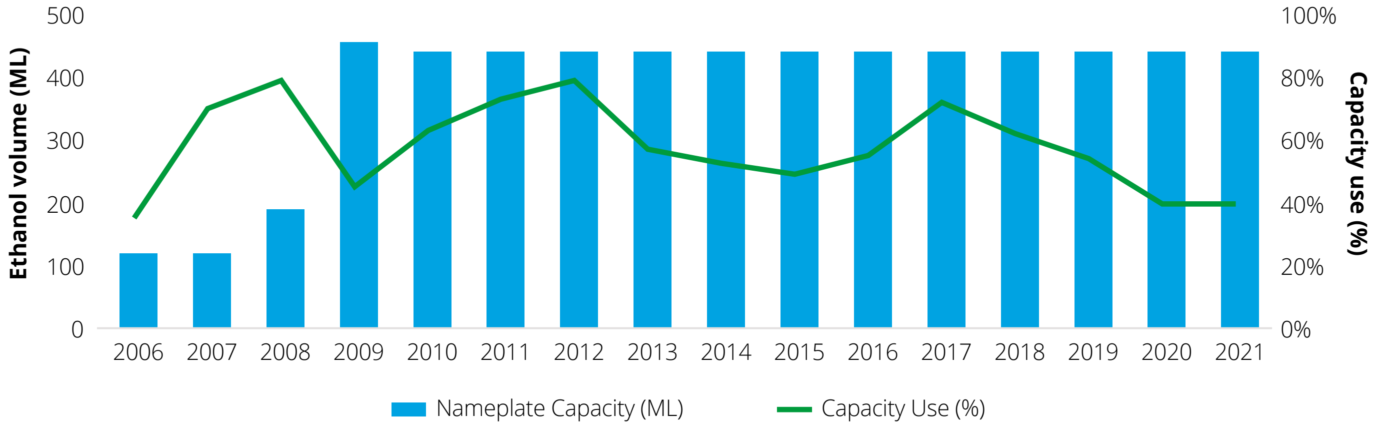
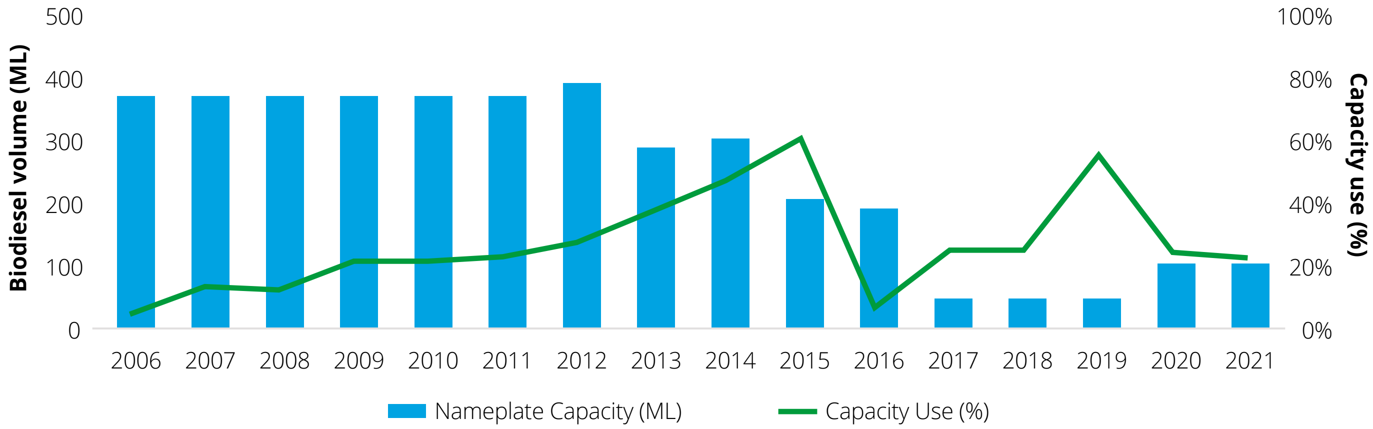


Figure 15: Australian biodiesel production over time[2]



Sources: 1. Biofuels Annual (2016 & 2022). 2. Ibid 3. Australia's 1st purpose-built biodiesel facility opened. 4. Australia's ethanol plants underutilised by 60pc.

Australia has the opportunity to move up the value chain by leveraging our comparative advantage in feedstocks to expand fuel production capacity

Consumption of domestic LCLF feedstocks is mature for both first-generation and some second-generation feedstocks. These feedstocks have existing end applications as food products and for energy generation.

Australian feedstocks are being exported to markets with supportive policy infrastructure for LCLF production. Feedstocks of particular interest for the development of an Australian LCLF industry include:

- **Canola:** more than 70 per cent of Australian canola seed is exported, a significant portion of which is utilised in European biorefineries
- **Sawmill residues:** exported or used for combined heat and power generation at sawmill sites
- **Used Cooking Oil:** exported and refined to LCLFs
- **Bagasse:** stockpiled and used in power generation to power sugar mills and for sale to electricity markets
- **Tallow:** majority exported to Singapore with the US set to capture a greater share with incoming tax credits on tallow-based biofuels

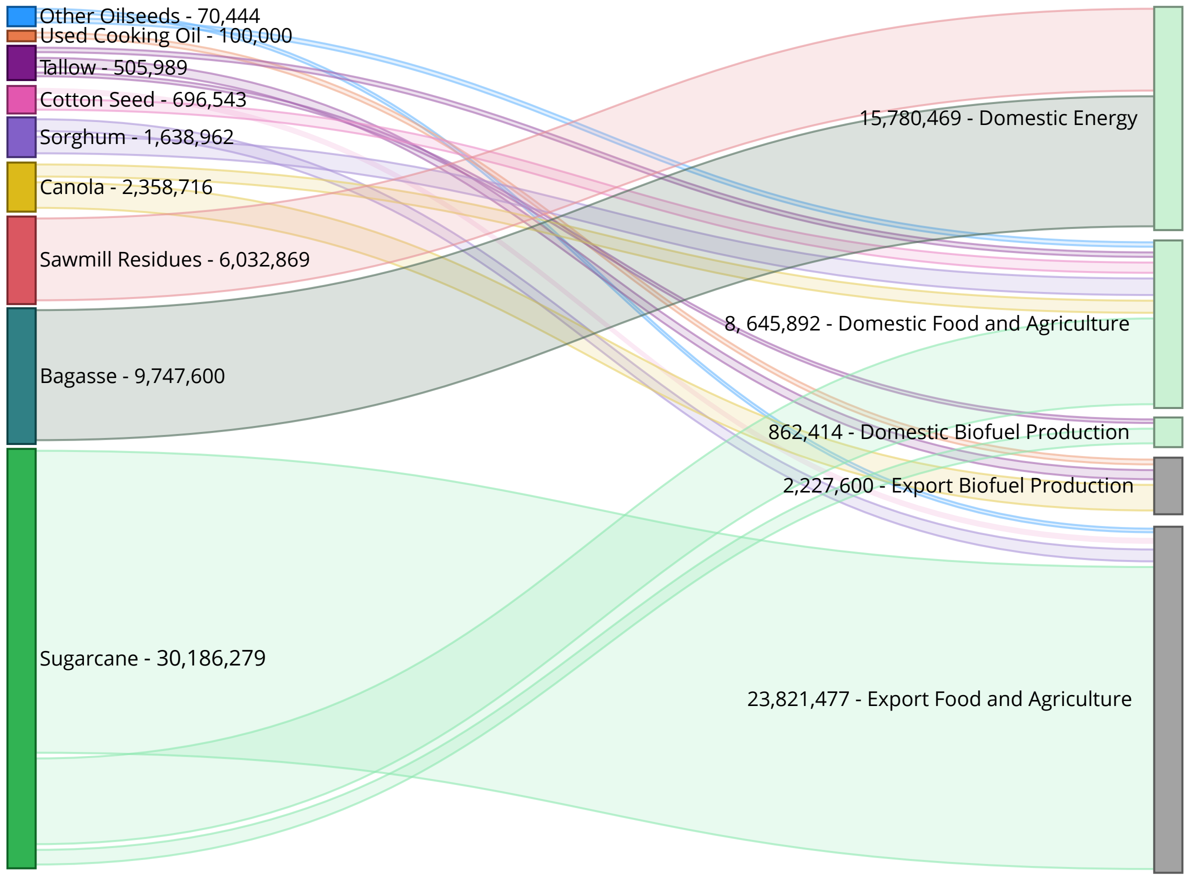
The development of collection, aggregation and sorting infrastructure for other second-generation feedstocks is underdeveloped. At present, agricultural and municipal solid wastes are either not collected or inadequately sorted to support LCLF supply chains. This is inhibiting project development for key LCLF pathways.

In the long-run, feedstock supply chain development is required to access greater supply to meet emerging LCLF demand. This is contingent upon:

- Diverting feedstocks from existing use cases, including attracting domestic supplies to Australian projects,
- Accessing feedstocks with limited commercial value, or
- Growing dedicated crops and plantations and/or adapting crop rotations to support boosted supply.

However, despite the existence of an abundant feedstock base, a large-scale LCLF market will need significant work to get off the ground. In many cases this will require standing up novel supply chains for collection and aggregation and liberating sufficient feedstock supply from other uses whilst driving strong innovation in production pathway yields.

Figure 16: Indicative breakdown of Australian feedstock by existing end-use (mass flow, tonnes)



Sources: UCO, Tallow – FAS. Bagasse – energy.gov. Sugarcane – FAS. Other Shares and Production Values – ABARES. Tallow – FAO. UCO – DCCEEW.
Note: analysis excludes some feedstocks presently utilised to produce biofuels in Australia.

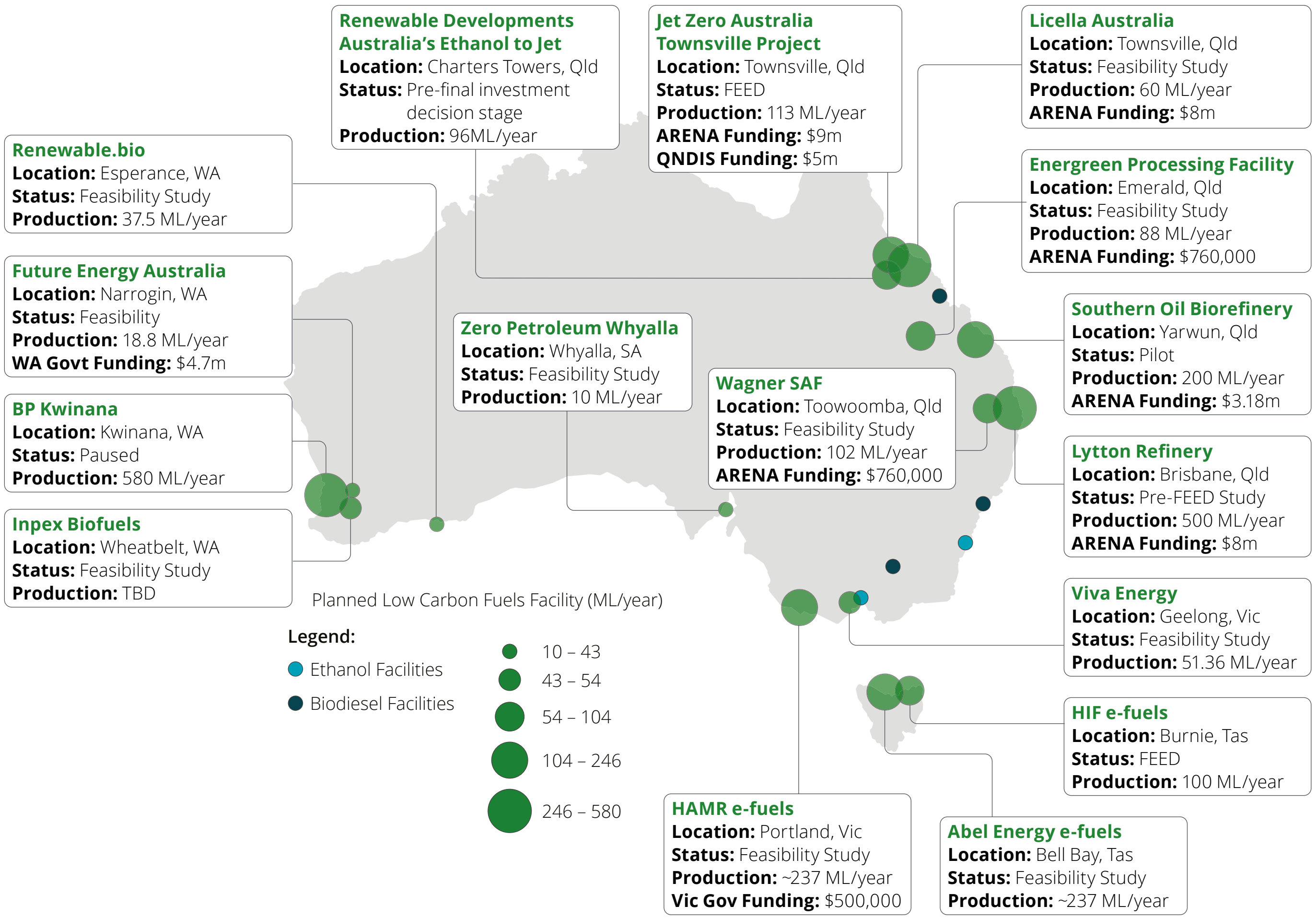
Momentum is growing for second generation LCLF production in Australia, with a steadily expanding pipeline of 12 biogenic and 4 e-fuel projects

Australia has several comparative advantages in LCLF production. These are grounded in competitive agricultural industries, access to renewable feedstocks, proven robust demand for liquid fuels and an experienced process engineering workforce.

In response, the domestic LCLF project development pipeline has grown, consisting today of ~12 biogenic projects and at least 4 synthetic fuels projects supported by a range of upstream feedstock processing facilities. These projects are proposing to leverage an abundant domestic supply of oil crops, wheat, sugarcane and waste feedstocks, as well as Australia's green hydrogen potential, to produce globally competitive LCLF. The pipeline is currently backed by government support in the form of ARENA's $30m SAF Funding Initiative and various State Government feasibility and proof of concept funding allocations. ARENA notes that more investments are to be announced, even though it has now allocated $33.5m across three projects targeting production, and two targeting SAF infrastructure - $2.4m to Viva Energy for supply infrastructure at Pinkenba, QLD and $6.1m to GrainCorp for a SAF Oilseed Crushing Facility[1,2].

Despite strong recent progress, the Australian LCLF landscape will not be immune from the headwinds driving global project delays and cancellations. Domestic market activation will turn on overcoming long-term price, demand and feedstock supply uncertainty which is currently plaguing bankability efforts globally.

Figure 17: Changing Gears – Current LCLF production infrastructure, and announced projects[3]



Sources: 1. ARENA (2024). 2. ARENA (2025). 3. Deloitte analysis based on various sources.

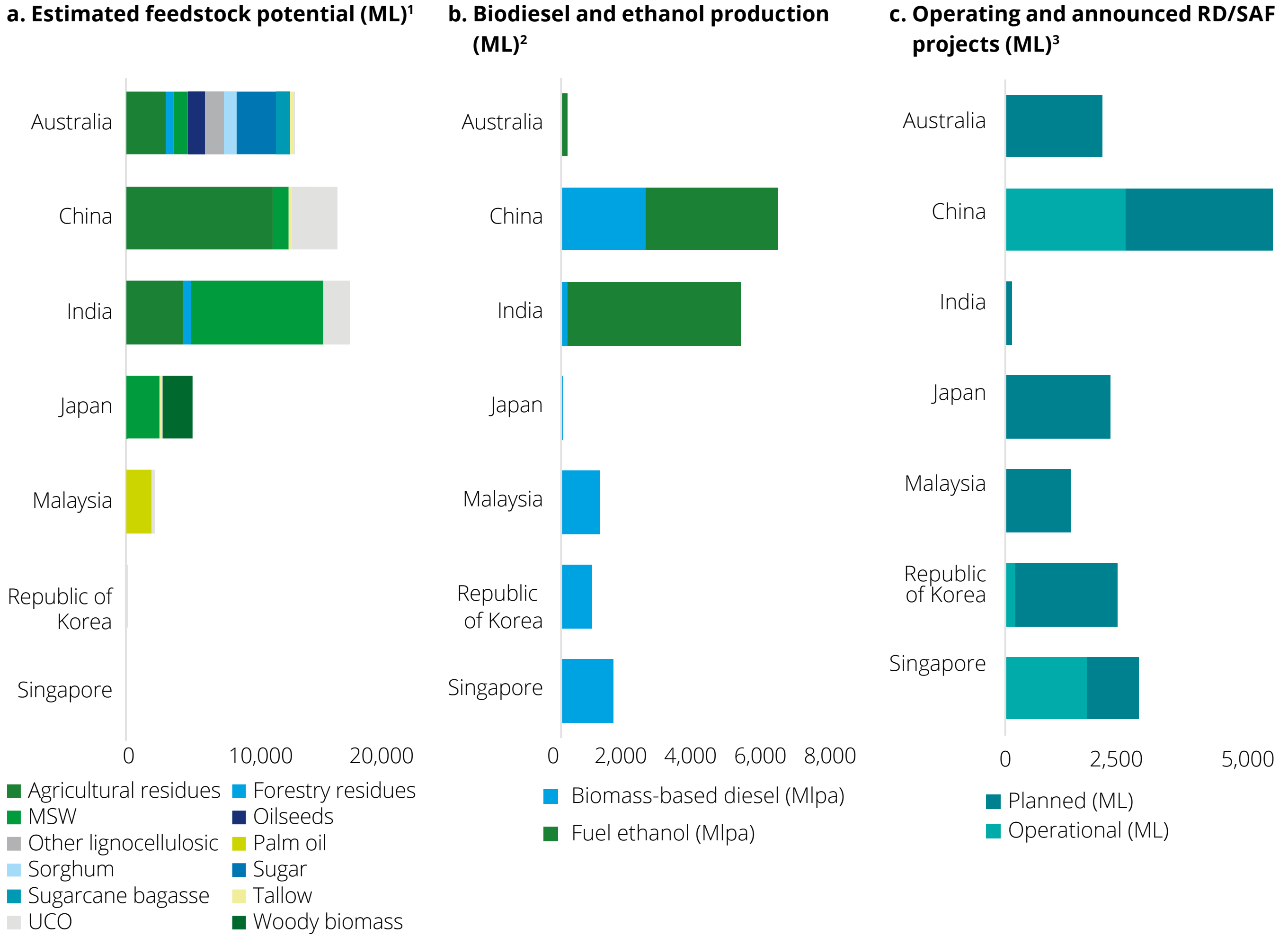
Australia's pipeline and feedstock industries are regionally significant, unlike for first generation production

Australia's existing participation in the global LCLF markets through feedstocks just scratch the surface. Panel (a) of Figure 18 shows feedstock production potential in LCLF-equivalent terms across a range of Australia's fuel trading partners. Australia's production potential is significant – comparable to very large markets like China and India. Importantly, Australia's feedstock potential could facilitate exports. In comparison, estimates from other markets suggest they may need imports to meet decarbonisation objectives.[4]

While Australia's feedstock potential is significant, this has not translated into a regionally significant ethanol or biodiesel industry. Panel (b) of Figure 18 shows operational ethanol and biodiesel capacity across the same set of markets. Here China and India are clearly the largest producers. There is some biodiesel production in other APAC markets, but not on the same scale. Neither Australia or Japan have significantly developed first generation LCLF production.

Australia is positioned to be a significant regional market participant in new LCLF production. Panel (c) of Figure 18, shows operational and planned renewable diesel and sustainable aviation fuel across APAC markets. The current project pipelines show Australia developing nearly 2,000 ML of capacity, comparable to other emerging regional players like South Korea (2,300 ML) and Japan (2,100 ML). **Taken together, this suggests Australia has the potential to leapfrog straight to second generation LCLF production.**

Figure 18: Estimated feedstock potential, first generation and second-generation production in selected APAC countries



Sources: 1. Deloitte analysis based on various sources. Likely feedstocks for each country based on CSIRO Sustainable Aviation Fuel Roadmap (2023). 2. U.S. Energy Information Administration (2022). 3. Deloitte LCLF Project Database. 4. See for example, Deloitte SAF in China, 2023 and ICF, SAF Ecosystem in Japan, 2024.

Establishing domestic LCLF value chains could deliver on economic, security and climate objectives for Australia

Fuel users and prospective LCLF producers consistently highlight the need to develop domestic LCLF value chains for three reasons: to diversify regional economies, to accelerate decarbonisation, and to increase Australia's energy security. The significant abatement potential of LCLFs is a key factor in their recognition under the Net Zero Transformation Stream of Treasury's National Interest Framework for Future Made in Australia.[1]

Three nuances are important to recognise about how and when Australia should expect significant dividends from the development of a LCLF industry:

1. **Australia may need to sequence when and how to achieve these objectives.** For example, export-oriented production may be a first step to gain a foothold into the market, with supply subsequently diverted onto the domestic market to accelerate decarbonisation as demand matures.
2. **Significant impacts will depend on structural market activation.** Indicators of success for a LCLF industry include the scale of emissions abated, and the size of the domestic value-added industry. But this is an end outcome – initial steps to market formation are likely to be more costly and risky than when the market is well established.
3. **Development will be necessarily local and specific.** First of a kind projects in Australia need to overcome a range of challenges. Leading projects will likely need to prioritise their delivery against the three strategic outcomes with reference to local conditions.

Figure 19: Three key strategic outcomes of a domestic LCLF market

1. Decarbonisation

Australia currently relies on liquid fuels for more than half of our final energy demand. LCLFs represent an opportunity to decarbonise sectors of the economy reliant on fossil liquid fuels, which will be necessary to reach our legislated emission reduction targets. There is currently insufficient alignment of decarbonisation and economic incentives. Reaching net zero will require going beyond ACCU purchasing to drive direct abatement in these sectors.

Indicators: abatement and marginal abatement cost

2. Energy security

Currently, Australia has limited domestic refining capacity and relies on imported fuels, leaving supply chains exposed to risk of supply interruption or price fluctuations. Developing a domestic LCLF value chain would reduce dependence on foreign involvement in fuel production and increase sovereign capacity. Diversification of fuel production methods will further increase domestic energy security, particularly during periods of high demand or when specific suppliers face disruptions.

Indicators: domestic refining capacity as a share of annual demand

3. Economic diversification

In a global net zero economy, LCLFs will be in high demand, with the market for advanced biofuels and e-fuels (drop in LCLFs) already rapidly expanding. Capitalising on this opportunity would allow Australia to diversify its economy and enhance productivity. It would support the creation of new jobs, many of which would be generated in regional communities. Particular opportunities include growing feedstock infrastructure and R&D.

Indicators: size of fuel and feedstock markets in $m, infrastructure capex

Note: these metrics are revisited in the scenario analysis chapter, please see page 58. Sources: 1. Australian Government Treasury, 2024

3: How will Australian demand for LCLF evolve over time?

Australian liquid fuel users in hard-to-electrify sectors have consistently emphasised the role LCLFs can play within Australia's decarbonisation journey. However, market participants have also consistently expressed a view that Australia's demand outlook for LCLFs is unclear given the cost gap which exists, and that demand is a necessary precondition for market formation.

Previous studies have taken a top-down view of potential demand. In contrast, this section develops bottom-up estimates of potential LCLF demand across six hard-to-electrify sectors, which account for around half of 2023 liquid fuel emissions. Three demand scenarios are constructed by interrogating specific asset decarbonisation trajectories within each sector, with assumptions validated by interviews with 10 fuel users across the market.

Unsurprisingly, the scale of policy intervention and supply-side cost reductions are the determinants of LCLF uptake. Stronger policy settings are needed to shift abatement from the use of carbon offsets to on-site decarbonisation. LCLF demand rises significantly in the medium scenario, which imposes constraints on offset use, and very significantly in a scenario which mirrors European mandates. In all scenarios, demand from the aviation sector always accounts for more than half of LCLF demand between 2030 and 2050.

Six hard-to-electrify sectors account for half of liquid fuel emissions, and will need focused effort for Australia to deliver on net zero targets

Differences in the commercial maturity of decarbonisation pathways, combined with nuances in the relative contribution of liquid fuels to overall scope 1 emissions mean that some sectors will be more likely to decarbonise using LCLF than others.

As economy-wide emissions reduction efforts evolve, on-site abatement is likely to reflect a premium relative to carbon offsetting. This will be driven by evolving environmental regulations and approvals processes, which are likely to scrutinise the use of offsets where on-site abatement technologies are commercially feasible. This trend is already being observed in WA Part IV Environmental Approvals, which requires proponents to justify the use of offsets where a clear pathway to on-site abatement exists. Adoption of on-site abatement can also drive innovation in technologies and processes that lead to additional emission reductions.

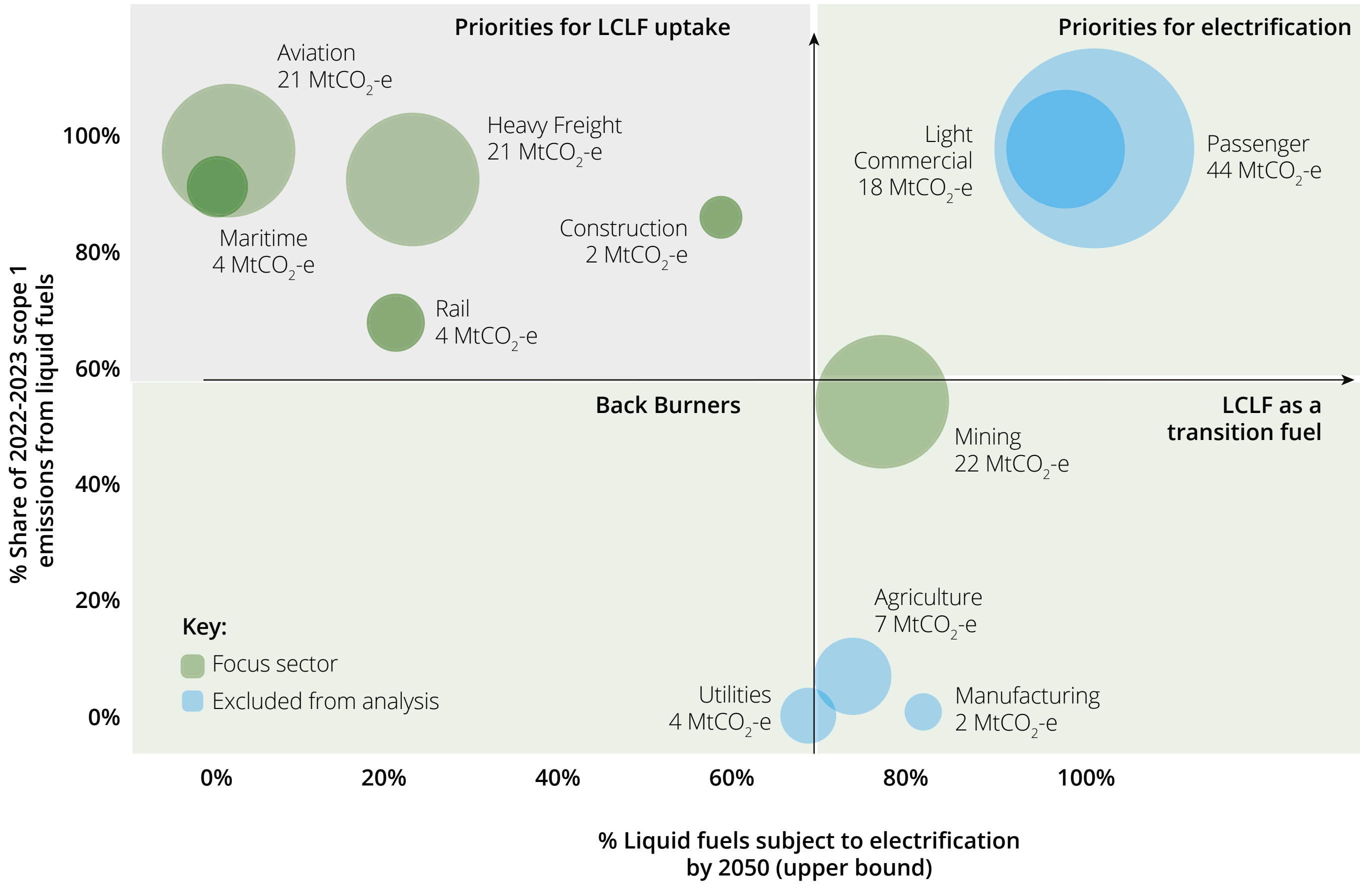
Noting this, LCLF uptake is likely to be **prioritised** in sectors where electrification is not possible or commercially mature, and where liquid fuel use represents an outsized share of total scope 1 emissions.

For some sectors with higher longer-term electrification potential, technology deployment constraints will position LCLF as a **key transition solution** on the path to net zero.

Acknowledging this uptake dynamic, the following demand analysis focuses **on 6 of the 11** primary users of liquid fuels in Australia:

- **Heavy Freight**
- **Mining**
- **Aviation**
- **Maritime**
- **Rail**
- **Construction**

Figure 20: Unpacking electrification potential by 2050 of current liquid fuel use cases



Sources: Bubble size represents the total liquid fuel emissions (Scope 1) in 2022–23. Refer to Appendix A for the percentages of liquid fuels subject to electrification by 2050 for each sector.

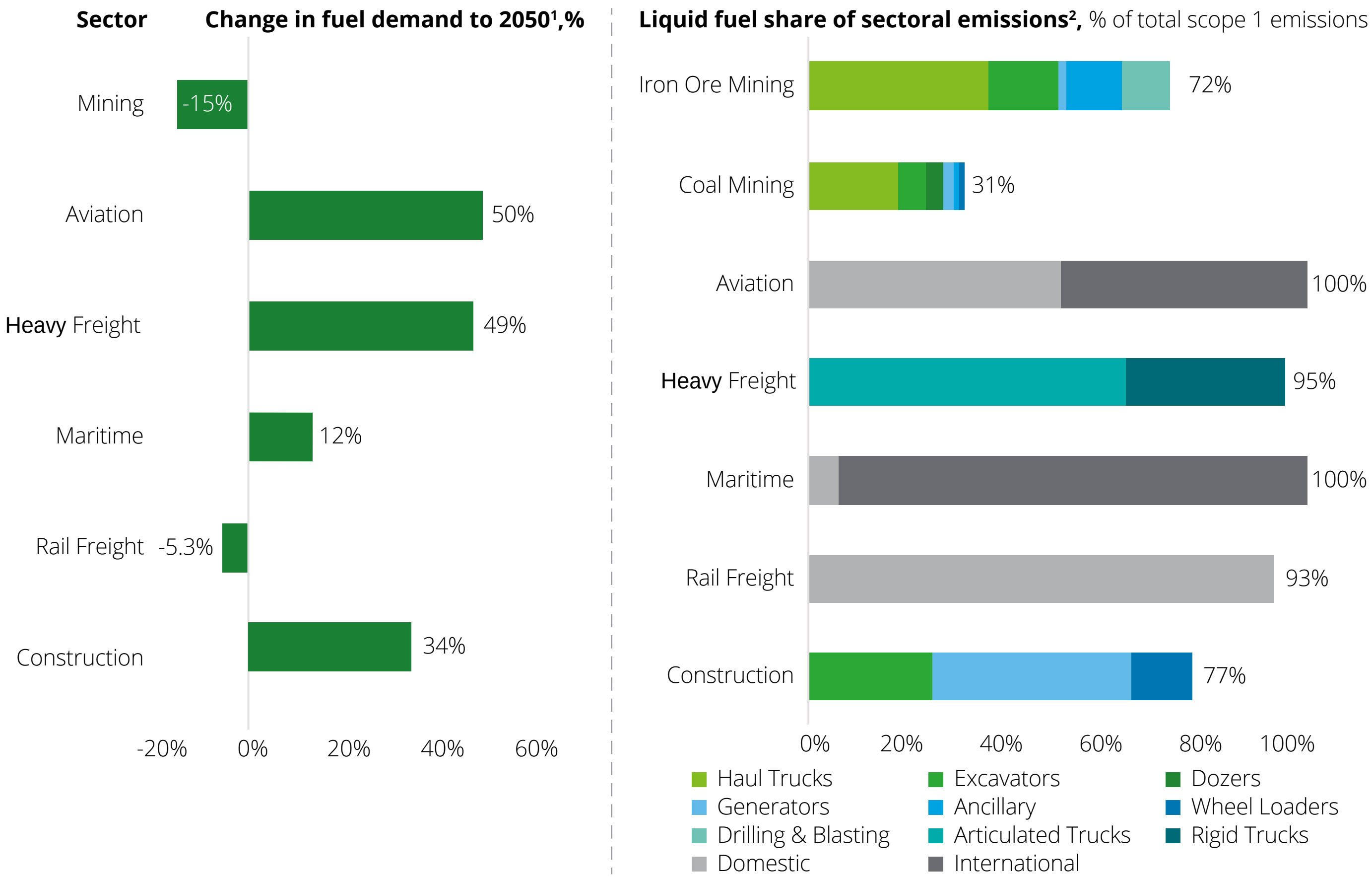
Fuel demand is rising in four of the six hard-to-electrify sectors, even accounting for efficiency gains

Liquid fuel demand is expected to grow for four of the six subsectors in focus by 2050, even accounting for efficiency gains. The sectors anticipated to see the highest growth are aviation and road freight, projected to grow by 2.6 per cent and 1.9 per cent annually, respectively, by 2050.[3] Without action, fuel demand growth across the majority of these hard to electrify sectors will result in an increase in liquid fuel emissions, undermining sectoral and whole of economy decarbonisation commitments.

In the medium- to long-term, electrification and direct hydrogen use are slated to displace 32 per cent of fossil fuel emissions across these sectors. Of the six sectors, mining and construction boast the highest electrification potential. Figure 21 unpacks sectoral liquid fuel emissions by asset level, with literature indicating that the scaled electrification of liquid fuel demand from generators and ancillary equipment may be possible pre–2040. For mobile mining and construction assets, scaled electrification relies on technology breakthroughs, which are not expected to be commercial and/or scalable pre–2040.

LCLF uptake can enable decarbonisation of the residual 68 per cent of emissions and offer a transition pathway for assets reliant on decarbonisation innovation. Aviation, maritime, rail freight and heavy road freight are expected to continue to rely on liquid fuels post–2050, with LCLF the most viable decarbonisation lever. While electrification is expected to represent the primary decarbonisation solution for the remaining assets, delaying abatement while awaiting breakthroughs in these technologies will be inconsistent with necessary decarbonisation targets. If sufficient breakthroughs do not eventuate, and in a timely fashion, then inaction presents a significantly higher risk of failing to meet net zero. For these assets, LCLF is essential as a transitionary solution for at least one asset cycle.

Figure 21: Unpacking the evolution of liquid fuel emissions to 2050 in hard or late to electrify sectors



Sources: 1. Demand growth minus efficiency gains. Mining, Road Freight, Maritime, and Rail estimates based on BITRE Freight Forecasts, 2022, Aviation based on BITRE Aviation Forecasts, 2024, Construction based on the Australian Construction Market Report. All estimates adjust for assumed efficiency gains. 2. See Appendix A for full analysis. 3. BITRE Aviation Forecasts and Navigating Australia's Freight Future.

Prospective Australian LCLF users have clear views about necessary conditions to unlock demand and activate the market

Across the six in focus sectors, Deloitte and the CEFC conducted interviews with **ten** prospective LCLF users and **one** OEM. These interviews were used to inform insights into:

- Current fuel usage
- Sector specific LCLF uptake considerations
- Willingness to pay under different scenarios
- The long-term outlook for domestic LCLF demand
- Future OEM product plans
- Challenges facing uptake
- Discussions of the proponent's future LCLF use alongside other feasible abatement options.

The adjacent key perspectives on future LCLF demand dynamics emerged from the interview process.

Users will purchase on an abatement cost basis

Demand for LCLF will be determined by the relative cost of abatement options rather than on a $/L basis, placing a premium on production pathways that can demonstrate strong carbon intensity credentials

Abatement cost parity is required to drive structural demand outside aviation

Intervention is needed to accelerate the bridging of the cost gap between production cost and the ACCU price, which is currently not expected to be bridged until the 2040s. In sectors where electrification is practical, stakeholders see LCLF primarily as a transition fuel as asset cycles and technologies are proved up, phasing out LCLF use pre-2050

Capacity to pass on current LCLF cost premiums to end customers is limited for most prospective users

Stakeholders highlighted limited willingness to absorb premiums on margins, or capacity to pass-through to customers who are price sensitive. The exceptions were subsections of aviation and construction which represent a small premia

Cost premium aside, prospective users agree most LCLF adoption barriers have largely been addressed

For example, OEMs are adapting warranty conditions to support the use of RD in existing assets, with emerging evidence indicating second generation LCLFs have negligible impact on engine degradation or operating performance. These findings are assisting second generation LCLFs to overcome consumer scepticism

Depending on the use case, LCLF will be either a hedge against delayed electrification or a long-term abatement solution

Electrification constraints position LCLF as a key decarbonisation lever on the path to net zero for certain use cases, including in mining. For end-use sectors like aviation, LCLF represents the only viable decarbonisation solution

Proponents must ensure appropriate environmental impact management

It will be necessary to balance the benefits of transitioning to LCLFs with the potential adverse effects on ecosystems and agricultural systems. In particular, focus will need to be given to water resource allocation and mitigating negative land use changes (either natural habitats or food production land into biofuel crop land) and subsequent emissions

A clear and comprehensive enabling regulatory framework is essential

There is still some ambiguity surrounding the regulatory framework for LCLF production and use. For example, this includes interaction with the Safeguard Mechanism, ACCU scheme, and certification waivers to use lower density fuels on public roads

Maintaining decarbonisation integrity is a non-negotiable

The developing LCLF industry should prioritise on-site abatement over primarily relying on offsets. Where offsets are being used, they should be high integrity

RD and SAF have significant cost gaps relative to incumbent fossil fuels with current policy settings

The concept of willingness to pay is reflective of what the end user of the fuel can and will pay as a premium for the abatement which the LCLF achieves. When the cost of LCLF production exceeds the end user willingness to pay, a cost gap exists which must be bridged for LCLF purchases to make commercial sense.

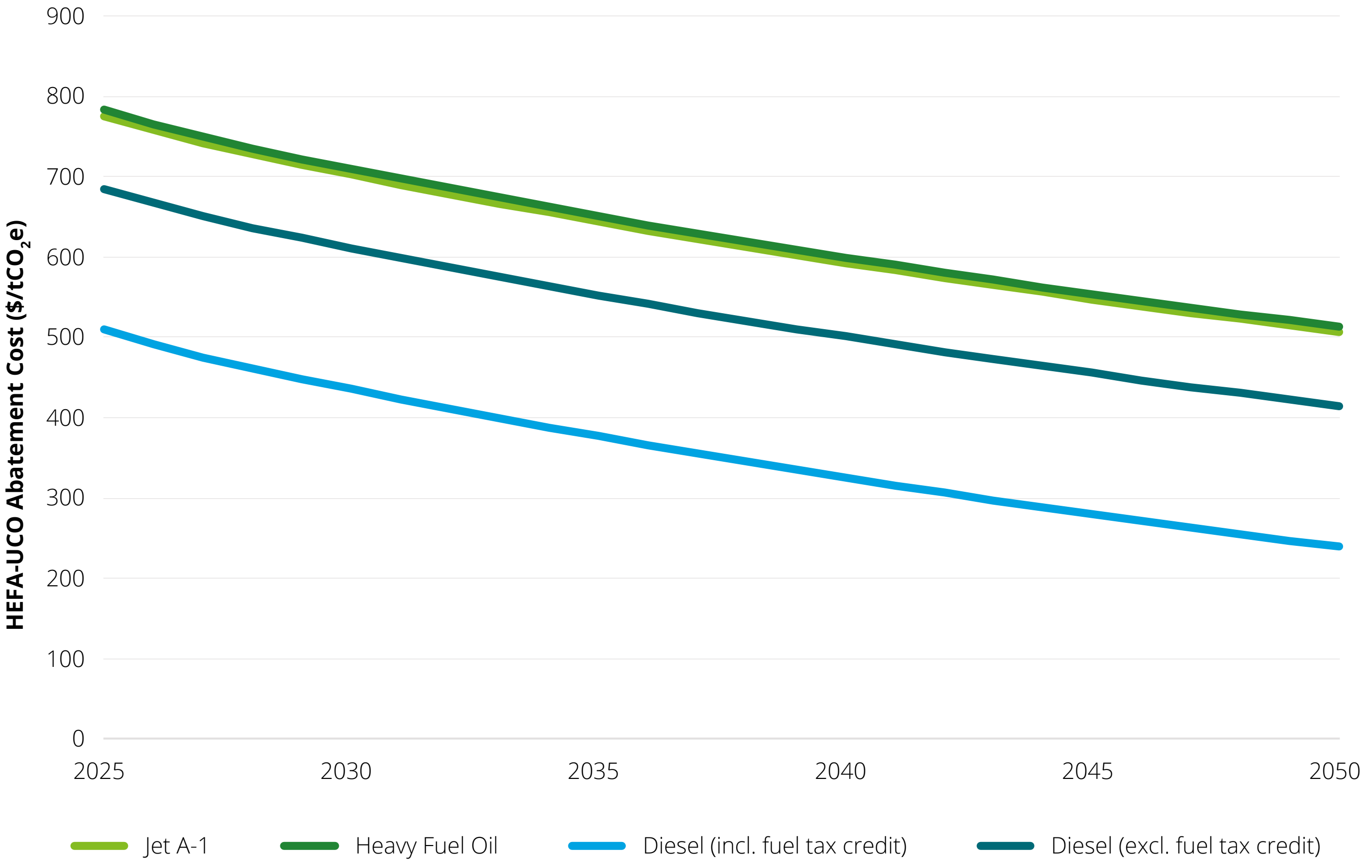
As market participants are primarily purchasing LCLFs for the abatement they achieve over the incumbent fossil fuel, the cost gap represents the carbon cost which must willingly be paid by the end user to adopt the LCLF. In many cases, an ACCU or the Safeguard Mechanism Credit cap is used as a proxy carbon cost.

The abatement cost gap varies by sector depending upon the fossil price of the incumbent fuel. As shown in Figure 22:

- **Diesel has the smallest cost gap** reflective a higher incumbent fuel price, but this is only applicable for heavy freight users who predominately drive on public roads.
- **The Australia Fuel Tax Credit (FTC) adds approximately \$170/tCO_2-e to the abatement cost gap.** The FTC is claimed by fuel users who consume fuel off road. It has a significant distortive effect on the willingness to pay of some industrial sectors (mining, construction, rail), meaning a larger cost gap needs to be bridged.
- **Low conventional fuel costs mean Jet A-1 (aviation) and Heavy Fuel Oil (maritime) have structurally higher cost gaps.**

While the abatement cost gap declines over time, Figure 22 shows no convergence with the incumbent fossil fuel price. At a \$75/tCO_2-e price growing at 2 per cent per annum in real terms, no convergence occurs, with the gap between the line and \$0/tCO_2-e indicating the shortfall needed to stimulate demand. Notably, the lowest modelled cost of production LCLF is shown, with policy action and cost reductions required to unlock offtake.

Figure 22: The abatement cost gap emerging within the market at present fossil fuel prices and with a \$75/tCO_2-e carbon price[1,2]



Sources: 1. Jet A-1 – IATA Asia & Oceania Price; Heavy Fuel Oil – EIA No. 2 Heating Oil; Diesel – Australian Petroleum Institute; Fuel Tax Credit – ATO Fuel Tax Credit Rates from 1 July 2024 to 30 June 2025. 2. The abatement cost gap is calculated as the difference between the fossil fuel price and a modelled LCLF alternative for each year to 2050. WTP assumptions are included at Appendix A. This chart uses HEFA-UCO on a current cost trajectory as detailed in Appendix B.

Aviation and mining represent the two largest sources of potential LCLF demand, but are thinking about offtake quite differently

Aviation

2022-2023 Fuel Share: 14.0 per cent | 2024 Fuel Costs: ~$0.93/L | 2024 WTP: ~$1.16/L

- The global aviation sector has committed to **net zero emissions by 2050** and have implemented a phased Carbon Offsetting and Reduction Scheme for International Aviation **(CORSIA)** in support of this target.
- There are **limited alternative methods of decarbonisation** for this sector. Even if electric planes are developed and commercially available by 2050, electrification is not viable for most Australian routes due to battery weight and payload capacity - most Australian flights (and aviation emissions) are medium and long haul. SAF likely to represent greater than 75 per cent of the aviation technology split in 2050.
- Due to the low price of fossil jet fuel, **SAF has a substantial cost gap** to bridge at ~$2.80/L.[2]
- Fuel represents a high proportion of operating costs (20–30 per cent) and margins are slim.[1] This suggests **airlines will struggle to buy SAF at scale without passing costs onto customers.** However, **Aviation players are already active** in this space and are **working to catalyse a domestic SAF market.** For example, the Australian Sustainable Aviation Fuel Partnership signed by Qantas and Airbus. Additionally, government and industry and collaborating through the Australian Jet Zero Council to mitigate market challenges.
- There is **emerging evidence from the Australian market to suggest that business customers could be willing to pay a premium to demonstrate scope 3 emissions reductions. In the US, this premium equates to roughly $200–650/t$CO_2$-e,**[3] after accounting for policy support.
- Government travellers account for 1.5 per cent of domestic flights,[4] and large cap business travellers a further ~9 per cent.[5] At this stage of market development, these are the only market segments who may reliably pay a premium for scope 3 emissions reductions.

Mining

2022-2023 Fuel Share: 14.3 per cent | 2024 Fuel Costs: ~$1.24/L | 2024 WTP: ~$1.49/L

- The Minerals Council of Australia has confirmed the mining industry's commitment to **net zero emissions by 2050**, with many individual corporations setting **additional interim targets** often specific to scope 1 and 2 emissions. However, as the majority of mining businesses are diversified, **fuel use makes up a smaller proportion of their scope 1 emissions** compared to the aviation sector (e.g. fugitives for coal).
- In general, **miners are prioritising electrification,** though this is governed by **site-specific considerations.** For example, electrification requires new renewable assets and associated transmission and storage infrastructure – today the majority of mine sites remain off grid. New equipment including overhead trolly charging infrastructure and extra batteries are also required.
- Greenfield mines are the easiest to electrify, with **electrification of brownfield and shorter life mines harder to justify** given the payback on new energy infrastructure. In comparison, **as a drop in fuel, RD does not require costly infrastructure overhauls.**
- There is **early evidence miners are playing in the LCLF value chain.** For example, Rio Tinto has committed to replacing its entire fossil diesel consumption with RD at its Kennecott and Borax operations in the US and has announced a pilot to develop Pongamia seed farms in Australia.[6]
- **RD is competing against other diesel abatement options** in miners' portfolios **and has a higher marginal abatement cost than the purchase of ACCUs**. There are international case studies where RD has come close to breakeven pricing, such as Rio Tinto's Kennecott copper mine at $100/t$CO_2$-e,[7] but this is yet to be reflected in the Australian market.
- **The benefits of RD to end users vary by commodity.** For example, in steelmaking, the emissions impact of RD is an order of magnitude smaller than DRI and other more established processes. This results in limited ability to pass costs onto end consumers.
- Fuel use is **exempt from the fuel tax credit,** meaning the tax treatment of LCLFs will partially determine the cost gap.

Sources: 1. IATA Airline Profitability Outlook, 2024. 2. Based on SAF Class II fob Singapore price and industry WTP range. 3. Low end based on residual cost gap from DOE SAF Liftoff Report, high end based on SABA market tender. 4. Based on Aviation Green Paper submissions. 5. Based on Tourism Research Australia, 2024 . 6. Rio Tinto, 2024. 7. Rio Tinto Climate Change Report 2023, 2024

Rail and maritime customers have few abatement options, but operate on thin margins and with considerable exposure to the mining sector

Rail

2022-2023 Fuel Share: 2.5 per cent | 2024 Fuel Costs: ~$1.24/L | 2024 WTP: ~$1.99/L

- **The majority of rail freight sector emissions come from freight.** Of that, **mining and agriculture are the primary demand drivers**, representing a combined 94 per cent of total rail freight freight emissions (65 per cent iron ore, 26 per cent coal, three per cent grains, and one per cent sugar).[1]
- Australia's main rail freight operators have acknowledged the importance of achieving net zero but highlighted that **feasible options for decarbonisation are limited.**
- Alternatives to LCLF in this industry are not robust. Miners in the Pilbara are exploring deployment of battery-electric locomotives, although these remain early stage.[2] Electrification is challenging for rail freight given long asset lives (40-60 years) and long flat haul routes requiring limiting solutions like regenerative braking. Generation and distribution infrastructure will also need to be built.
- RD is a promising near-term solution given the drop in nature. However, RD faces substantial cost challenges, with a cost gap of ~$1.50/L.[3] This problem is exacerbated by the fact that **while diesel currently has a fuel tax credit, RD does not.**
- Rail may have an opportunity to leverage RD use in mining. The rail freight sector has low margins, so would likely need to pass on costs to customers, which is difficult due to the limited appetite. However, because the industry is so tightly coupled to its customers, this could also represent an opportunity. For example, if a miner procured RD for its own operations, it may also consider RD for its rail freight freight.
- Similar to the mining sector, **decarbonisation options will vary materially by route and distance due to infrastructure requirements.** For example, there are a significant number of routes where electrification will not be feasible, including due to the size of rollingstock locomotives and distances, such as East–West services across the Nullarbor.

Maritime

2022-2023 Fuel Share: 2.7 per cent | 2024 Fuel Costs: ~$0.96/L | 2024 WTP: ~$1.20/L

- The primary driver for decarbonisation in this space is the International Maritime Organisation's Marine Environment Protection Committee and net zero framework.[4] Few maritime operators are covered by the Safeguard Mechanism.
- When considering trade, **Australia's imports and exports represent 14 per cent of global sea freight, but only account for four per cent of global shipping emissions**. The lower emissions on average are attributable to the frequent use of energy efficient large bulk carriers, and the relatively short sailing distances between Australia and Asia, where the vast majority of trade is.[5]
- **Coastal shipping,** which counts towards Australian emissions targets, **is only 2.7 per cent of liquid fuel use**. Almost 40 per cent of coastal shipping is attributable to bauxite and alumina, with coal and construction materials representing another 30 per cent.[6]
- **LCLFs are primarily being considered as an immediate maritime solution.** Due to the long asset cycles of vessels (20–30 years), the industry is more focused on technical efficiency in the near-term. Canada Steamship Lines (CSL) has conducted several trials to prove the effectiveness of B100 as decarbonisation transition solution for existing ships.[7] International shipping companies are **exploring the use of clean ammonia and methanol as a long-term solution.**
- **Bulk shipping tends to use heavy fuel oil,** which is very emissions intensive, but also very cheap. Since global shipping has low margins and is dependent on cheap freight, the additional costs would need to be passed onto customers. There is unlikely to be a high appetite for this, particularly for bulk shipping.

Sources: 1. CSIRO TraNSIT, 2024. 2. Including Roy Hill, Rio Tinto, BHP, and Fortescue. 3. Based on HVO Class II fob Singapore price and industry WTP range. 4. IMO, 2024. 5. Department of Infrastructure, Transport, Regional Development, Communications and the Arts, 2023. 6. Department of Infrastructure, Transport, Regional Development, Communications and the Arts, 2022. 7. CSL Case Study, 2022.

Road freight and construction are both fragmented sectors, with only large companies likely viable offtakers for LCLF

Road Freight

2022-2023 Fuel Share: 14.6 per cent | 2024 Fuel Costs: $1.74/L | 2024 WTP: ~$1.99/L

- **Road freight is the most significant mode of transport for goods in Australia**, accounting for approximately 75 per cent of total domestic freight by volume. It is expected to continue to grow at a rate of 3.5 per cent to 4.0 per cent per year. As a result, it is likely that **road freight emissions will continue to increase** before significant decarbonisation action can push them down.[1] Within road freight, 57 per cent of emissions are attributable to articulated trucks and 43 per cent to rigid trucks.[2]
- **The industry is highly decentralised,** with 98 per cent of operators classed as small businesses with fewer than 20 employees.[3] However, some of the larger operators are captured under the Safeguard Mechanism.
- Although **electrification** is viable for some routes and asset types, there are **challenges associated with long asset cycles**, and it has **poor suitability for the highest emission cases** (e.g. articulated trucks). There is some support for **hydrogen trucks**, including trials and policy initiatives like the Hume Hydrogen Highway. There are also **LCLF trials underway**, for example Cleanaway's HVO100 trial.[4]
- Within the road freight industry, a typical cost structure includes a fuel surcharge to protect operators from uncertainty and ensure fuel costs are passed directly onto customers. **This mechanism could be used to pass RD cost premiums onto customers where there is willingness to pay**. However, the industry typically operates in a network business, so passing cost premiums onto a vast array of customers could be challenging. Additionally, evidence suggests current premiums are too high for end users to have appetite either now or in the long-term. Anecdotal feedback suggests end users have an expectation cost premiums for scope 3 abatement will fall over time.[5]
- The **cost gap varies quite substantially**, partially depending on whether the **fuel tax credit** is applicable (dependent on usage of public roads). Those who pay a fuel tax credit have a smaller cost gap today, with B5 or B20 closer to diesel price, however, will represent a small subset of road freight.

Construction

2022-2023 Fuel Share: 0.9 per cent | 2024 Fuel Costs: $1.74/L | 2024 WTP: ~$1.99/L

- Although the construction industry only represents a small portion of liquid fuel use in Australia, **liquid fuels can represent up to 79 per cent of construction scope 1 emissions.**[6] Overall usage will continue to grow with increasing housing builds and a healthy pipeline of major infrastructure construction planned. However, the short-term nature of the construction pipeline makes it difficult to determine the specific equipment required and whether that equipment can be electrified.
- Construction of **linear infrastructure (e.g. roads, rail) consumes significantly more fuel** than construction of vertical infrastructure (buildings).
- **Electrification is not viable for heavy or remote assets,** where diesel remains a vital component of the energy mix, as it offers high energy density and reliability under demanding conditions. These assets are more likely be reliant on an alternatives like RD. However, the majority of construction **equipment is likely to electrify** due to lower marginal abatement costs.
- There have been **several successful examples of RD use in construction** globally. For example, there is considerable use of RD in the UK, with several construction companies on the road to becoming fossil fuel free.
- **Fuel emissions in construction are a scope 3 issue for customers.** In the UK, public procurement for infrastructure has elected to wear the cost premium, though the private sector is less open to this.
- Public sector procurement for transport represents 7.7 per cent of Australian linear infrastructure construction activity,[7] contributing significantly to Australia's liquid fuel emissions. By adopting strategies similar to the UK's approach of addressing scope 3 emissions through RD, Australia has a significant opportunity to improve sustainability in public procurement.

Sources: 1. Truck Industry Council, 2024. 2. DCCEEW Transport Emissions Projections, 2024. 3. Australian Trucking Association & Truck Industry Council, 2024. 4. Cleanaway, 2024. 5. Based on Deloitte stakeholder engagement. 6. Downer Group, 2024. 7. Australian Bureau of Statistics, Construction Work Done, Australia, Preliminary.

There are wide ranges for future Australian LCLF demand, with policy and supply costs the determinants of on-site abatement relative to offset reliance

Prospective Australian users are consistent in their views that policy change is necessary to overcome challenges to the development of an LCLF industry. Current policy is driven by the design of the Safeguard Mechanism and forecasted ACCU pricing trajectories, which drives proponents to invest in offsets over structural abatement through LCLF until at least the 2040s.

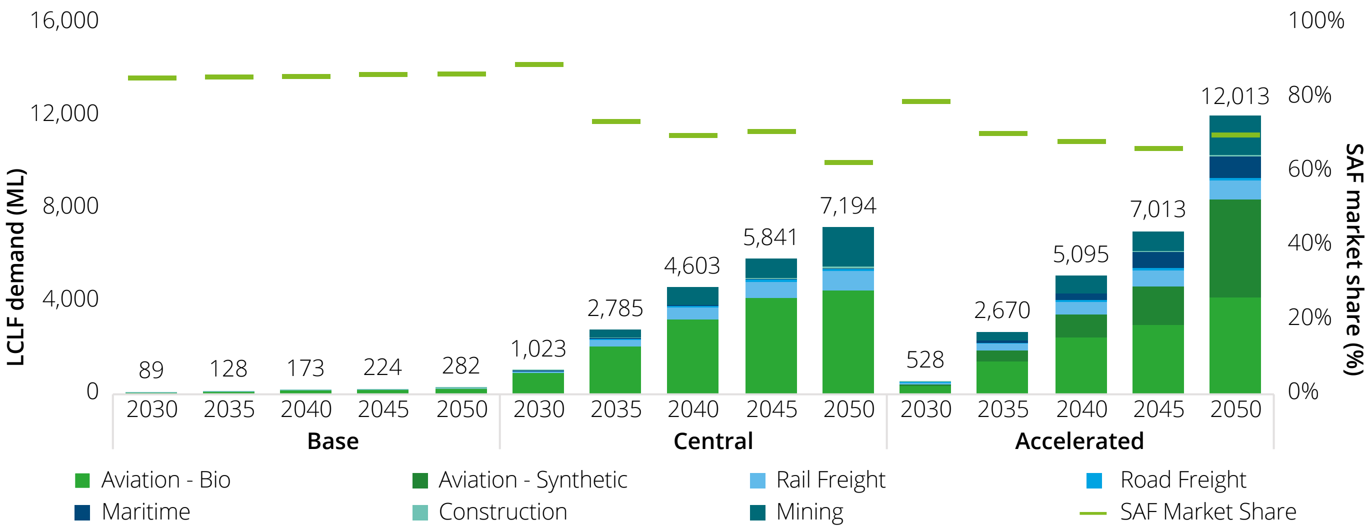
The base scenario reflects large business and Australian government aviation travelers, and public sector construction as the most likely to voluntarily adopt LCLFs, reflecting current policy settings. In 2035, a market reliant on premium demand underpins ~128 ML of LCLF and results in implied ACCU demand of nearly 8 Mt as proponents across the five sectors* address their liquid fuel use emissions obligations through offsets.

To develop the central scenario, this study adapts the Clean Energy Regulator's public disclosure requirements into a 30 per cent hard limit on ACCU use for liquid fuel related emissions by safeguard facilities whilst removing the trade-exposed baseline-adjusted classification.** In this scenario the order of decarbonisation decision making for liquid fuel intensive equipment is as follows: ACCU purchase, electrification (*timing of entry to abatement mix outlined in Appendix A*), LCLF uptake and finally, hydrogen-derivative uptake. In this scenario, the 30 per cent hard limit is purely applied to abatement relative to the baseline, meaning by 2050, only on-site abatement is permitted. **What emerges is LCLF uptake across all six sectors totalling 2,785 ML in 2035,** underpinned predominantly by demand from aviation (73 per cent), mining (12 per cent) and rail freight freight (11 per cent). Relative to the base scenario, the hard cap on offset use reduces ACCU demand in 2035 by 5.4 Mt.

Acknowledging the Australian Government is currently undertaking regulatory impact analysis on demand-side measures for LCLF, the accelerated scenario adopts the mechanics of the EU's SAF and shipping mandates to build demand for aviation and maritime, while maintaining the demand profiles of the central scenario across the remaining sectors. Importantly, the EU SAF mandate has established considerably more aggressive long-term targets than those currently in force in APAC, including for synthetic SAF, which drives scaled domestic demand from 2040 onwards in the accelerated scenario. Applying the FuelEU Maritime Regulation delivers a ~230 per cent and ~2,800 per cent increase in maritime demand on the central scenario in 2035 and 2050 respectively.

Across all uptake scenarios, SAF consistently accounts for greater than 60 per cent of domestic market share. Importantly, while not considered in these scenarios, ADF procurement of LCLF to service fuel demand would likely total a lower bound of 310 ML/year, based on 2020–21 demand.[2]

Figure 23: Sectoral LCLF demand to 2050 by uptake scenario[1]



Notes: *Due to the temporary nature of construction sites, the industry is not captured by the Safeguard Mechanism. **For transparency, where a Safeguard facility surrenders ACCUs equal to more than 30 per cent of its baseline, it will be required to make a statement to the Clean Energy Regulator (CER) setting out why on-site abatement has not been undertaken. These statements, excluding commercially sensitive information, will be made public on CER's website.
Sources: 1. Deloitte analysis, see Appendix A. 2. ASPI, 2022.

Bottom-up estimates of LCLF demand are generally high relative to other market benchmarks, which do not pick up the granularity of Australian conditions

Previous studies have taken a top-down view of future global LCLF demand, which can be downscaled to derive a benchmark for the Australian context. This top-down model simplifies the decarbonisation decisions facing proponents to provide a useful common-sense heuristic of how LCLF demand may evolve. In contrast, this study develops bottom-up estimates of potential domestic LCLF demand across the six core sectors, interrogating specific asset decarbonisation trajectory decisions and abatement cost pathways within each.

Demand in 2030 across top-down estimates is 200–410 per cent greater than the accelerated case, largely attributable to discrepancies in road freight uptake. This is driven by assumptions which see structural long-term abatement delivered in a straight-line rather than through gradual ramp up. In contrast, bottom-up estimates consider abatement costs in the Australian condition, calibrated to stakeholder claims that the current Safeguard Mechanism and ACCU pricing are insufficient to drive early LCLF uptake.

By 2050, Australian specific aviation and mining dynamics, targeted LCLF demand intervention and electrification assumptions commercially calibrated for the Australian context combine to catalyse scaled LCLF uptake across the central and accelerated scenarios. Unlike industry benchmarks, bottom-up estimates are calibrated to proponent views on the operational and commercial challenges arising from asset electrification in mining and rail. The unique application of the Safeguard Mechanism and mirroring European LCLF mandates drives enhanced SAF demand in the central and accelerated scenarios, respectively.

An analysis of top-down energy mixes in 2050 provides deeper insight into the opaqueness of how long-term decarbonisation will be delivered in liquid fuel dependent industries. Most notably, benchmarks forecast considerable penetration of electrification in rail freight and mining, and significant discrepancies across the energy mix for road freight, with electrification ranging from 7–51 per cent.

Figure 24: Projected Australian LCLF demand (PJ)

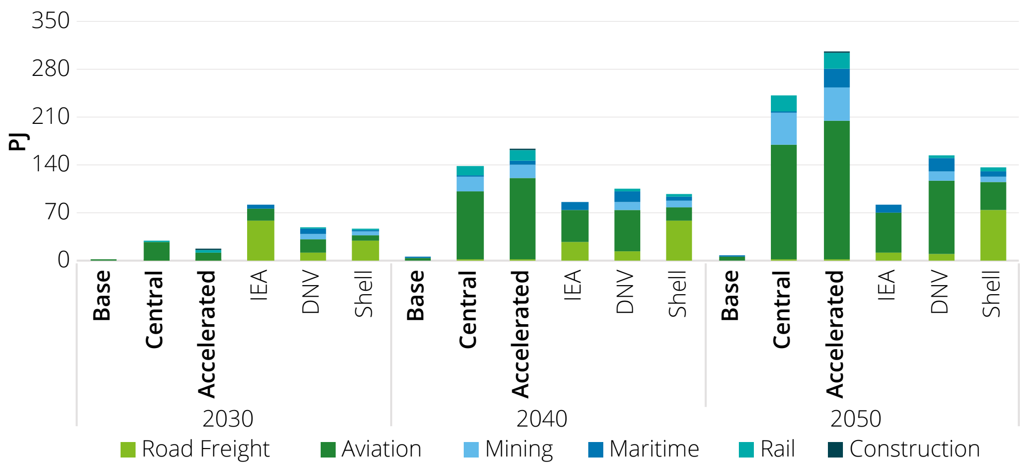
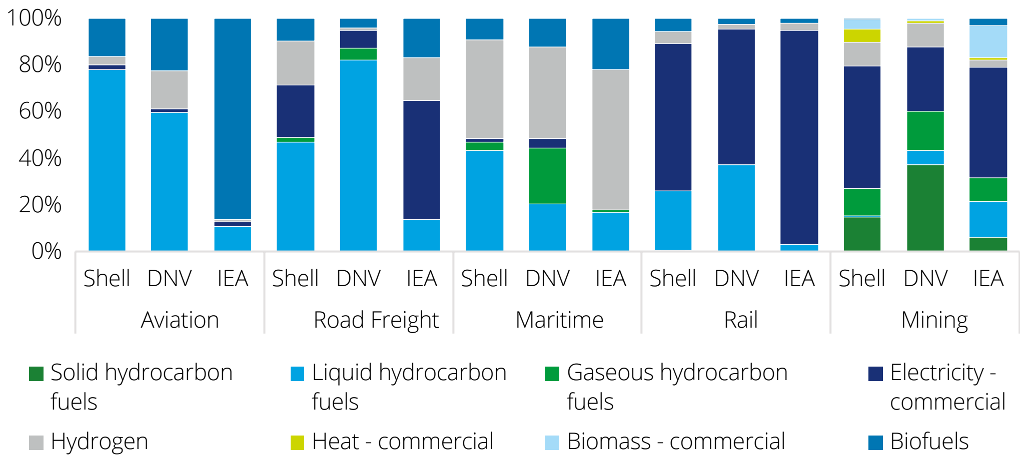


Figure 25: Projected shares of energy mix in 2050



Sources: 1. DNV, 2024. 2. IEA, 2024. 3. IEA, 2024. 4. Shell, 2023.

Stronger policy intervention will help bridge the cost gap and drive LCLF-enabled decarbonisation

The relative cost of abatement options available to fuel users will be the primary determinant of domestic LCLF uptake. LCLF products currently available in the Asia-Pacific market, including HVO and SAF, are largely derived from UCO or tallow feedstocks and trade at a premium relative to those produced in markets with generous production support such as the US. As Figure 26 illustrates, this has the net effect of driving the current abatement cost of Asia-Pacific LCLF products up relative to alternative decarbonisation levers. This includes alternative sources of LCLF, with Rio Tinto's US Kennecott Mine operation benefitting from generous US Government support for RD.

Industries such as aviation, with no commercially viable alternate long-term abatement solution, depend on material improvements in LCLF economics to deliver cost effective on-site decarbonisation. However, for some end-use sectors such as mining, electrification and hydrogen derivatives will lower the abatement cost curve and in the long-term displace most scope 1 emissions associated with liquid fuel use.

For as long as LCLF abatement costs remain higher than alternatives, domestic uptake will likely be constrained to volumes depicted in the base scenario. Delivering abatement cost reductions for LCLF use in the domestic context will require policy intervention to:

- Underpin scaled demand and encourage developers to compete on price and carbon intensity
- Drive production cost reductions through time-bound supply-side support and/or
- Intervene or catalyse a significant price increase in the ACCU market, to ensure proponents adopt on-site abatement.

Under current policy settings, LCLF uptake will deliver ~0.74 Mt of carbon abatement in 2050 (~85 per cent from aviation), representing ~7 per cent of 2022–23 domestic aviation liquid fuel emissions. Policy intervention in the form of an ACCU purchasing cap or adopting mandates mirroring those in the EU (see page 36 for detail) can drive scaled LCLF enabled decarbonisation across aviation, rail, maritime construction and mining, delivering an additional 18.2 Mt and 33.6 Mt of abatement in 2050, respectively.

Figure 26: Abatement costs in 2025 for key mining and aviation decarbonisation levers*[1,2,3,4,5,6,7]

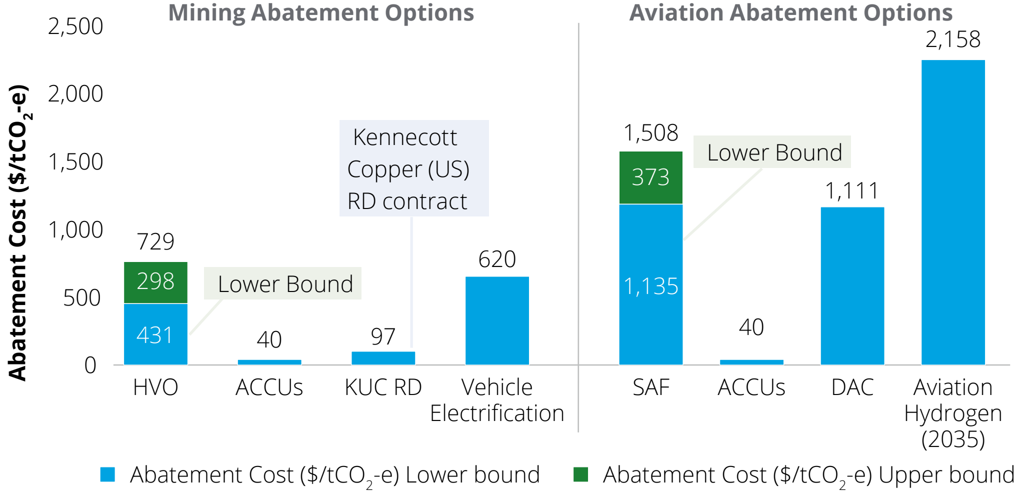
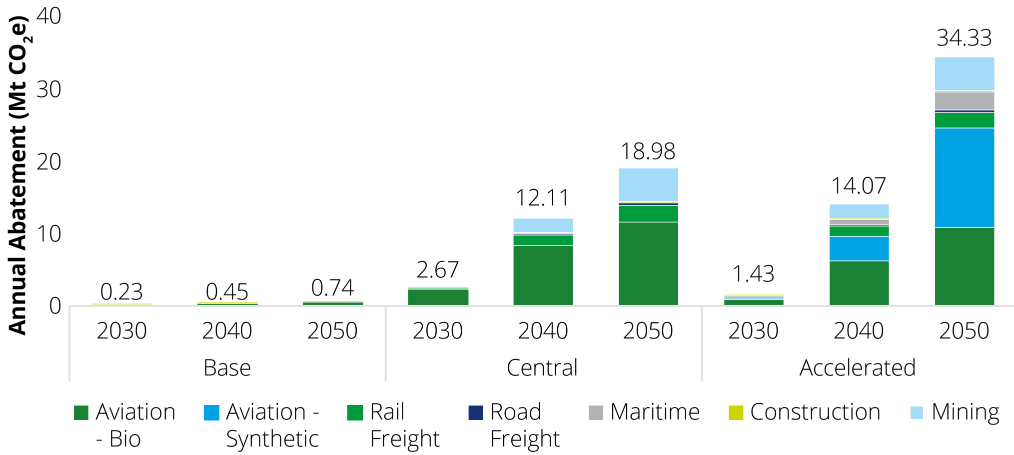


Figure 27: Potential abatement from LCLF uptake across scenarios in 2030, 2040 and 2050



Notes: *HVO and SAF pricing assumed historical range from Jul 24 – 2Q25 forecast, Class II fob Singapore (HEFA-UCO), adjusted for delivery to Australia using observed freight range of USD ~$40 - $80/T 1. Diesel price sourced from AIP Weekly Diesel Prices Report, week ending 12 Jan 2025. Jet A-1 price sourced from IATA Jet Fuel Price Monitor, week ending 10 January 2025. Mining vehicle electrification MAC of $256 in 2029–30 sourced from NSW Carbon Values Report and back dated to 2025 using decline rate for battery electric truck MAC Advances in Applied Energy. Sources: 1. Argus Biofuels Outlook, 2024. 2. December Quarterly Carbon Market Reports, 2025. 3. Rio Tinto Climate Change Report 2023, 2024. 4. NSW Carbon Values Report, 2024. 5. Advances in Applied Energy, 2023. 6. Pathways to Commercial Liftoff: SAF, 2024. 7. Advances in Applied Energy, 2023.

4: What is Australia's LCLF supply potential?

Prospective fuel buyers are clear – LCLF is a crucial lever to achieve their decarbonisation objectives, with significant volumes required. However, potential buyers have also emphasised that this must be at commercially viable abatement costs. A detailed consideration of Australia's LCLF production potential is necessary to determine what Australia can produce, how cost gaps may evolve, and major levers to materially reduce costs.

Consistent with previous studies, Australia has significant feedstock potential which is already supplying global LCLF production. However, an even greater value-add opportunity exists if Australia can enable a scaled domestic LCLF industry. But today, only HEFA-based production is likely to be competitive, and this could require access to currently exported feedstocks.

Continued innovation is needed to structurally lower LCLF production and abatement costs across all production pathways to unlock widespread adoption. This can primarily be achieved through innovation. Priorities include (1) pathways to reduce feedstock prices, (2) process yield improvements, and (3) feedstock carbon intensity reductions. R&D and novel feedstocks will become an important part of market development. As we wait for these dynamics to play out, a relative hierarchy of feedstock suitability for fuel production is emerging which could inform a lowest cost abatement pathway for LCLF use.

Australia has significant feedstock potential which could enable a scaled LCLF industry

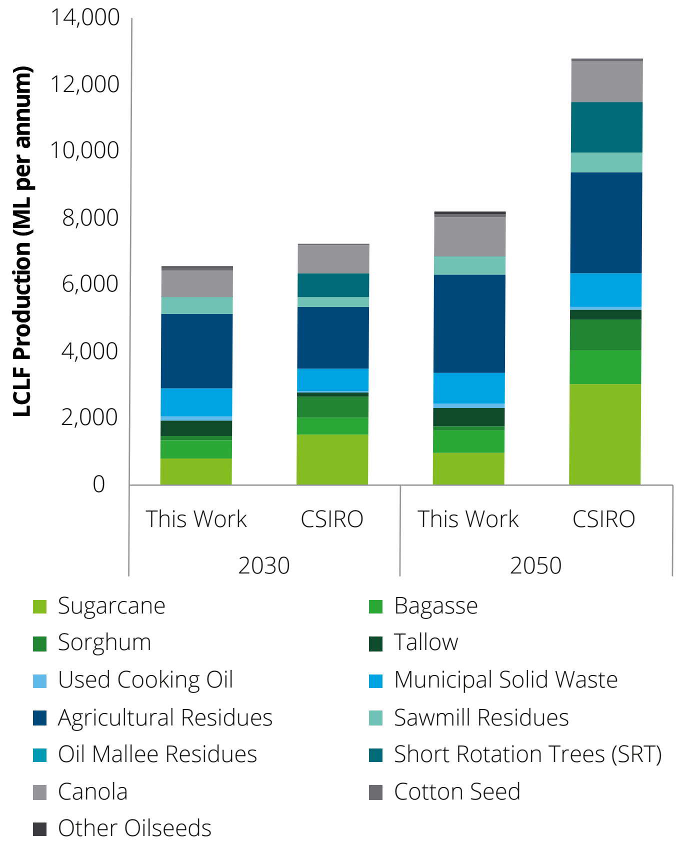
Australia's significant agricultural industries offer material comparative advantage in LCLF production via widespread availability of biogenic feedstocks.[1] This advantage is being captured with feedstocks such as tallow and canola already exported for the production of LCLF. CSIRO also estimates an LCLF industry could contribute between $6-12 billion in direct benefits with additional regional co-benefits.[1, 3]

The widespread availability of biogenic feedstocks places Australia in a unique position relative to most other markets which typically seek to leverage LCLFs from waste-based feedstocks. These markets are actively planning how to manage feedstock shortfalls to remain aligned to their decarbonisation trajectories.[2] In contrast, CSIRO estimate that Australia is unlikely to experience physical feedstock shortfalls with recent work emphasising further opportunities exist to expand Australia's biogenic feedstock supply to beyond 12.8 bn litres if these feedstocks lead to cost competitive abatement.[3]

Australia's challenge is not our comparative advantage in biogenic feedstock supply, but the viability of unlocking domestic LCLF production using these feedstocks. There are four important dynamics which are likely to shape how Australia's feedstock market develops:

1. **Competition and climate change can constrain availability:** Most feedstocks are not waiting for an Australian LCLF market to develop. Domestic biorefineries will likely need to compete with international buyers and demand from other emerging domestic industries such as biomethane and biochar. In parallel, the changing climate can be expected to redraw growing regions and impact supply.
2. **Rising feedstock prices will trigger a supply response:** Increased competition for feedstocks could put upward pressure on fuel prices. But the market will react – avenues for increasing supply will arise from new crop rotations, plantings on marginal land, increased waste collection rates, and deployment of novel energy crops. These pathways could boost supply beyond the projections in Figure 28.
3. **Infrastructure investments are needed to make new supply accessible:** Capital investments will be needed in many cases in irrigation, pre-processing and processing infrastructure to ensure reliable feedstock supply. Securing equity or debt investment for these expansions will turn on visibility of end user demand for LCLF and the relative competitiveness of new feedstock entrants in the market.
4. **Increasing marginal costs are inevitable without collection and aggregation innovation:** Increasing collection of existing and new feedstocks will come with additional costs which will inevitably need to be recovered. For example, each new tonne of agricultural residues is likely to be more complex to aggregate and process than one already in the market, and the opportunity cost of taking this biomass out of an agricultural system will need to be factored into the price. Continued innovation in collection and aggregation of these feedstocks is a prerequiste for preventing marginal cost increases.

Figure 28: Australian feedstock availability across 2030 and 2050 within this work and work by CSIRO considering boosted feedstock supply[4]*.



Sources: 1. CSIRO, SAF Roadmap, 2023. 2. See for example ICF, SAF Ecosystem in Japan, 2024. 3. CSIRO, Opportunities and Priorities for a Low Carbon Liquid Fuel Industry in Australia, 2025

Notes: * This works projected Australian feedstock availability data displayed in Figure 28 is consistent with work previously completed by CSIRO; Sustainable Aviation Fuel Roadmap (2023). The CSIRO values presented reflect a recent study which considers opportunities to boost feedstock supply.

Australia's feedstock potential lends itself to the four major LCLF production pathways

LCLF production pathways can be classified into two groups: biogenic and synthetic (e-fuel) pathways.

The biogenic pathway utilises organic feedstocks to generate LCLFs, including agricultural residues and used fats, oil and greases. In contrast, e-fuel or synthetic fuel is developed by integrating renewable hydrogen produced through electrolysis with captured CO_2 from either air, point sources of carbon (such as from steelmaking, cement manufacturing, etc) or biomass gasification.

At present, only some pathways are approved by the American Society of Testing and Materials (ASTM) for SAF specifically, as outlined in Figure 29. These pathways can also be applied to RD. Relevant to biogenic SAF production, three SAF pathways are the most developed, namely HEFA, AtJ and FT. These technological pathways use a variety of organic feedstock, ranging from oil crops, tallow, sugarcane and urban waste. They also have different maximum blend ratios, as defined by ASTM specifications. Note that at present, a maximum blend of 50 per cent is permitted but trials are ongoing for 100 per cent usage of SAF. Renewable diesel is already in use at 100 per cent with multiple OEMs providing certification.

While some of these technologies are mature, significant development challenges remain, particularly concerning feedstock pathways. For example, the TRL for different gasification pathways varies widely. This variability presents obstacles in scaling up production and ensuring consistent quality and supply of feedstocks necessary for LCLF production. An additional synthetic pathway, PtL is not ASTM-approved, however is a promising long-term LCLF pathway if commercial viability is improved. For the purpose of assessing LCLFs in Australia, and considering future feedstocks currently prioritised by the market, **this report focuses on HEFA, AtJ, FT and PtL production pathways (see Appendix B for detailed descriptions).**

Figure 29: ASTM-approved LCLF production pathways

LCLF Production Pathways

Pathway	Intermediate	Processing	Feedstocks	
9 HEFA	Lipids	Rendering	Animal Fats	
		Neutralisation	Used Cooking Oil	Plant Oils
7 AtJ	Ethanol	Fermentation	Oil Mallee Residues	Sawmill Residues
			Agricultural Residues	Bagasse
			Sugarcane	Sorghum
4 FT	Syngas	Separation	Municipal Solid Waste	Oil Mallee Residues
		Pre-treatment	Agricultural Residues	Sawmill Residues
		Gasification	Bagasse	
		Electrolysis & air capture	Renewable Energy	
4 PtL upgrading (e-fuels)	Methanol	Electrolysis & air capture	Renewable Energy	

Legend: 1 Technology Readiness Level (1: research to 9: deployment)[1]

Sources: 1. DOE SAF Liftoff Report.

The carbon intensity of LCLFs vary significantly by feedstock and production pathway

The carbon intensity, or overall emission abatement potential, of a LCLF is measured using Life Cycle Assessments (LCA). There are several approved LCA assessment methodologies, with International Sustainability & Carbon Certification (ISCC) and Roundtable on Sustainable Biomaterials (RSB) as the two main certification bodies. The feedstock and production pathway of an LCLF will significantly impact the carbon intensity, with some feedstocks and technology pathways exhibiting higher lifecycle emissions compared to others, as seen in Figure 30. This variability can affect the competitiveness of different feedstocks in the market.

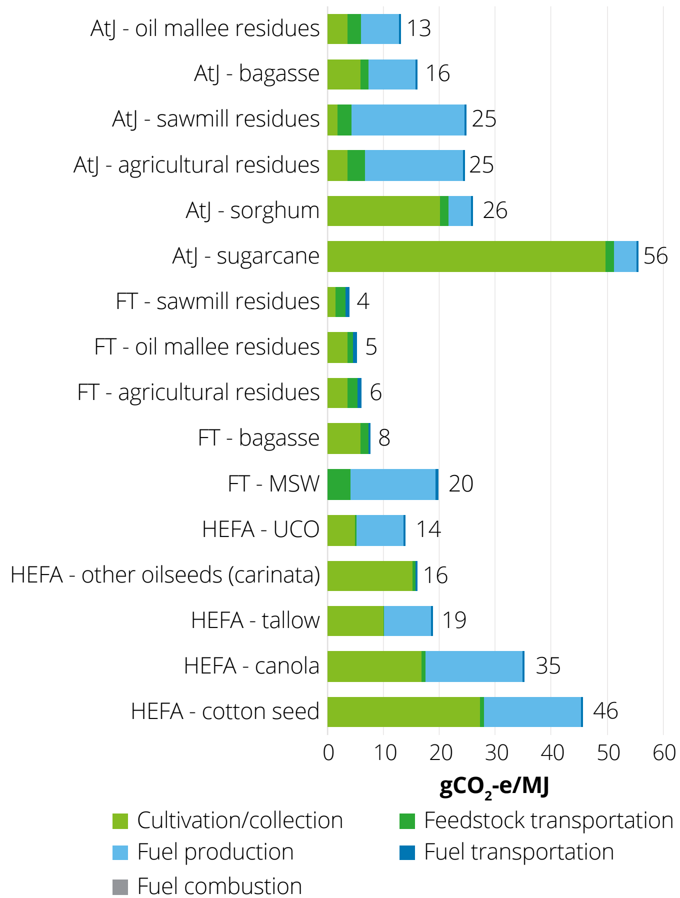
There is a growing focus on adverse trade-offs associated with land use changes. Producing feedstocks for fuel production has the potential to displace land currently used for food production or carbon-absorbing forests. These impacts are captured using Direct Land Use Change (dLUC) and Indirect Land Use Change (iLUC) factors added to an LCA.

Different LCA frameworks utilise varying methodologies, with some substantial differences between them. In particular, there are significant variations in the treatment of land use changes and soil organic carbon (SOC) changes. The difference in treatment of dLUC, iLUC, and SOC factors can greatly influence the competitiveness of certain feedstocks.

Regionally specific data and farming practices can have a major impact on carbon intensity and land use change calculations, and more work needs to be done to tailor guidelines to the Australian context. Default factors for dLUC and iLUC are being established using data from foreign farming systems, predominantly in the Northern Hemisphere, where farming systems are quite different from Australian conditions. This means that, in some cases, Australian feedstocks are inappropriately penalised. For example, research by CSIRO has revealed that the GHG emissions from canola cultivated across NSW, VIC, SA and WA are significantly lower than the global defaults recognised under LCA frameworks like CORSIA.[1]

It is noted that adverse trade-offs associated with land use changes have recently been subject to media scrutiny and social licence concerns. Some land users have suggested that valuable agricultural land has been subject to land use changes for carbon sequestration. There have been criticisms into the integrity of Australian carbon farming practices, including interactions with the ACCU framework.[2] In light of this, it will be essential that any Australian-specific carbon intensity and land use change frameworks are of high integrity and defensible.

Figure 30: Fuel carbon intensities based by feedstock and production pathway[3]



Source: 1. CSIRO, Opportunities and Priorities for a Low Carbon Liquid Fuel Industry in Australia (2025). 2. Carbon Market Institute, Response to carbon farming issues raised in nine newspapers (2025). 3. Carbon intensities based upon the CORSIA/GREET Model. Where a feedstock does not have a direct GREET value, it has been approximated using the closest comparator within the GREET dataset.

The HEFA pathway in Australia could be competitive on the global market, but would require access to currently exported feedstocks

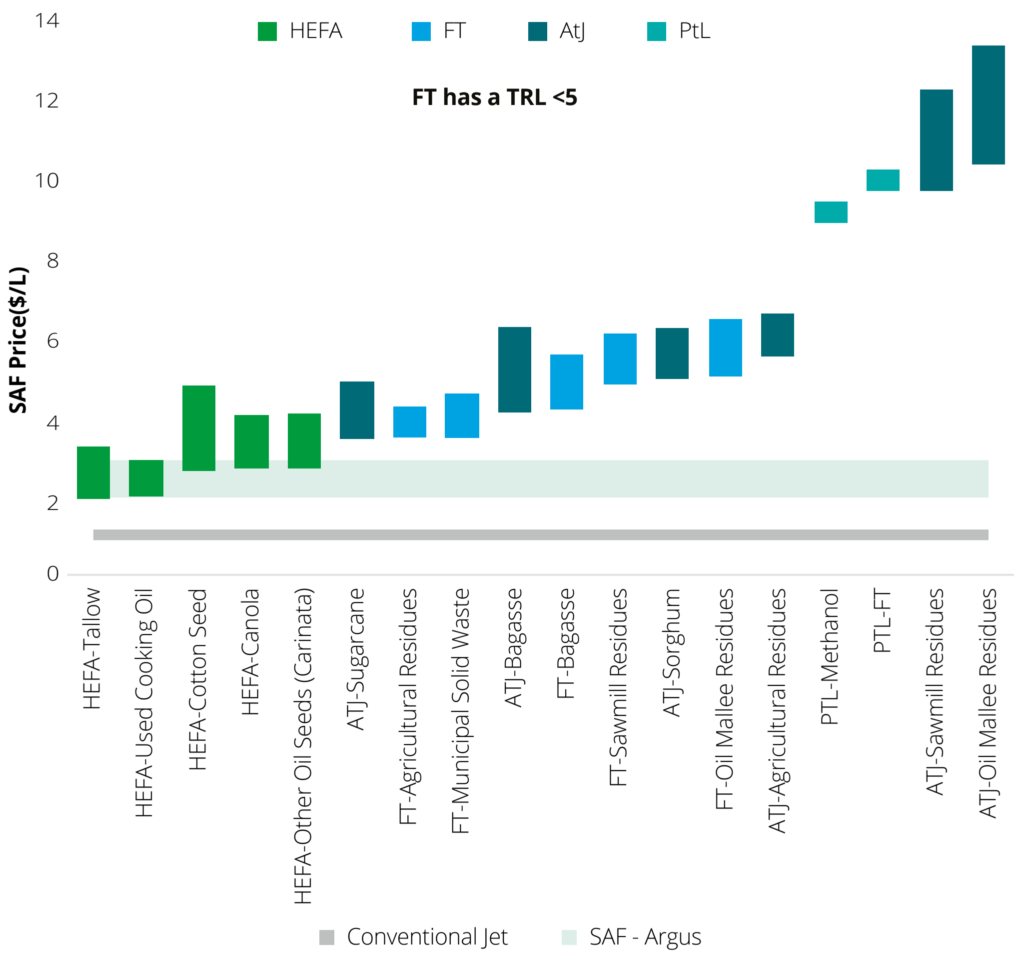
As part of this market study, a production cost analysis has been undertaken to build up supply costs for 20 technology–feedstock combinations across HEFA, AtJ, FT, and PtL processes. This assessment takes account of best available market information and has been validated with a range of current project developers. Further details of the modelling are included in Appendix B.

Figure 31 has ordered estimated production costs for SAF for each technology–feedstock combination. Overlaid on top of this curve is the 2024 Argus SAF price range (freight adjusted) and the 2024 conventional jet fuel price range.

All pathways remain at a significant premium to the conventional jet fuel price. If a production pathway is *within* the Argus price range, the pathway could be profitable. If it is *above* the Argus price range, the pathway is not currently commercial. Four insights emerge:

1. **Australia could be a globally competitive HEFA producer by 2030 with large-scale projects:** Specifically, tallow, UCO, canola and newer oilseeds could offer pathways for profitable SAF production in the medium term, falling within the Argus SAF range. However, investors would likely need confidence that a refinery would be in the lowest quartile of a global cost curve to ride out price cycles and ensure profitability. It is less clear that Australian projects can meet this benchmark.
2. **Cost blow-outs or feedstock price increases could easily make HEFA uneconomic:** However, as HEFA serves as the benchmark minimum price for SAF globally, this is only likely to become a factor with the emergence of other technology pathways into greater share of the supply curve globally.
3. **AtJ and FT based pathways will need significant support to compete :** These processes require technological innovation to improve process yields and capital cost declines to move into a competitive position with HEFA in the intermediate and long-term. Unlocking these pathways will be contingent upon policy dedicated demand to reduce preferencing of ACCU uptake.
4. **In 2030 hydrogen production costs remain too high for PtL:** It is clear for PtL to become a viable solution the hydrogen price needs to fall dramatically. This is unlikely to happen prior to 2040 and could be limited long-term regardless.

Figure 31: 2030 SAF production cost ranges on a $/L basis[1]



Source: 1. Modelling based on assumptions in Appendix B.

Australia's LCLF supply curve suggests cost reductions will be required to unlock scaled demand and create new value in feedstock markets

Fuel buyers have indicated they will purchase LCLFs on an abatement cost basis, rather than a flat $/L metric. Based on feedstock collection and production cost estimates it is possible to trace the shape of the emerging Australian LCLF supply curve in $/tCO_2$-e.

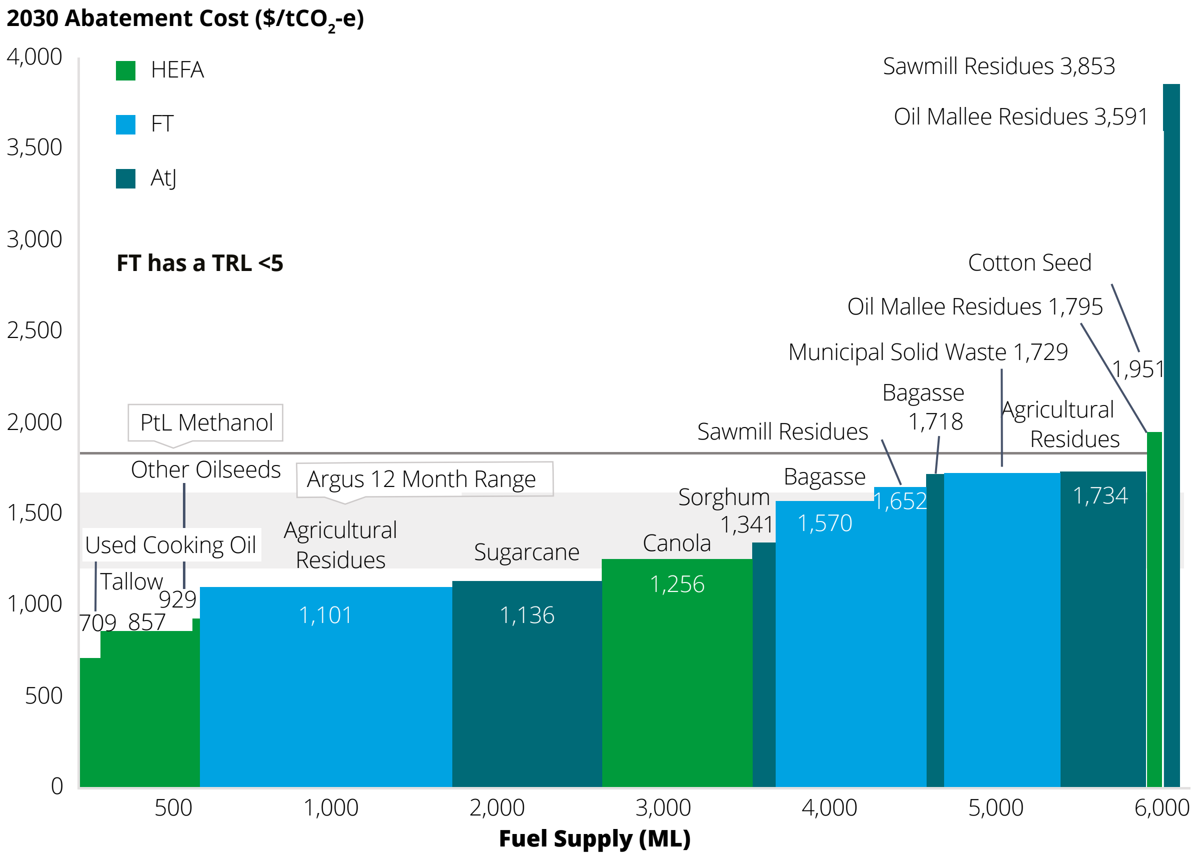
High abatement costs are a clear challenge – without overcoming this, demand is likely to remain muted and Australia will not value add to its significant feedstock potential.

Four trends stand out from the indicative supply curve:

1. Only three technology–feedstock combinations are available below a $1,000/t abatement cost*, collectively accounting for ~600 ML of fuel demand.
2. HEFA based production is limited to ~1,300 ML p.a. in 2030 (a meaningful share of this fuel potential is currently exported tallow and UCO) in the early market, although there is potential to expand the domestic supply of oilseeds.
3. The middle of the cost curve is quite flat – with small changes between HEFA–Canola, FT–Agricultural Residues, and AtJ–Sugarcane. Competition dynamics between these pathways will likely be fierce noting all three feedstocks offer x4.5 more production potential than the first three feedstocks entering the market.
4. Abatement costs rise steeply after producers' exhaust canola, with lignocellulosic, bagasse and MSW feedstocks offering over two times the abatement cost of more competitive pathways. These are likely subject to material competition from PtL in the long-run.

It should be noted that the equivalent supply curve for Renewable Diesel is structurally lower but remains at a significant premium to conventional diesel.

Figure 32: Supply curve 2030 assuming conservative cost reductions[1,2]



Notes: 1. A comparable supply curve for renewable diesel and the Argus price is included in Appendix B1. 2. Supply availability is based on Figure 28. It is to be noted that this supply curve considers a refinery configured for SAF production. Refinery decisions could shift the overall fuel supply achieved. *Abatement cost is in terms of SAF, but fuel supply captures all SAF and RD production, noting abatement costs of RD would be lower.

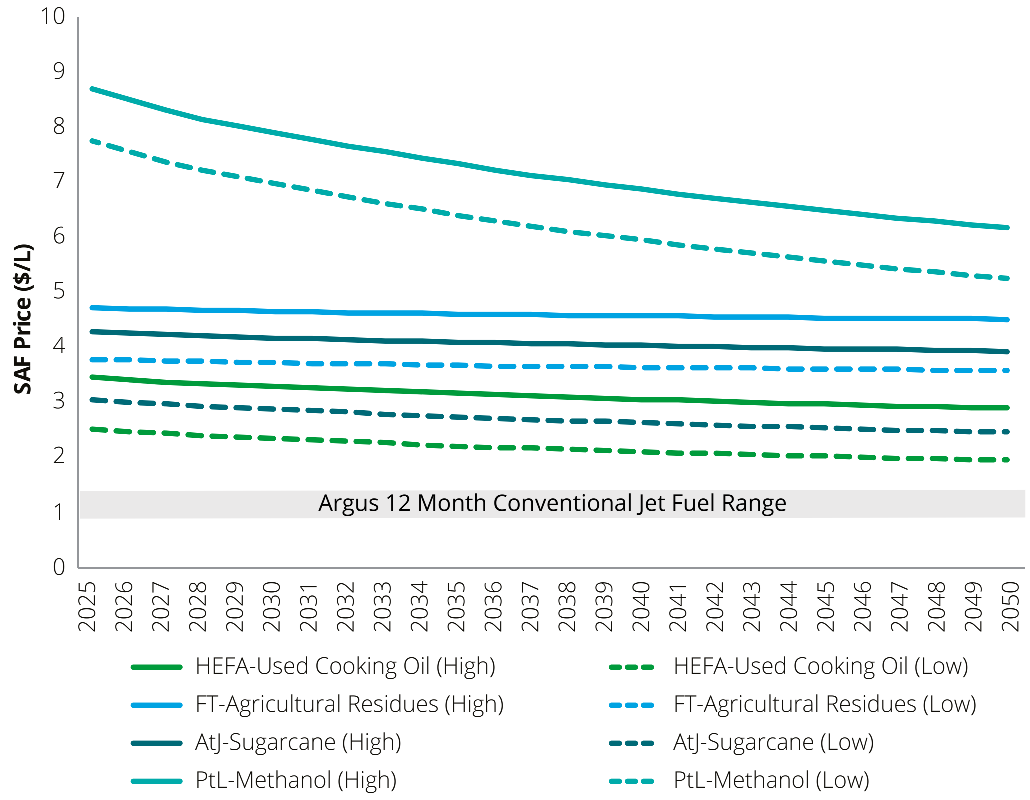
Newer pathways can become cheaper before 2050 if innovation continues and real feedstock costs decline

Indicative production cost ranges out to 2050 have been developed for each production pathway, largely based on historical trends in feedstock prices and technology learning rates. It is common to assume that low carbon technologies will reduce in price over time, as technology innovation and economies of scale take effect. These forces are present in LCLF production, but due to the influence of feedstocks on production costs, are significantly blunted. There is significant uncertainty with how feedstock markets will respond to market forces, with recent competition driving up prices[1] and real price increases observed over the past decade for most studied biogenic feedstocks.[2]

A market outlook is included at Figure 33:

1. HEFA remains on the price floor of the market but is unlikely to experience material price declines to 2050. HEFA is less capex intensive than other pathways, and limited learning rates are expected. Moreover, rising LCLF demand could create more feedstock competition with upward pressure on prices.
2. FT is more capital intensive and has the potential for cost reductions via this channel. At present most FT feedstocks have yet to be collected and valued, potentially presenting an attractive prospective – although a clear preference will be needed for homogenous feedstocks to contain pre-treatment costs and maintain equipment performance. However, the potential for feedstock price drops over time is likely limited by competing feedstock demand from alternative end users (e.g. waste-to-energy and biomethane). It is to be noted FT has yet to reach commercial operation, with zero facilities operating globally.
3. The outlook for AtJ hinges on future sugarcane and other ethanol feedstock prices. Potential declining global ethanol demand as road vehicles electrify could see lower feedstock costs and therefore advantage AtJ. But operating parameters for AtJ facilities are still emerging, with only one facility operational globally.
4. PtL is the only pathway with structural cost decline expected. This is predominately driven by falling hydrogen costs as renewables become cheaper. But as we have seen in the hydrogen market over the past 18 months, the timing of cost reductions remains uncertain.

Figure 33: Real production cost ranges to 2050[3]



Sources: 1. Neste Investor Report Q3 2024, NREL SAF State of Industry Report: HEFA, 2024. 2. See Appendix C for feedstock assumptions. 3. Note that the range for each pathway represents the modelled current trajectory and accelerated trajectory for each pathway. This makes the lower bound of each estimate reliant on significant technology breakthroughs.

On an abatement cost basis, only a handful of technology–feedstock combinations may become more attractive over time without a cost step change from innovation

Should global demand for LCLF continue to grow enough to incentivise significant supply-side competition, the way the relative costs of technology–feedstock combinations change over time will emerge as a key determinant of price and profits.

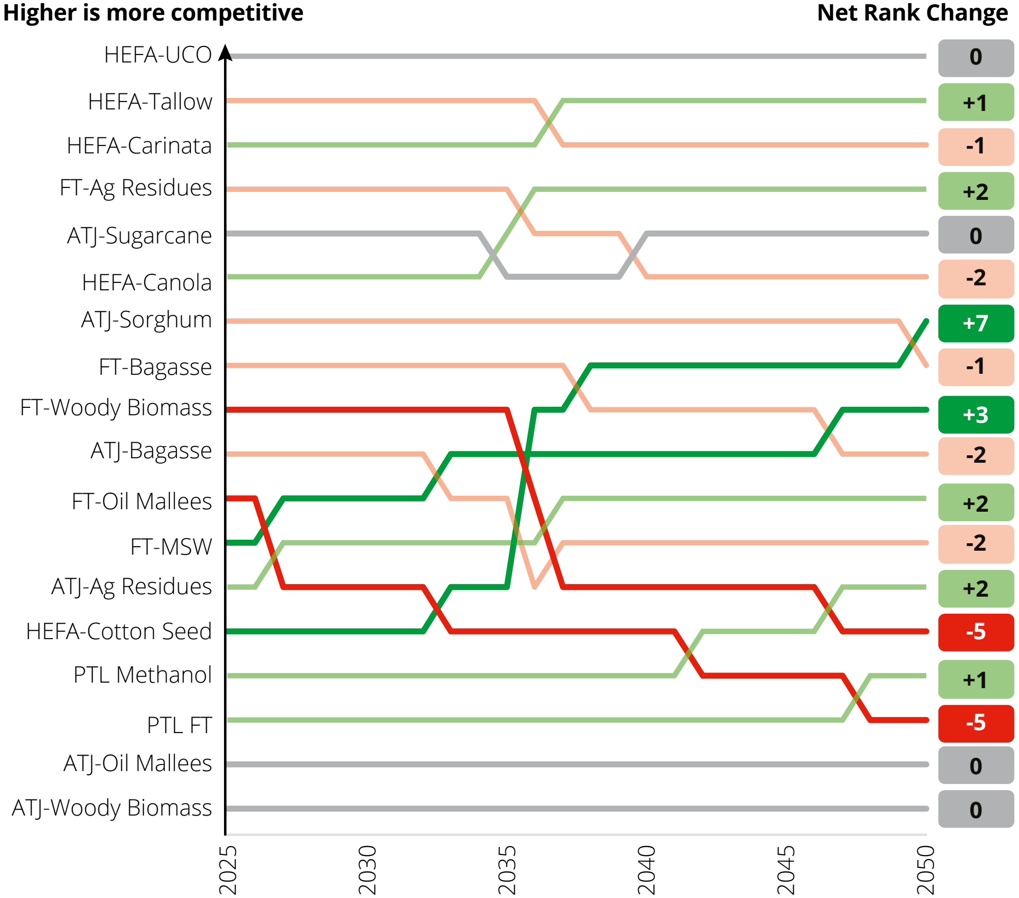
Figure 34 shows an example of how the merit order of SAF production technology combinations in Australia may evolve to 2050. Ranks are assigned based on the lowest possible abatement costs in each given year for a facility that commences operation in that year. What emerges is a clear picture of:

1. **Wide Moats:** UCO and Tallow can be expected to deliver lowest cost abatement relatively unchallenged by alternative technologies or feedstocks.
2. **Steady Improvers:** Oilseeds like Canola and Cotton Seed, as well as PtL and FT-MSW appear to gain in competitiveness over time largely because future feedstock prices are expected to change slower than others – this is subject to significant uncertainty (e.g. MSW pretreatment costs).
3. **Potential Pitfalls:** Some waste-based processes such as woody biomass, agricultural residues, and bagasse lose competitiveness over time.

Any analysis of how costs will evolve over 25 years is necessarily constrained, however, it can indicate dynamics for feedstock providers, fuel refiners, fuel users and investors to observe closely. For example:

- Excessive feedstock competition that structurally raises tallow or UCO prices could overcome the wide moats of these processes. Similarly, regulatory restrictions or market integrity scandals could limit demand and crash feedstock prices.
- Material improvements in feedstock yields, process yields for AtJ or FT, reductions in feedstock collection costs, or feedstock carbon intensities could see higher ordered ranks leapfrog towards the front of the cost curve.

Figure 34: Mind the gap – SAF production merit order ranks over time based on abatement cost, by technology–feedstock combination to 2050



A relative hierarchy of feedstock suitability for fuel production is emerging which could inform market participants

The emerging LCLF market requires a framework to strategically assess feedstock/process combinations. This should align with the optimisation objective of maximising abatement at least cost. Key considerations include:

- **Cost:** Today's competitiveness on both a production cost and abatement cost basis.
- **Pathways for cost reduction:** The viability of options for reducing capex, feedstock costs and improving yields.
- **Supply potential:** The existing supply and pathways for feasibly boosting supply whilst supporting ease of aggregation.

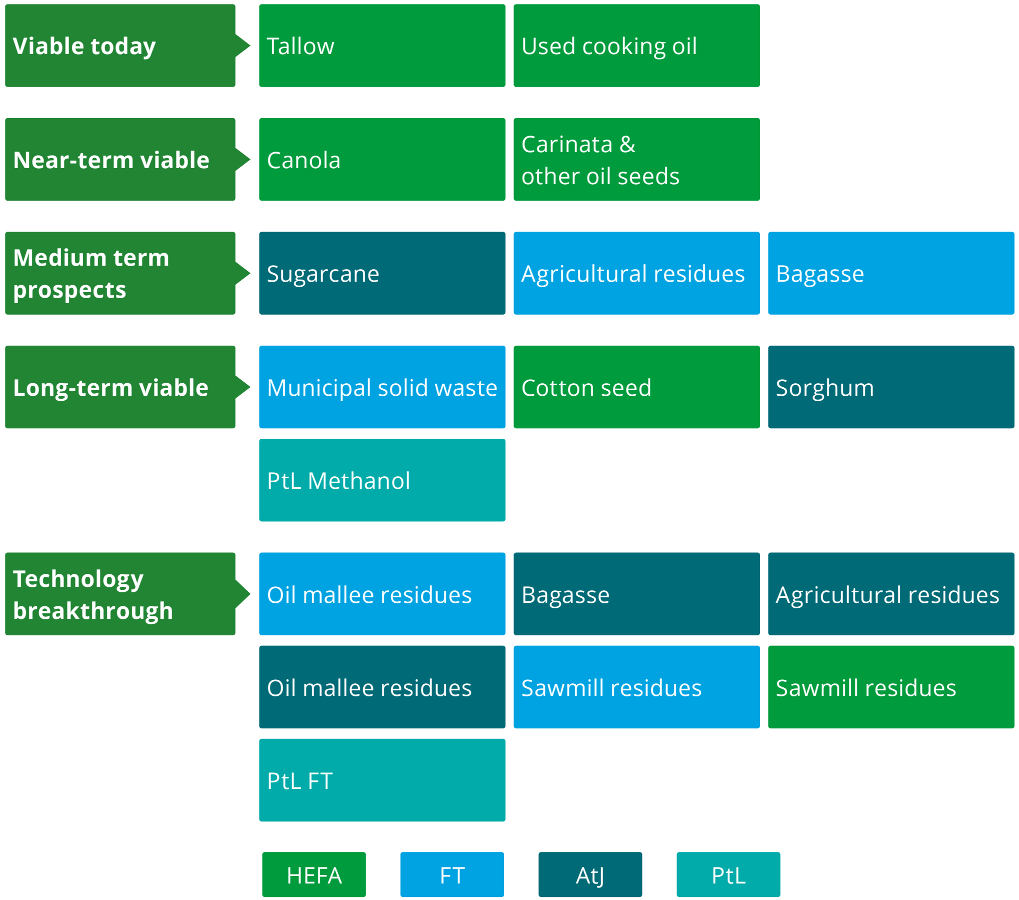
HEFA-based feedstocks offer the most compelling abatement pathway for immediate support. There is an opportunity for Australian policy makers to unlock the feedstocks which are closest to commercial viability today to incubate industry development. HEFA feedstocks offer an immediate pathway to decarbonisation at low cost, catalysing this development.

Waste-derived FT pathways offer a long-term commercial opportunity. The combination of low-cost feedstocks with limited high-value competing use cases and a pathway for yield improvement aligned with cost-reductions in low-carbon hydrogen production offer a compelling pathway for long-term viability of FT. Additionally first generation AtJ and the methanol pathway for PtL offer a long-term competitive option.

Lignocellulosic feedstocks require a step change in yield and feedstock cost reductions to become competitive. Without a step change in yield or substantial feedstock cost reductions, these feedstocks are unlikely to serve as an economically viable decarbonisation option for FT or AtJ production.

Market participants need to be able to identify step change improvements in feedstock price, yield and supply potential which would shift a feedstock up the ladder. This ladder is designed to help the market understand what a competitive feedstock/process combination looks like. It should be noted that not all potential feedstock/fuel combinations are considered and that feedstocks can improve their relative position through technological innovations or favourable market dynamics. Market participants will need to continue to review relative competitiveness as technologies and costs evolve.

Figure 35: Australia's feedstock ladder, reflecting the competitiveness of different feedstock–fuel combinations.



Continued innovation is needed to structurally lower LCLF production and abatement costs

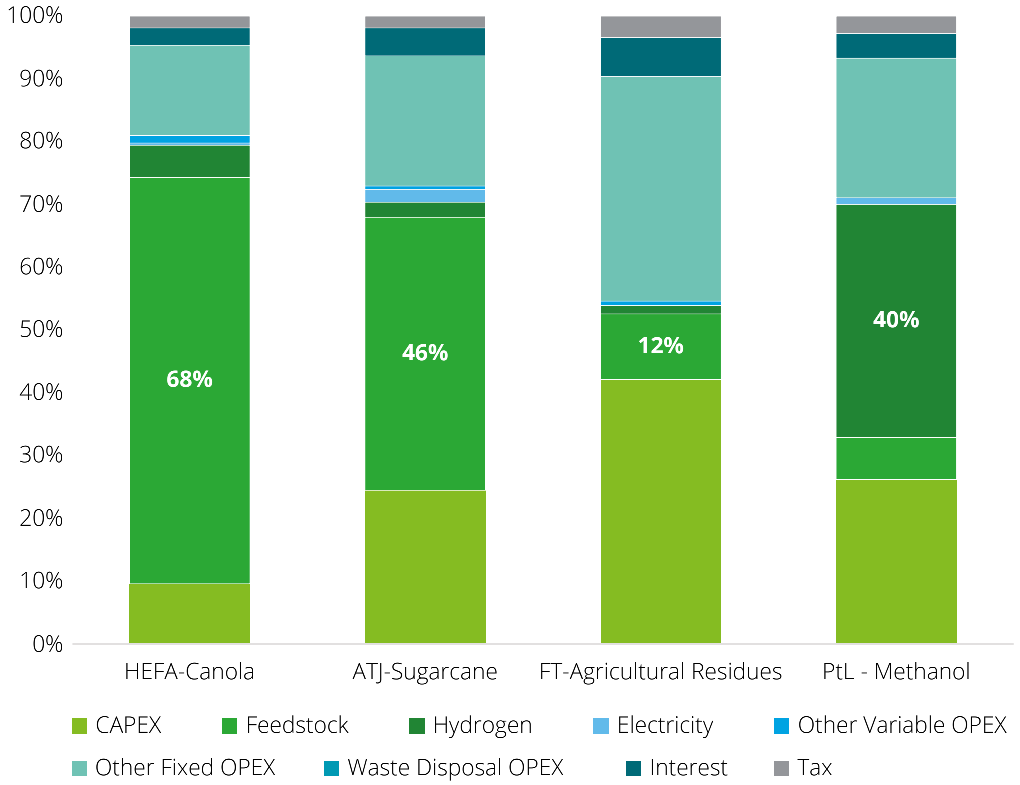
LCLFs are yet to experience the cost reductions seen in electricity generation and storage technologies. Wind, solar, and batteries are capex intensive and have exhibited significant learning rates.[1] In contrast, feedstock prices are the fundamental cost driver of LCLF abatement costs – as Figure 36 shows, feedstock costs can represent up to 68 per cent of end fuel costs. However, many feedstocks have existing markets, and rising competition could put a floor under LCLF costs if feedstock demand rises.

Without lower future LCLF production costs, fuel users face structurally higher abatement and operating costs. Demand for LCLF is closely linked to the cost gap – if this does not close due to flat feedstock prices, demand may remain subdued, and the abatement promise of LCLF may not be realised.

Innovation to reduce LCLF production costs is ongoing, however, there is a clear need to further boost efforts – broadly there are three possible pathways to achieve this:

1. **Reduce feedstock costs:** the simplest way to reduce LCLF production costs would be to reduce feedstock costs. This may be more possible for some feedstocks than others – if economies of scale can be gained in feedstock collection, aggregation and pretreatment.
2. **Improve production efficiency:** cost reductions can also come from economies of scale in fuel production, reducing financing costs, and innovation in fuel production pathways to increase fuel yields from the same feedstock inputs.
3. **Increase fuel emissions reductions:** because LCLFs will be purchased on an abatement cost basis, reducing the carbon intensity of the fuel can also offer a pathway to reduced costs. The primary levers to achieve this are through on farm decarbonisation to reduce cultivation emissions, or through carbon capture during intermediate processing.

Figure 36: Feedstock as a share of 2030 fuel costs by pathway



Feedstock cost reductions can meaningfully reduce LCLF costs, but there are limits in improving the competitiveness of non-HEFA pathways

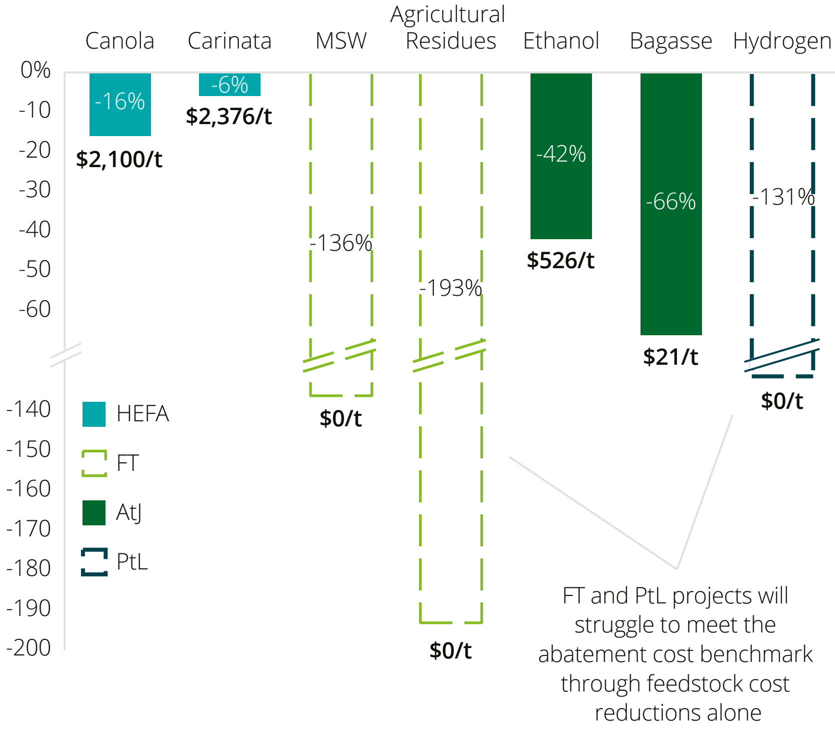
Feedstocks have historically exhibited significant price volatility, implying volatility in LCLF cost structures. Feedstock price changes arise because of global agricultural markets (e.g. Canola) or more local dynamics for waste-based feedstocks. Moreover, given structural changes in demand as a result of decarbonisation, long-term trends are difficult to extrapolate from. For example, significant price volatility is observed in Canola over a 30 year period (1992 to 2022), with a 38 per cent price increase observed in 2021–22 and 32 per cent price decrease in 1994–95.

While HEFA feedstocks are unlikely to see material reductions, production with grey hydrogen could reduce abatement costs in the near-term. Although grey hydrogen is materially more emissions intensive than green, availability at a reference price of \$2/kg offsets this disadvantage and could lower HEFA abatement costs by ~7 per cent for tallow or UCO-based fuel.[1] This effect is lessened for oilseeds given the higher carbon intensity of the feedstock.

Prospective producers evaluating technology and feedstock options can be expected to consider their costs against a HEFA-informed cost benchmark. An example of this style of analysis is included at Figure 37, which shows feedstock prices needed to achieve an abatement cost consistent with a benchmark aligned to the historic minimum market price of \$1,000/tCO_2-e.[2] Three trends emerge:

- **Feedstock cost reductions within historical price ranges are needed for HEFA to meet the benchmark.** These reductions are readily achievable through market dynamics, negotiation and policy change.
- **Ethanol price reductions of 42 per cent are needed to make AtJ competitive, with lignocellulosic ethanol improbable without yield improvements.** Rapid electrification of passenger transport may lead to oversupply in the ethanol market which could cause a price contraction up to 20 per cent by 2030.[3] Figure 37 suggests that for AtJ to compete with the benchmark, a substantial price contraction would be needed relative to the January 2025 spot price of \$871/t.[4] Further, AtJ facilities based on second generation ethanol near feedstocks at near zero pricing – similar to FT this suggests a focus on yield improvements over absolute feedstock costs.
- **Feedstock cost reduction alone cannot get FT or PtL pathways to the price benchmark.** For FT, this is because feedstock costs are a relatively small share of the cost stack. It is also worth noting that low waste feedstock costs may be implausible given pretreatment and opportunity costs, and competing demand from alternative end users in Waste to Energy and Biomethane. Yield improvements are likely to be the pathway to cost competitiveness. For PtL, very high initial abatement costs, and high capex limit the impacts of potential hydrogen cost reductions.

Figure 37: Feedstock cost reduction required to reach a benchmark \$1,000/tCO_2-e abatement cost[5]



Sources: 1. Based upon an emissions intensity difference from NREL. 2. This is 20 per cent below the Q1 Argus SAF price, but consistent with the historic minimum market price. 3. Kaiser and Parga (2024). 4. Argus Americas Biofuels 8 January 2025 Chicago Argo Ethanol Price. 5. Bold feedstock prices on each bar represent the required feedstock price to achieve the cost benchmark ceteris paribus (oil feedstock considered rather than bulk crop). The per cent figure represents the cost reduction relative to the modelled feedstock cost.

Economies of scale and yield improvements offer significant potential to reduce LCLF costs

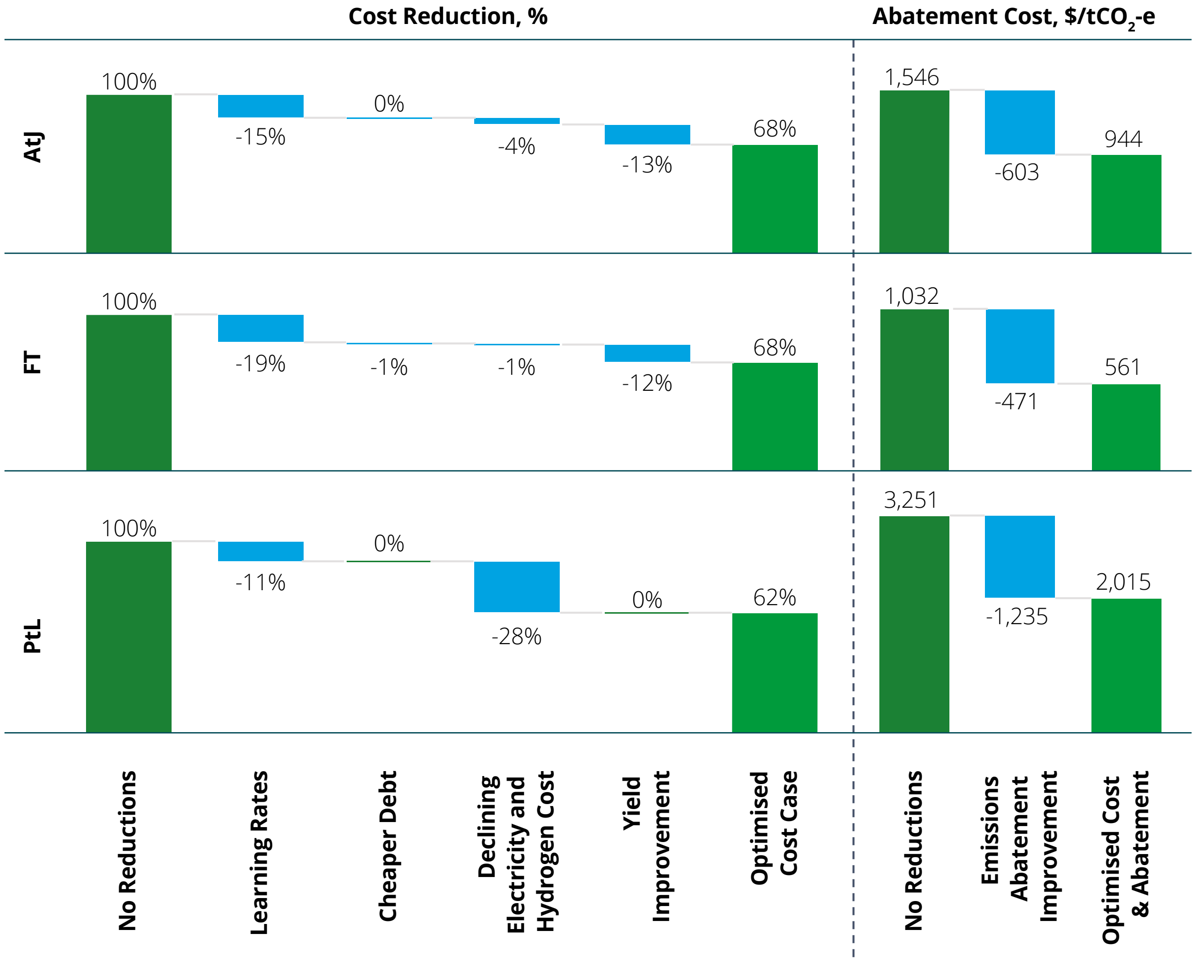
There are clear and emerging limits to servicing LCLF demand from HEFA-based production alone. The UK for example has implemented a HEFA cap to ensure alternative production pathways can get a foothold in the market and begin to compete to supply fuel users, to increase competition and reduce long run abatement costs. In the Australian context, HEFA feedstock supplies could be exceeded if LCLF demand exceeds ~2,000 ML depending on the year (assuming no new oilseed rotations or crop innovation).

AtJ, FT and PtL production processes are likely to operate at a cost premium to HEFA in 2030. However, unlike HEFA each of these newer technologies has further cost reduction potential.

There are three non-feedstock cost reduction levers available to non-HEFA production processes, with relative dependence varying by process:

1. **Capital cost and learning rate reductions:** Increasing scale and learning from first-of-a-kind project implementation could reduce the end price of AtJ by 15 per cent, FT by 19 per cent and PtL by 11 per cent. PtL experiences a second benefit from falling renewable capex structurally reducing the hydrogen price by almost 30 per cent by 2050.
2. **Production yield improvements:** A 10 per cent increase in energy yield of each feedstock could reduce the optimised end price of AtJ & FT by 13 per cent and 12 per cent respectively. Yield improvements are likely less viable for PtL.
3. **Reduced financing costs:** As the technology is implemented at scale, the cost of finance is likely to reduce to reflect the decreasing deployment risk, with less then a one per cent impact on all pathway end fuel costs.

Figure 38: Relative impact of cost reduction levers across non-HEFA pathways, and impact on abatement cost



Australian growing conditions could offer competitive advantages for some production pathways, depending on feedstock policy choices

Typical global default carbon values for LCLF may not reflect Australian farming practices. Default carbon values are typically calculated using models such as US DOE's GREET. However, these tend to incorporate cultivation emissions from Northern Hemisphere sources.[1]

Shifting towards Australian-specific emissions factors would have a material impact on some feedstocks. As the first panel of Figure 39 shows, Canola emissions would be reduced by 23 per cent relative to the CORSIA Default value.[2] This would then reduce the abatement cost of HEFA–Canola by 20 per cent as per Figure 40.

Further on farm decarbonisation is achievable for Australian feedstocks. For example, CSIRO's lifecycle carbon assessment for Canola shows that fertiliser use on farm is responsible for up to half of emissions in a single purpose cropping system.[3] This could be reduced through use of green ammonia-based fertilisers. Similarly, shifting to a crop rotation for Canola could reduce carbon intensity by half relative to single purpose cropping systems. The CEFC's Agricultural Pathfinder can support farmers to identify on-farm decarbonisation opportunities.[4]

Recognition of Australian-specific factors could arbitrage the feedstock market and open a pathway to expand Australia's feedstock opportunity. Assuming half the 20 per cent abatement cost differential created by Australian-specific factors was shared with the feedstock provider, a domestic fuel refiner could pay an additional ~$140/t for Australian Canola oil, above the global market price.[5] Note this is only valid if there is sufficient demand to bring Canola-based HEFA into the market.

Some Australian feedstocks may have higher emissions, which could reduce the competitiveness of LCLFs.

Figure 39: HEFA-Canola carbon intensities under different assumptions[6]

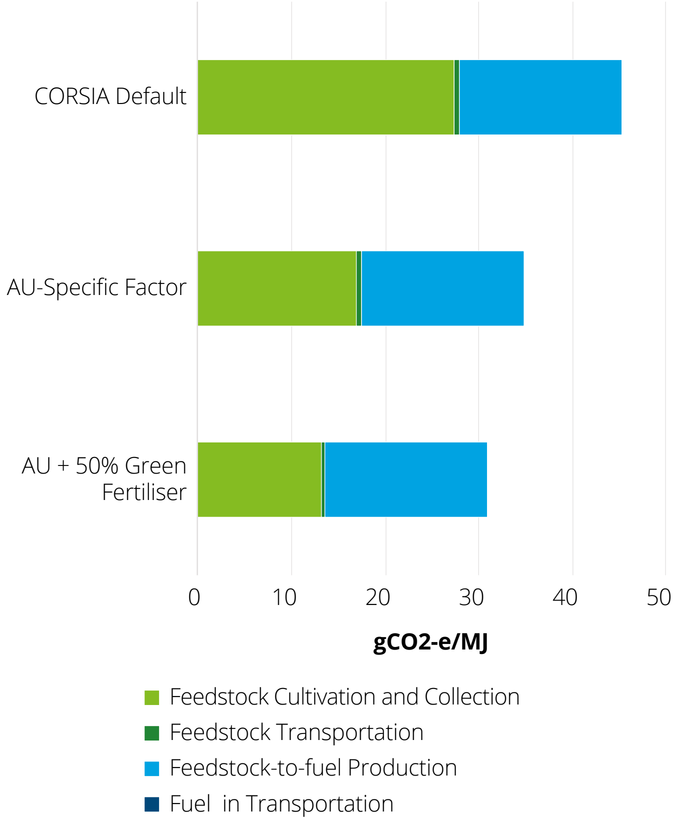
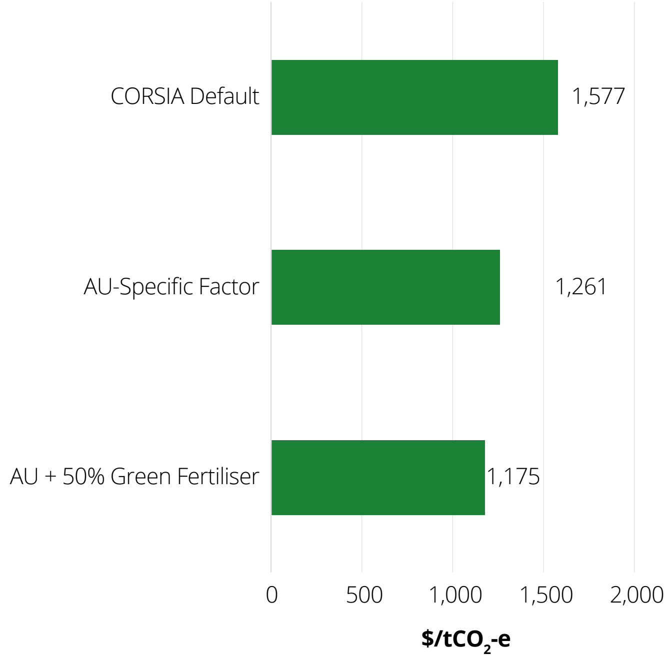


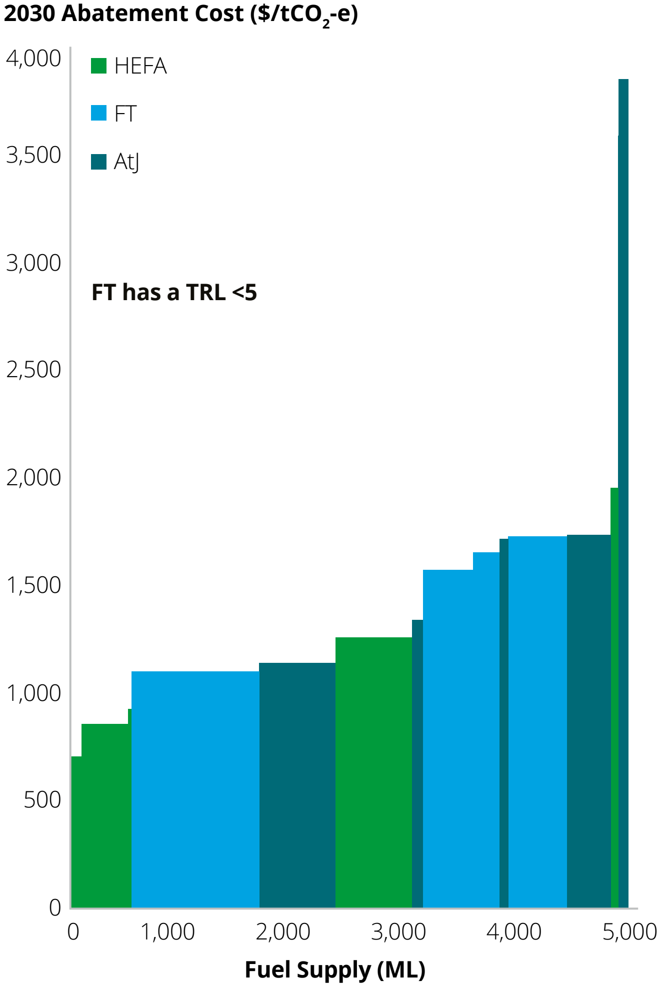
Figure 40: HEFA-Canola fuel abatement cost[6]



Sources: 1. ICAO, CORSIA Methodology, 2022. 2. CSIRO, Australian Canola LCA, 2023. 3. Ibid. 4. CEFC, Toward Net Zero Agriculture Pathfinder, 2025. 5. This calculation assumes that 50 per cent of the reduction in fuel abatement cost is shared with the feedstock provider as a premium for lower carbon feedstock. The resulting fuel could still be sold at a lower abatement cost than typical HEFA-Canola, but only 50 per cent of the abatement cost saving would be passed onto consumers. 6. Figures 39 and 40 do not include the induced land use change component under the Carbon Offsetting and Reduction Scheme for International Aviation.

Shifting from our current LCLF cost trajectory to a structurally lower accelerated trajectory will require a focus on 11 innovation priorities

Figure 41: Cost curve on current trajectory



Possible innovations to reach the accelerated trajectory include:

Feedstock cost reductions

1. Lift feedstock production yields
2. Raise feedstock supply through new crop rotations
3. Improve the cost efficiency of collection
4. Improve feedstock logistics and sourcing networks
5. Reduce costs through economies of scale for collection and pre-treatment

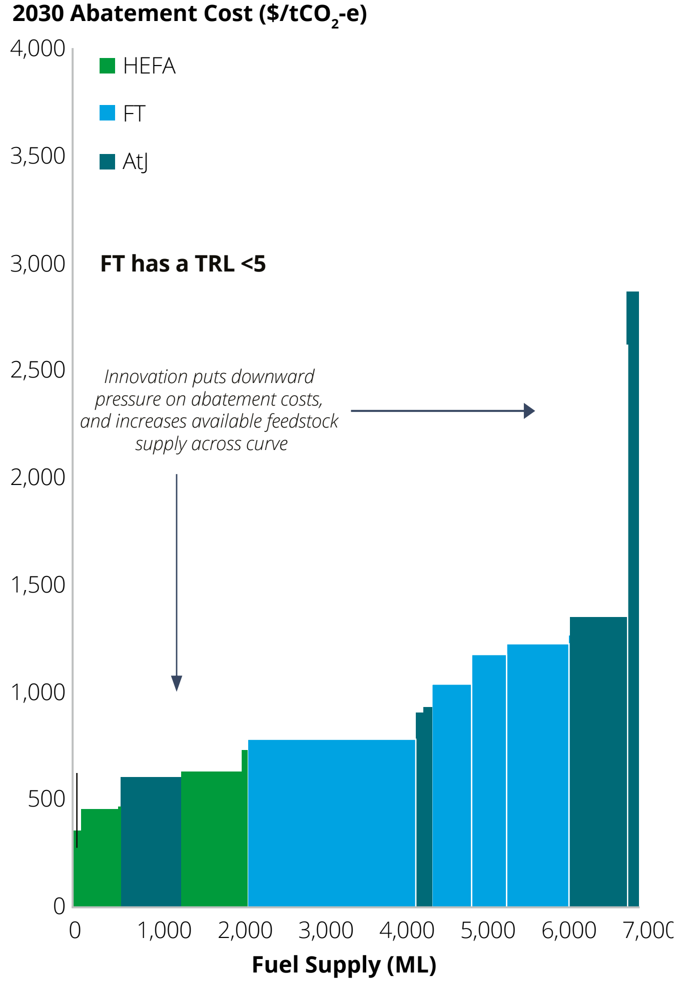
Yield improvements

6. Develop and refine dedicated energy crops (e.g. increasing oilseed yields)
7. Advanced process control to optimise the syngas ratio using hydrogen injection in FT
8. Improve sugar extraction in AtJ via new enzymes or catalysts

Carbon intensity improvements

9. On farm decarbonisation (e.g. low carbon fertilisers)
10. Inclusion of CCS for intermediate processing
11. More efficient boilers for intermediate processing

Figure 42: Cost curve on accelerated trajectory



5: How might the LCLF Market develop in Australia?

A series of scenarios have been analysed to understand how supply and demand dynamics may evolve in the Australian context and to understand changes in key outcomes such as abatement costs, technology shares, feedstock market shares, and end user reliance on LCLFs. Four consistent trends emerge:

1. Competition between production pathways is a prerequisite to lower abatement costs. A large demand signal that drives innovation in the market can deliver much lower costs for fuel uses. However, there could be a step change in costs if biogenic feedstocks are exhausted and e-fuels are required.
2. The speed of cost reductions will determine the timing of biogenic and synthetic fuel competition in the market. If AtJ and FT can scale and price signals drive investment in feedstock infrastructure, biogenic feedstocks can supply the market for a long time. However, as the market matures, stranded asset risk for feedstock infrastructure will emerge.
3. Efficient market pricing will be key to manage the co-evolution of SAF and RD demand. Policy settings that distort price signals could have unintended consequences and increase costs for all.
4. Policy will ultimately determine how quickly LCLF demand emerges, the complexity of domestic value chains, and market competition dynamics. But the first projects will likely have an export focus.

Three scenarios have been analysed to understand how supply and demand dynamics may evolve in the Australian context

While the development of Australia's LCLF market is subject to significant uncertainty, key dynamics including fuel user willingness to pay, decarbonisation targets, and the shape of the supply curve will determine commercial outcomes. Scenario analysis has been undertaken to interrogate how market outcomes may change based on different assumptions about supply and demand. Figure 43 outlines the three assessed scenarios. Further details about the scenario analysis can be found at Appendix C. This is intended as an illustrative and stylised analysis of market dynamics, rather than a definitive forecast of expected outcomes.

The policy assumptions driving demand in scenarios 2 and 3 are not announced government policy or included as optimal policy interventions. They have been included to illustrate how market dynamics could react to different types of policy intervention and should not be relied upon for decision making.

Notably, the Australian Government, through the LCLF Consultation Paper, has made clear a preference for on-site abatement through LCLFs, saying:[1]

"Greater use of LCLF's would support the legislated safeguard outcome to provide a material incentive to invest in facility level abatement rather than offsets, in a way that is consistent with an efficient pathway to achieve Australia's overall objective of net zero by 2050."

This is further supported by the development of Safeguard Mechanism Credits as a part of the Safeguard Mechanism which reward on-site abatement efforts.

The scenario analysis sheds light on five interrelated outcomes for an Australian LCLF market:

1. The abatement contribution of LCLF and how marginal abatement costs evolve
2. How sectoral demand evolves, and relative reliance on LCLF and ACCUs by sector
3. Which production technologies and feedstocks are needed to service demand, and when
4. The scale of feedstock demand (crops, wastes, hydrogen) and the evolution of market share
5. Whether there are common sequencing dynamics across the scenarios which could guide or gatekeep investments in feedstock or production infrastructure

Figure 43: Outline of assessed scenarios

Scenario	LCLF Demand Dynamics	LCLF Supply Dynamics
Base Scenario: Market-Led Transition	Carbon prices remain too low to drive significant LCLF uptake across most sectors. Demand for LCLF is driven by a small subset of end customers willing to pay significant premiums to reduce their scope 3 emissions.	Production costs remain largely flat, as technology innovations are countered by price competition to secure feedstock supplies. Synthetic fuels become more competitive as ongoing renewable deployments reduce electricity and therefore hydrogen costs.
Central Scenario: Offset Constrained Transition	Firms are more focused on direct on-site decarbonisation initiatives to meet their transition to a lower carbon economy. This outcome is achieved through adapting the Safeguard Mechanism and/or voluntarily by participants by adopting a minimum 70 per cent direct on-site decarbonisation as opposed to utilising the majority of offsets in the Base Scenario. They achieve this direct on-site decarbonisation in a rational manner – prioritising lower abatement cost initiatives over higher ones. For the purposes of this work, this has been modelled through a hypothetical government intervention to cap the use of ACCUs to meet decarbonisation obligations at 30 per cent of the baseline and removes baseline adjustments for trade-exposed baseline-adjusted facilities.	The emergence of material demand triggers a positive supply-side response, driving significant technology deployment and competition between pathways and feedstocks. Relative to a market-led transition, production costs fall faster driven by economies of scale and process innovation and other factors outlined on page 52. Cost improvements are gradually realised in the market. Feedstock collection rates rise in response to proven fuel demand, increasing availability of biogenic feedstocks.
Accelerated Scenario: Highly Regulated Demand	Policy intervention mandates LCLF uptake in a manner identical to the ReFuelEU policy on the aviation and maritime sectors. Demand for other sectors is consistent with the Offset Constrained Transition Scenario.	

Sources: 1. Australian Government, 2024

A market-led transition would see: (i) a feedstock export focus, (ii) limited domestic uptake of LCLF due to costs and, (iii) rising demand for offsets

Left to the market, uptake of LCLF is muted, at most supporting a single 200ML production facility in the 2040s. If projects are able to be developed, HEFA-based production would be the most likely to eventuate, owing to the lowest production and marginal abatement costs. Early in the market demand is too low to underwrite a facility, leading project developers to prioritise export opportunities.

More likely, demand will be too low to sustain domestic production at all. It is possible in this scenario that Australia could become reliant upon the import of LCLF to service the pockets of demand willing to pay a higher price. In this scenario, Australian fuel users could remain price takers needing to outbid other sources of demand on a global market.

Australian feedstocks are likely to continue to be exported to existing markets, including for LCLF production internationally. This reflects the relative competitiveness of these feedstocks within international markets.

If domestic HEFA facilities are able to become established, Tallow and UCO based production would be prioritised, assuming these feedstocks can be liberated from their existing applications (including export for LCLF production in Singapore and the US). A small amount of Carinata enters the market, but available supply is very limited. Even in 2050 the feedstock market remains below $1 billion, compared to $3 billion for current canola exports.

The abatement of liquid fuel use within Australia would be heavily reliant upon ACCUs where electrification is unviable. On-site decarbonisation in 2050 would be limited, with LCLF use accounting for less than one per cent of 2022–23 emissions from the six focus sectors.

While this may serve as the least cost pathway for overall abatement, greater pressure will be placed upon the ACCU market – up to 7.35 Mt of ACCUs would be needed to meet demand in 2035 and 15.5 Mt by 2050. As a point of comparison, 19 Mt of ACCUs were created in 2024.

Figure 44: LCLF Supply (ML) (Base Scenario)

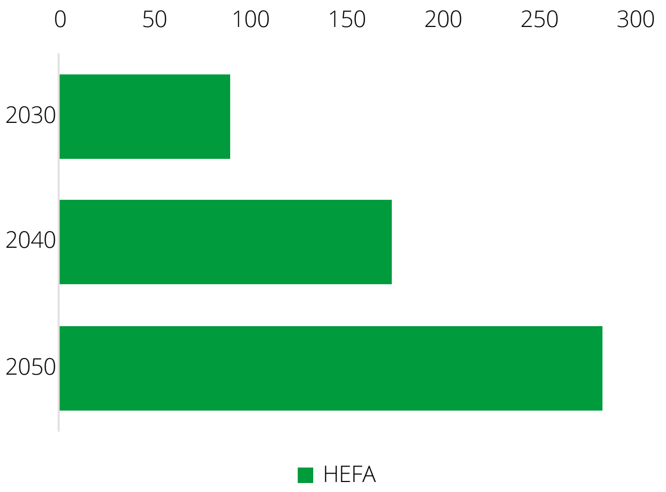


Figure 45: Feedstock Supply Mix (Base Scenario)

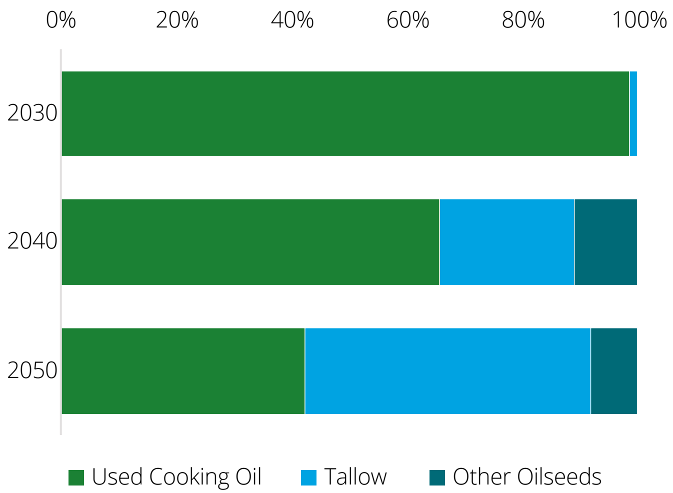
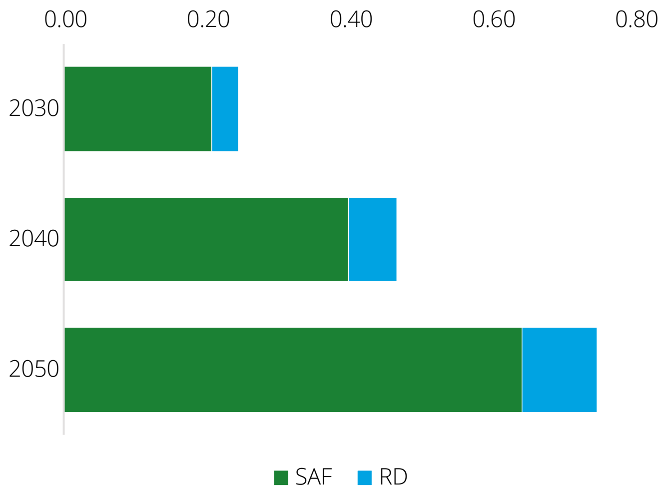


Figure 46: Abatement ($MtCO_2$-e) (Base Scenario)



An offset constrained transition could lead to a sizable seven billion litre LCLF market by 2050, abating up to 20 Mt of carbon each year

Preferencing on-site emissions reduction over ACCU abatement through the Safeguard Mechanism would drive the development of an LCLF market. By 2050, 36 facilities at a scale of 200ML would be required, representing a significant advancement relative to an unguided transition. Approximately 1,000 ML of capacity is expected to be required by 2030, further supporting this.

The size of the market would entice project development on Australian shores, driving greater competition with imported LCLFs. However, the immediate market could still require imports until demand reaches sufficient scale. HEFA would initially dominate, but as these feedstock supplies meet their limits, FT, AtJ and PtL production would enter the system.

Greater volumes of domestic biogenic feedstock are unlocked through demand-side incentivisation. Cellulosic feedstocks through the FT pathway, sugarcane through the AtJ pathway and methanol-based PtL production enter the feedstock supply market by 2050.

The penetration of PtL methanol serves as the marginal producer, with collection rates and cultivation of dedicated energy crops likely to be incentivised in this scenario. This would mean the value of the PtL methanol feedstock pathway likely serves as an upper bound. Furthermore, the competitiveness of PtL methanol is highly dependent upon declining green hydrogen prices by 2040.

Constraints on abatement type would lead to greater on-site abatement but would increase marginal abatement costs. The requirement for on-site abatement using LCLFs would reduce pressure on the ACCU market.

LCLF adoption in this scenario reduces emissions by 12 Mt in 2040 and 20 Mt in 2050. In 2050, 57 per cent of emissions reduction from LCLF use are realised in the aviation sector, the remaining 43 per cent are realised through diesel displacement.

Figure 47: LCLF Supply (ML) (Central Scenario)

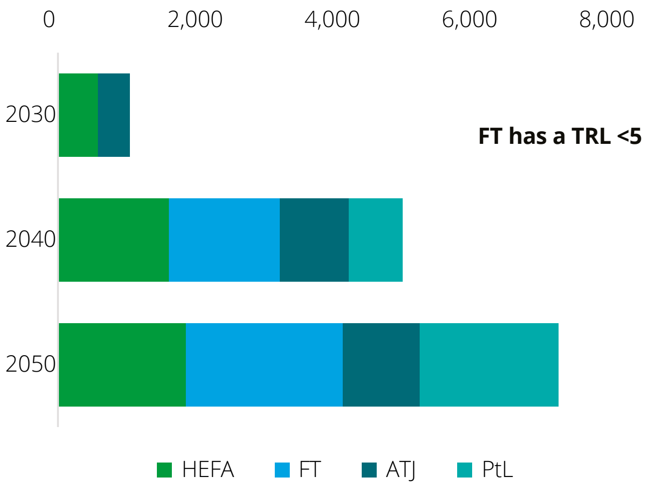


Figure 48: Feedstock Supply Mix (Central Scenario)

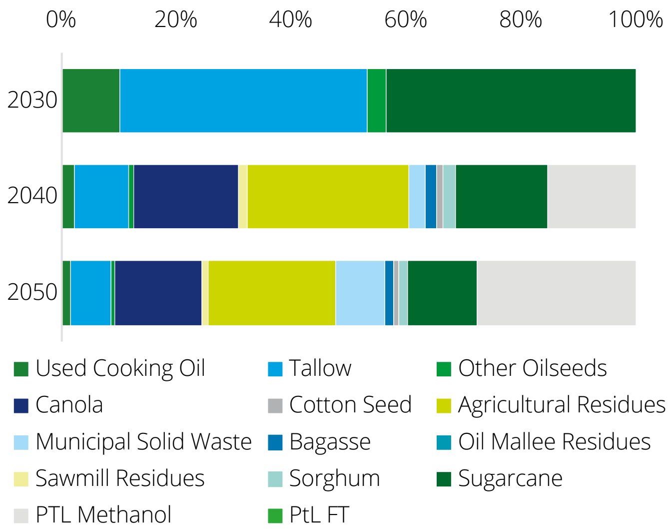
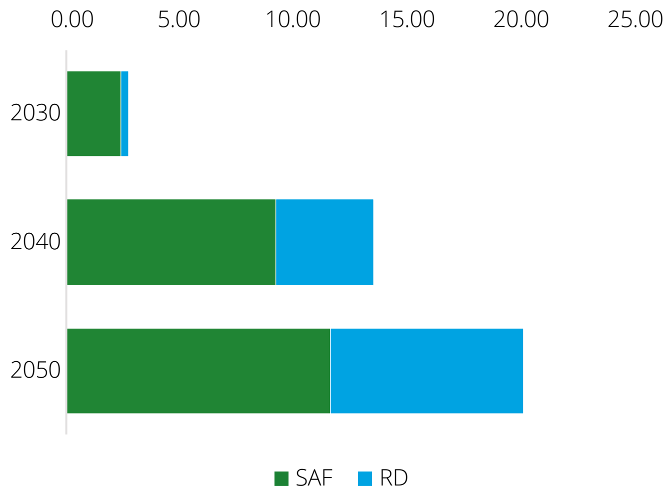


Figure 49: Abatement ($MtCO_2$-e) (Central Scenario)



Highly regulated demand could result in an almost 12 billion litre LCLF market by 2050, reducing liquid fuel emissions by 35 Mt CO_2-e p.a.

Introduction of a comparable mandate to ReFuelEU would drive significant LCLF activity in the 2030s. Supply would need to grow significantly to exceed 5,500 ML by 2040, with HEFA and FT-based processes dominant. AtJ also enters the market, but only via first generation ethanol. Multiple facilities would be needed each year to deliver required volumes.

The dynamic then changes materially in the 2040s as biogenic feedstocks are outcompeted. The resultant activity switches to PtL which is needed in significant volumes and is cost advantaged relative to prospective supply from a range of lignocellulosic sources.

Consistent with the offset constrained transition scenario, wastes and oilseeds dominate the early market. In the event that Australia is unable to divert tallow and UCO from current export pathways, oilseeds and agricultural residues would be needed to meet early market demand. By 2040, agricultural residues could meet up to 26 per cent of demand.

The doubling of demand between 2040 to 2050 driven by the mandate drives a material re-organisation of the feedstock market with the shift from biogenic to synthetic. **3.4 Mt of hydrogen could be required to meet the PtL fraction of mandated demand.** The pace of renewable deployment could limit hydrogen availability which could constrain PtL from the implied scale in this scenario.

The mandate drives significant abatement across liquid fuel sectors, with up to 35 Mt p.a. abated by 2050. This is significant abatement noting the CCA project Australia could have 134 Mt of positive emissions in 2050.[1] The majority of this is driven by aviation which is subject to the most aggressive mandate. Despite the mandate also extending to maritime, the bulk of RD uptake remains in the mining sector.

The biggest challenge for mandated demand is the increasing marginal cost of abatement. In 2040, the average abatement cost for a HEFA/FT dominated market is estimated as $457/t$CO_2$-e. By 2050, this rises to over $744/t$CO_2$-e as a result of PtL crowding in.

Figure 50: LCLF Supply (ML) (Accelerated Scenario)

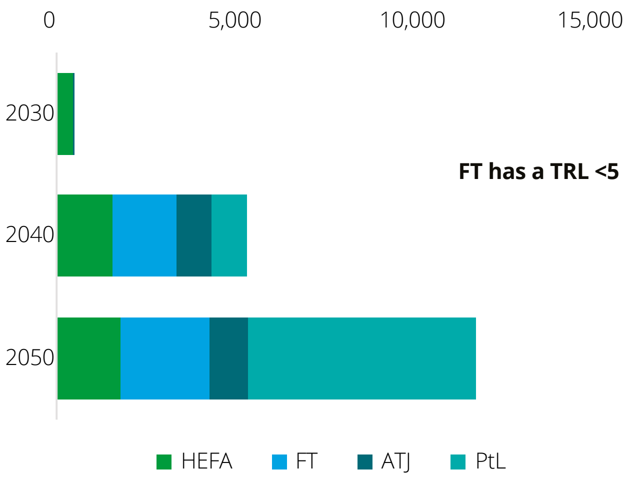


Figure 51: Feedstock Supply Mix (Accelerated Scenario)

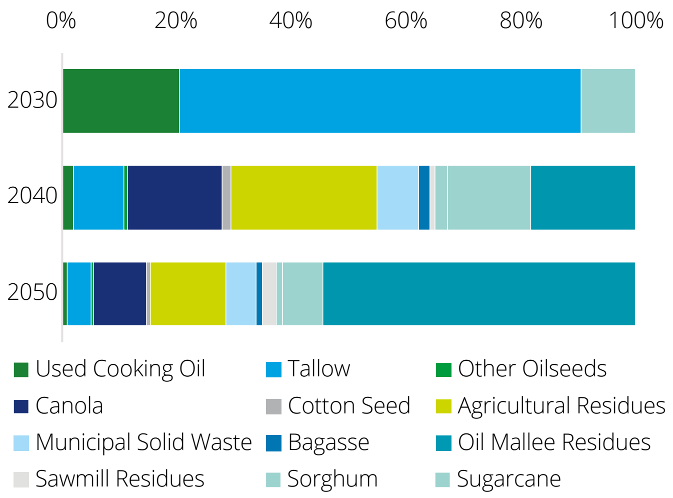
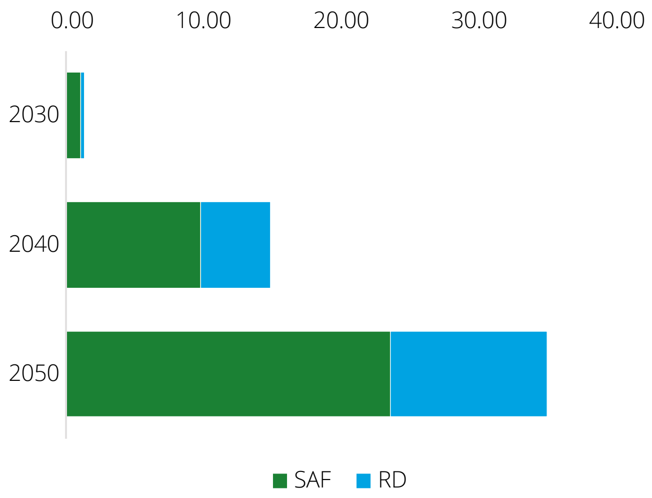


Figure 52: Abatement (MtCO_2-e) (Accelerated Scenario)



Sources: 1. CCA, Sector Pathways Review, 2024

Headline outcomes vary significantly across scenarios, but can also obscure the evolution of these dynamics over time as the market develops

	Fuel Security Outcomes	Emissions Outcomes			Investment Outcomes				
	LCLF as share of projected 2050 liquid fuel demand[1]	**2050 Cumulative Abatement ($MtCO_2$-e)**	**Average Real Abatement Cost over time ($/$tCO_2$-e)**	**Average annual ACCU demand to 2050[2]**	**2050 LCLF market ($b)**	**2050 Feedstock market ($b)***	**2050 Hydrogen demand (kt)**	**2050 Cumulative Implied Refinery Capex ($b)**	**2050 Cumulative Implied Feedstock Processing Capex ($b)**
Base Scenario: Market-led Transition	1 per cent	10	$650	9.2 Mt (~49 per cent of 2024 supply)	$0.8	$ 0.7	9	$0.4	–
Central Scenario: Offset Constrained Transition	25 per cent	230	$460	2.4 Mt (~13 per cent of 2024 supply)	$36	$15	1,100	$16.9	$13.8
Accelerated Scenario: Highly Regulated Demand	41 per cent	290	$560	1.7 Mt (~9 per cent of 2024 supply)	$77	$16	3,400	$19.1	$16.1

Sources: 1. Assuming 29.3 BL of liquid fuel demand in 2050 consistent with electrification assumptions. 2. Assuming 19 Mt of new ACCU generation as per 2024 CER quarterly reports.*Feedstock market excludes hydrogen.

Sequencing Insight #1: Competition and innovation are needed to lower average abatement costs, but these will rise after biogenic feedstocks are exhausted

There are very significant differences in the evolution of abatement costs for fuel users across the three scenarios. Abatement costs are calculated as a volume-weighted average of all fuels cleared and their respective abatement costs – this means that Figure 53 is influenced by (1) fuel production costs, (2) fuel abatement potential and (3) feedstock availability.

A market-led transition (Base Scenario) will deliver slowly declining abatement costs for the subset of fuel users who opt to uplift LCLFs. Abatement costs decline only slowly because the absence of a scaled demand signal fails to provide the market an incentive for innovation. As a consequence, fuel costs do not decline materially over the period to 2050, and feedstock supplies only expand gradually.

An offset constrained transition (Central Scenario) drives competition between fuel suppliers and technology pathways, which puts downward pressure on abatement costs. Abatement costs are on average ~40 per cent lower than scenario 1 without the accelerated cost trajectory. This is entirely a function of a step change on the supply-side, which has been assumed to respond to a stronger demand signal. This creates an incentive for technology breakthroughs and to expand the feedstock supply pool.

Exhaustion of competitive biogenic feedstocks as observed in the highly regulated demand (Accelerated Scenario) marks a step change in abatement costs for fuel users. PtL starts phasing into the market in the highest demand scenario from the late 2030s, with a big uptick in demand in 2045 as a function of the mandate. But by this point in time, while PtL remains cheaper in abatement terms than a range of lignocellulosic feedstocks, it is still structurally more expensive than a range of biogenic pathways. As a consequence, average abatement costs rise steeply as PtL crowds into the market. This trend would only be moderated if hydrogen prices dropped more steeply than assumed in the modelling.

Figure 53: Back to the future – evolution of weighted-average abatement costs by scenario

Sequencing Insight #2: The speed of cost reductions and feedstock innovation will determine the timing of biogenic and synthetic fuel competition in the market

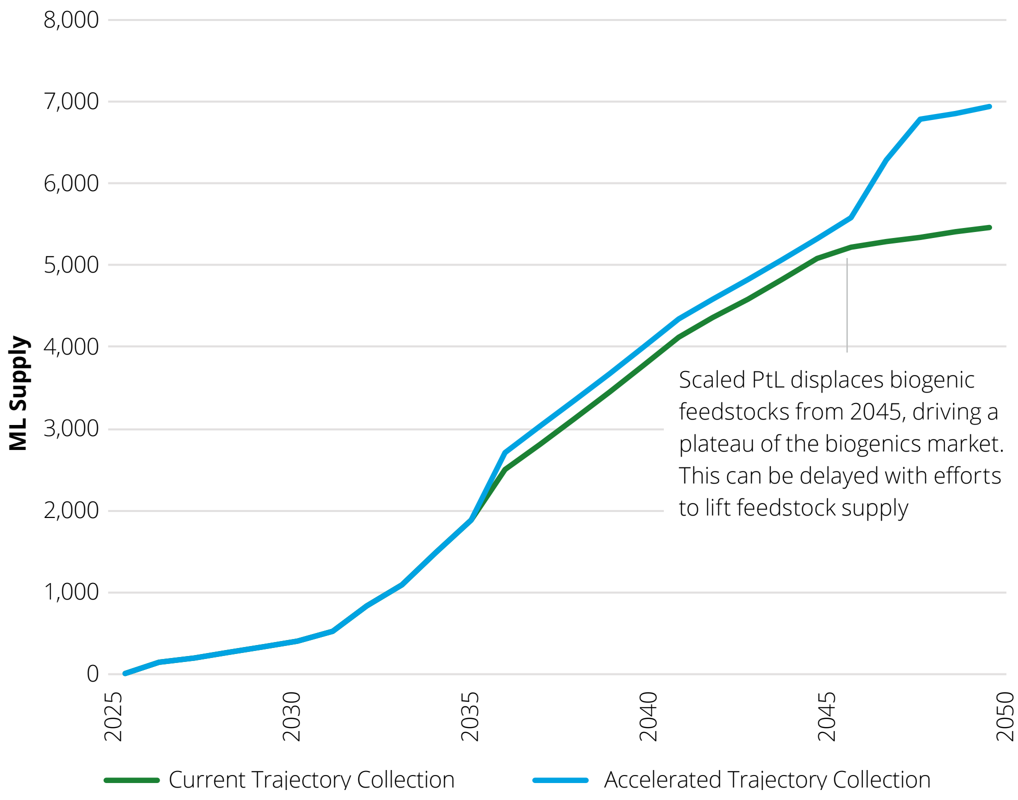
The scenario analysis shows consistent competition between biogenic and synthetic fuels. This is likely to be the defining dynamic of the late LCLF market. The dynamic matters for three related reasons:

1. **PtL would leverage Australia's renewable energy potential.** PtL is currently very expensive but potentially offers a strong source of demand for green hydrogen and a viable export pathway unbounded by the land use constraints of biogenic feedstocks. Put another way, there are strong economic reasons to prioritise PtL deployment.
2. **The emergence of PtL will trigger a plateau of the biogenic feedstock market.** Biogenic LCLFs are the pathway to on-site abatement today, but the relative abatement cost reduction trend of PtL and biogenic pathways could see PtL preferenced over higher cost biogenic pathways as the market matures. If PtL becomes more cost competitive then biogenic pathways, it could force some biogenic pathways out of the supply mix. Alternatively, if biogenic pathways experience a structural cost reduction, new biogenic feedstock supply could enter the market, reducing the demand for PtL-based production.
3. **There are important investment implications from biogenic/synthetic competition.** If PtL does become more attractive than some biogenic pathways, the spectre of competition from synthetic fuels could undermine the investment case in some feedstock processing infrastructure, which could become stranded if outcompeted. Similarly, the competition could emerge within the payback period of refineries.

As Figure 54 shows:

- **PtL always outcompetes a set of lignocellulosic feedstocks** unless there is a technology breakthrough – investments in feedstock processing pathways should recognise this risk. It is worth noting that PtL–Methanol has a marginal abatement cost in excess of $1,000/t by 2050.
- **Technology breakthroughs in yield and collection rates can delay the crossover point by several years, whilst slowing the adoption trajectory.** Yield improvements drive a lower abatement cost, while increasing collection rates are primarily responsible for delaying PtL entry into the market. However, it is worth keeping in mind that faster cost reductions in hydrogen could have the opposite effect.
- **HEFA based feedstocks and agricultural residues are likely safe from PtL competition in the foreseeable future.**

Figure 54: Market cleared biogenic fuel over time within the Highly Regulated Demand scenario with low and high collection rates[1]



Sources 1. Collection rates applied for each feedstock (conservative, optimistic): MSW (30 per cent , 40 per cent), Agricultural Residues (40 per cent , 50 per cent), Sawmill Residues (40 per cent , 50 per cent) and Oil Mallee Residues (40 per cent , 50 per cent). Conservative costs reflect the supply costs from the market-led transition scenario. Optimistic costs reflect assumptions from the offset-constrained demand and highly regulated demand scenarios.

Sequencing Insight #3: Efficient market pricing will be key to manage the co-evolution of SAF and RD demand

The scenario analysis highlights the emergence of significant discontinuities in supplied fuel to aviation and non-aviation users. This can clearly be seen in both the offset constrained and highly regulated demand scenarios, where aviation accounts for ~80 per cent of demand in 2030 which rapidly falls to 70 per cent by 2035 and continues to drop as other sectors require RD to meet decarbonisation objectives.

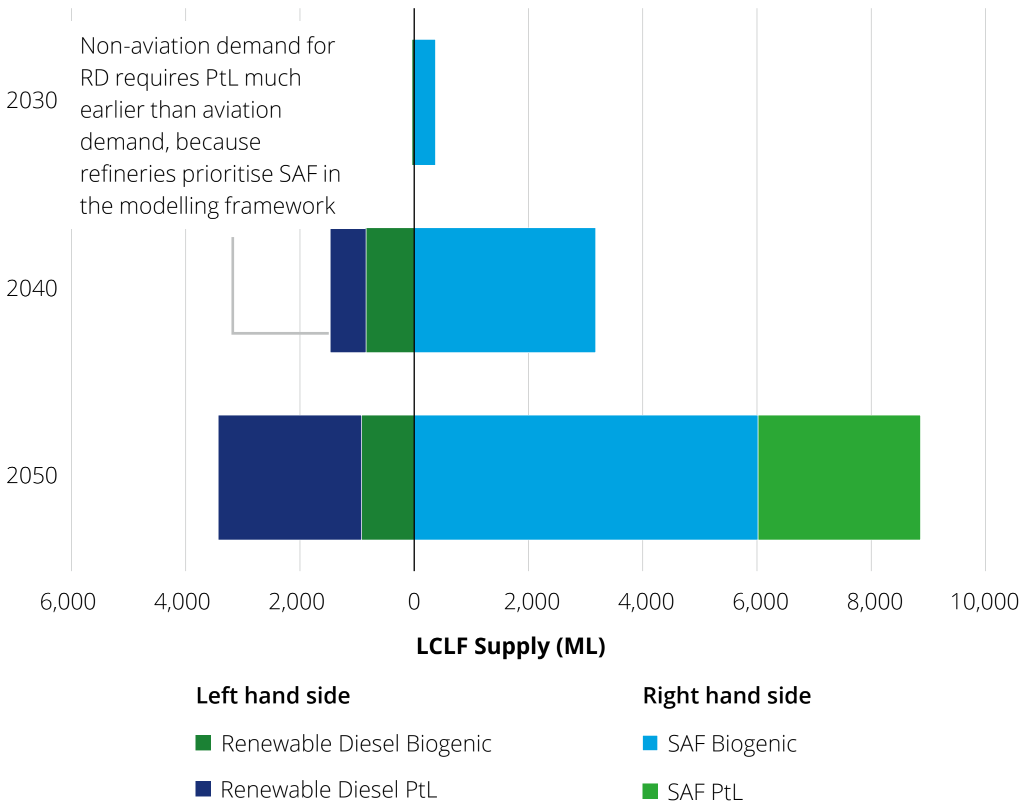
Each LCLF technology pathway has varying flexibility for the product slate to optimise for SAF or RD. Flexibility is higher for HEFA and FT than other pathways.[1] Given the dominance of aviation in early market demand, it seems logical that prospective refiners would tilt their product slate towards SAF – this was assumed for the purposes of modelling. It should be noted that refiners tend to preference RD over SAF at present[2] but this would need to change to meet mandated demand internationally.

A fixed refining product slate risks higher abatement costs for RD users. If refiners keep a very high SAF product slate, by the mid 2030s, RD users need to source fuel from alternative technologies as they are forecast to receive on average ~21 per cent of fuel produced from biogenic feedstocks.

In the modelling, this dynamic is exaggerated, with RD users needing PtL to enter the market ~10 years before aviation to meet demand. There is a cost consequence of this – RD users would face a marginal abatement cost higher than if PtL uptake was delayed to when aviation users cap out the biogenic fuels market. If faced with this situation, it is likely that RD users would instead opt for alternative abatement pathways or continue to purchase offsets.

Real world market dynamics could mitigate this risk, but only if efficient market pricing is not asymmetrically distorted across sectors. It is expected that refiners will regularly change operating parameters of refineries and tweak their product mixes in response to demand and price signals, as currently happens in the fossil fuel market. However, if policy settings such as mandates create imbalances, it may materially raise abatement costs for non-mandated users – in essence, un-levelling the playing field. Policymakers should be live to this risk, and the consequences of distorted price signals for allocative efficiency.

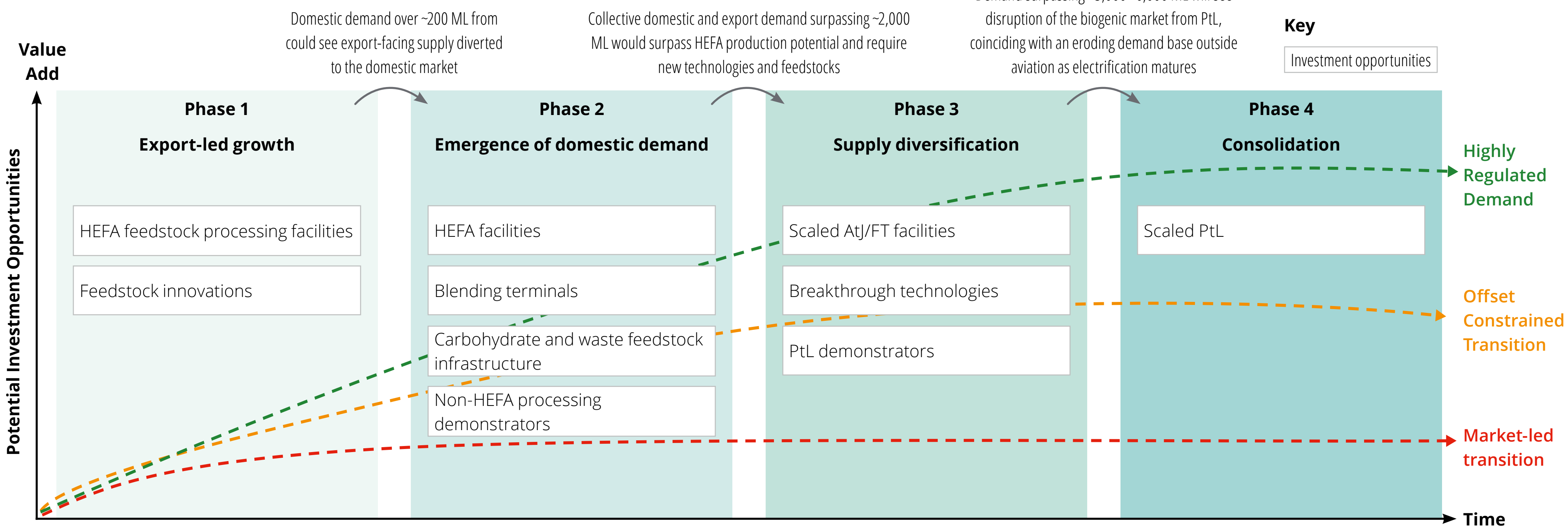
Figure 55: Supply mismatches between SAF and RD in Scenario 3: Highly Regulated Demand



Sources: 1. See for example Figure 9, NREL, State of HEFA, 2024. 2. See for example, Neste, Financial Statements Release 2024, 2025

Sequencing Insight #4: Policy will determine how quickly LCLF demand emerges, the complexity of domestic value chains, and market competition dynamics

Figure 56: Conceptual evolution of Australia's LCLF market



Characteristic Market Dynamics

Phase 1: Australia's LCLF industry is primarily focused on agriculture, with exports of raw and processed feedstocks in the absence of new Australian policy. Opportunities emerge for feedstock innovations which improve fuel yields or abatement costs. Export facing HEFA refineries may be viable if LCLF prices rise and with some domestic demand.

Phase 2: Should Australian fuel users send clear demand signals, the domestic market will unlock. Domestic HEFA refineries and blending infrastructure will become viable. Investments will begin to be made in non-HEFA processing technologies and feedstocks, but HEFA remains the dominant production pathway.

Phase 3: LCLFs establish as a competitive commodity market, with efficient pricing and improving consumer outcomes. Main processing technologies largely derisked with increasing competition between novel biogenic processes and e-fuels. Stranded asset risk could emerge for new biogenic feedstock infrastructure.

Phase 4: The market will reach a saturation point as electrification and other break-through technologies potentially erode demand. Consolidation is inevitable, with vertically integrated value chains expected to specialise to improve efficiency and scale the path to ongoing competitiveness for refineries.

6: What are the main barriers to investing in LCLF today?

Investors recognise Australia's LCLF production potential, and the growing pipeline of feedstock and refinery projects. But five related investment risks currently make capital allocation challenging in the Australian market.

These risks range from the unpredictability of demand and associated price uncertainty, feedstock risk, immature technology deployment ecosystems and policy uncertainty.

Resolution of these risks can ensure a competitive, efficient, and lowest abatement cost LCLF market will develop in Australia.

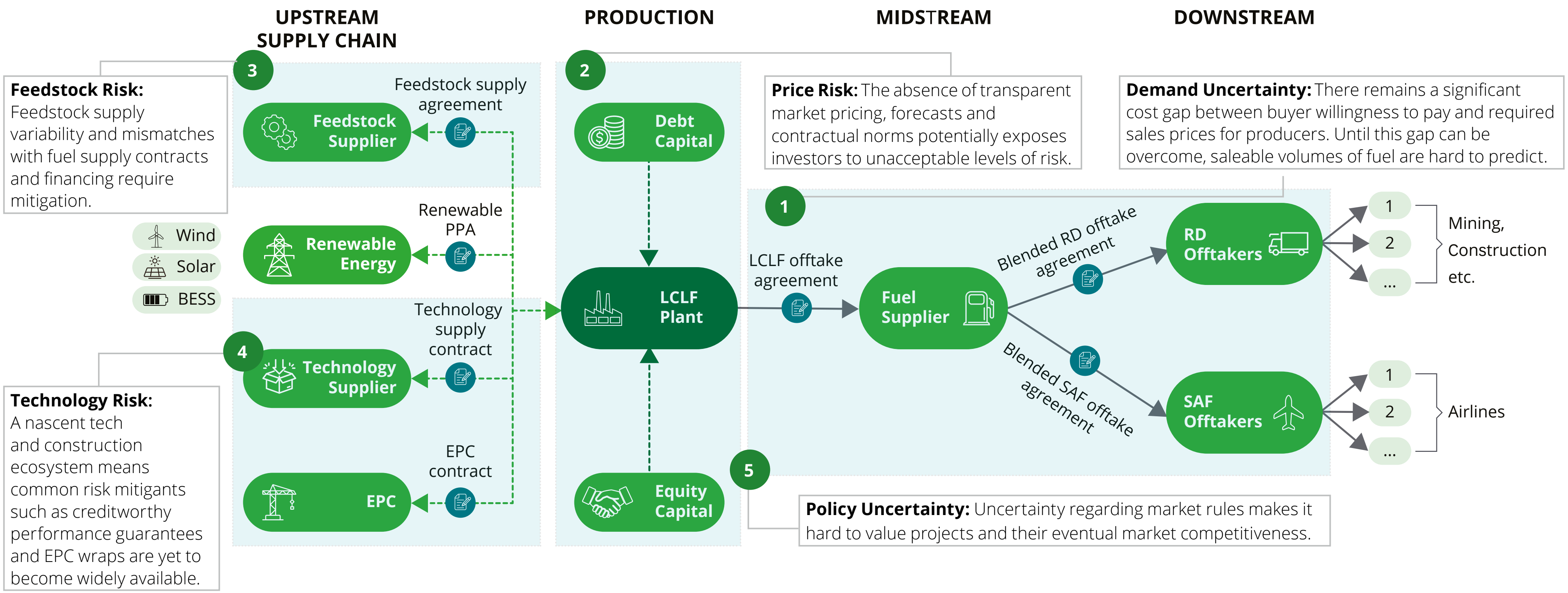
International markets have overcome these barriers, and progressed to real transactions, live projects, and actual abatement. Their approach to market activation and coordination of action across the value chain is a template for Australia to follow – and provides a clear guide to LCLF stakeholders of how they can lead the conversation and mature the market.

LCLF projects in Australia are contending with five interrelated risks which will inhibit private investment and industry scale up if not mitigated

LCLF projects require development of a sophisticated supply chain, with multiple feedstock suppliers and offtakers. Figure 57 shows a stylised supply chain including contractual relationships and touchpoints for finance across the piece.

LCLF production is an immature market with significant uncertainty. This attracts a risk premium and can make financing projects challenging. Five specific investment risks have been mapped onto the supply chain diagram. Mobilising private investment at scale to build these facilities will require overcoming these challenges in a timely manner to facilitate decarbonisation and economic gains.

Figure 57: LCLF supply chain and contracts diagram highlighting key investment risks



Risk #1 – Demand Uncertainty: A functional market requires the cost gap between LCLFs and traditional liquid fuels to be bridged

The Challenge: As the scenarios earlier in this paper have shown, there is a very wide range of demand for LCLF in Australia, but very few real datapoints in the market. Demand uncertainty persists for two primary reasons.

- First, because of the significant and persistent cost gap between LCLFs and fossil alternatives, even adjusting for premiums paid for by end consumers. Importantly, the cost gap will fluctuate with the underlying fossil fuel price – for example, the gap narrowed significantly following price shock in early 2022.
- Second, because of the absence of policy measures used in other jurisdictions. As covered earlier in this report, tradable certificates and direct incentives have also helped to close a material share of the cost gap.

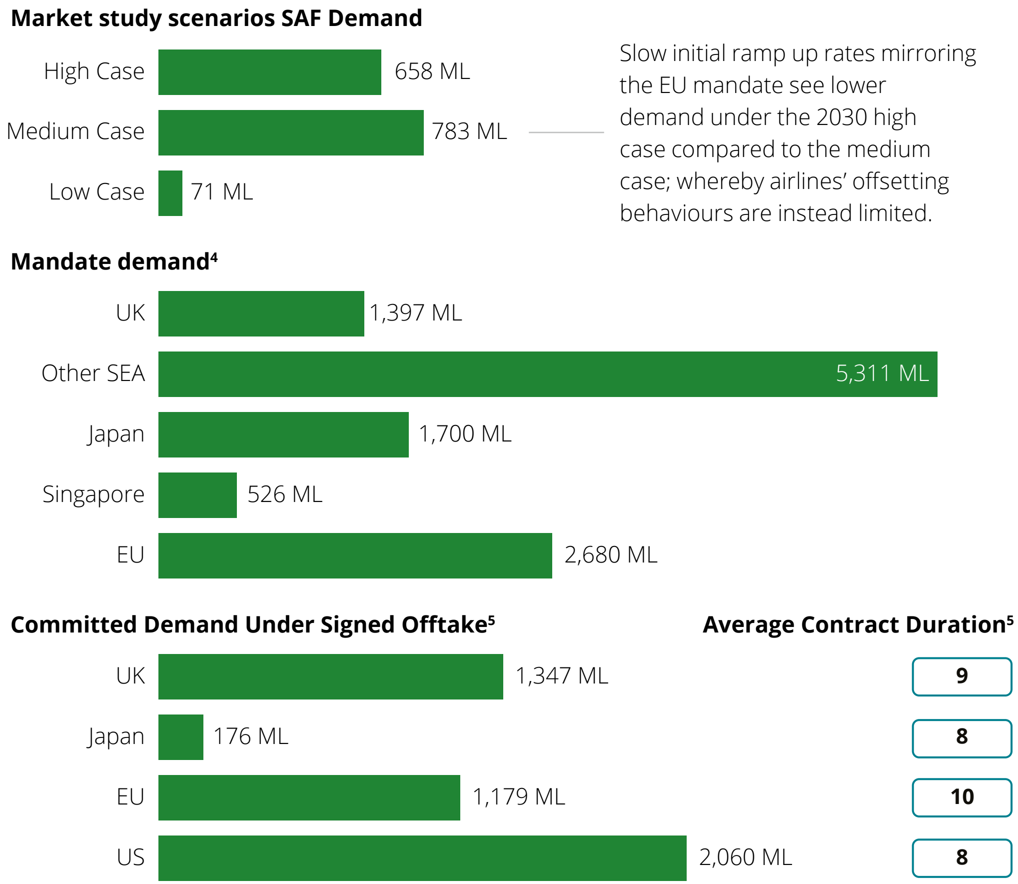
Until the cost gap is reduced, it is likely that domestic fuel users will shy away from binding offtake terms for LCLF, instead persisting with small scale trials and demonstrators.

In contrast, as Figure 58 shows, there is significant demand coming onto the global market, primarily driven by mandates. There is also evidence that markets with existing or imminent policy support long offtake contract durations. This would suggest that policy support provides offtakers with greater investment certainty regarding LCLF consumption and expectations regarding future pricing.

Investment Implications: LCLF production facilities will likely need long-term offtake agreements in order to attract finance. However, Australian buyers may not have an incentive to commit to long-term offtake where emissions reductions are voluntary and there is a possibility of cheaper LCLF entering the market in the future. While the Australian Government has committed to an impact assessment of demand side support including a mandate, this has yet to become policy.[1] In the absence of demand-side intervention and limited appetite for long-term offtake, projects may need to be financed on balance sheet, as has been the case for early developers such as Neste.[2]

Australian projects can focus on offtake opportunities in prospective exports markets where demand is underpinned by mandates. Here projects will need to compete with other prospective suppliers. But a preliminary analysis of announced policy suggests ~2.2 BL of mandated SAF demand by 2030 in Japan and Singapore with additional mandates in Malaysia and Indonesia and proposed in China, South Korea and Thailand.[3]

Figure 58: 2030 Australian SAF demand scenarios relative to mandated international demand,[3] and 2025 volumes under offtake (ML) with average offtake durations



Sources: 1. Future Made in Australia LCLF Announcement. 2. Neste Green Finance Report 2023. 3. SAF Regulation Tracker. 4. Based on DOE SAF Liftoff Report.
5. Volume-weighted offtake duration by carrier home market from ICAO offtake tracker. Contract duration unit is in years.

Risk #2 – Price Risk: Revenue uncertainty limits financing options for LCLF projects

The Challenge: The LCLF market remains small and fragmented, with all Australian transactions to date based on short-dated contracts (primarily for trials) rather than a spot price.[1] Contractual norms are still evolving, with some transactions indexed to the oil price, others to feedstock costs.[2] Compounding challenges, future prices based on emerging technologies and feedstocks cannot be forecast or hedged. All these factors make project revenues uncertain.[3]

Figure 59 shows a comparison between SAF and conventional jet fuel in the US between February 2024 and 2025. Two trends stand out:

1. **LCLF pricing is only partly correlated with traditional liquid fuels:** Feedstocks are the primary driver of LCLF prices, rather than crude prices. With global feedstock prices a product of supply-demand dynamics and agriculture (e.g. weather), a different set of drivers can be responsible for LCLFs costs.
2. **Pricing is sensitive to policy:** The willingness to pay of fuel users is still driven in part by the cost gap to the underlying fossil fuel price. As such, if policy incentives rise, the cost gap declines proportionately and LCLF prices can fall.

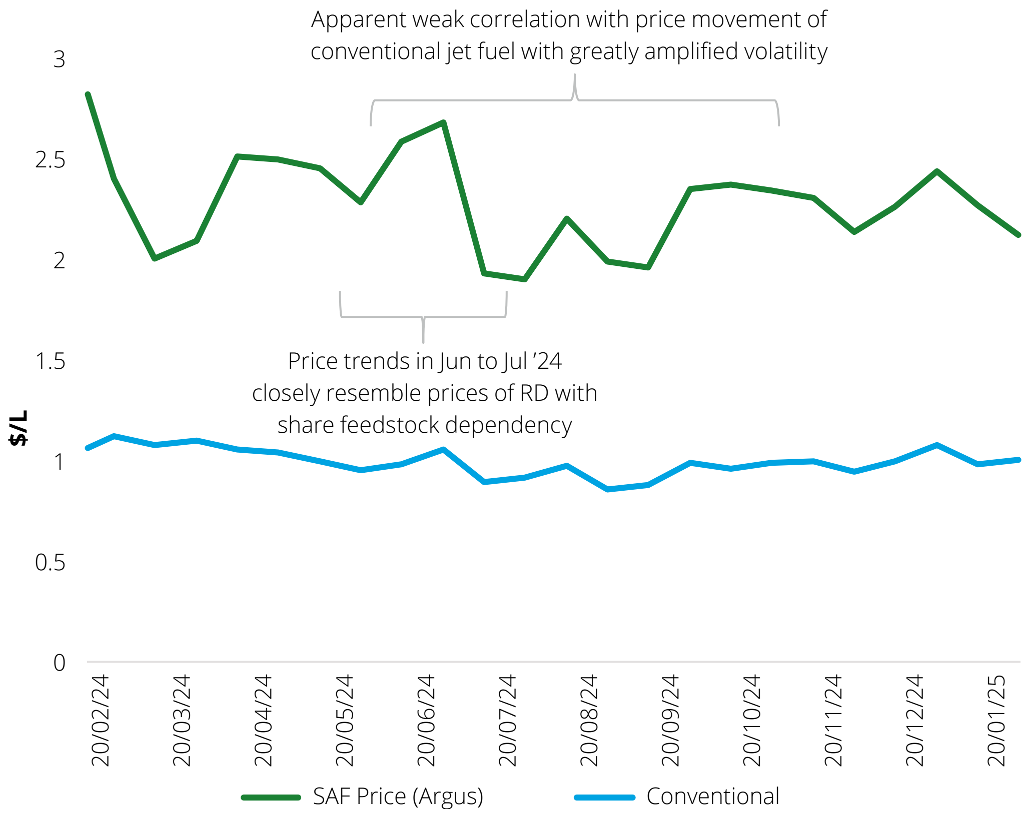
Given how illiquid LCLF markets remain to date, there is likely more pricing volatility present than for traditional liquid fuels.

Investment Implications: Investors need a degree of price certainty to have confidence of risk-adjusted returns for equity or debt. Longer duration offtake agreements with clear pricing formula are a potential risk mitigant although duration and the creditworthiness of offtakers are material considerations.

Investors will still need to manage downside price risk in the case of an oversupplied market. At present, only large diversified corporates with significant balance sheets are likely to be able to manage price risk, constraining potential market participants.

The UK has developed a revenue certainty mechanism to address price risk head on, in addition to their SAF mandate. The mechanism is implemented as a guaranteed strike price – in effect a one-sided contract for difference for SAF prices provided by an underwriter to create a floor price.[4] Of note, the UK has initially excluded HEFA-based SAF from this mechanism due to its relative maturity compared to other pathways.[5]

Figure 59: Volatility in Feb 2024 to Feb 2025 SAF prices relative to conventional jet fuel[4]



Sources: 1. Based on market interviews. 2. IATA, SAF Procurement: Pricing Options. 3. GFI, Towards an Investable SAF Sector. 4. DFT, SAF Revenue Certainty Mechanism Consultation, 2024. 5. DFT, Government Response to SAF RCM Consultation, 2025.

Risk #3 – Feedstock Risk: Investors need mitigants for variable feedstock volumes and price

The Challenge: Biogenic feedstocks are subject to significant volume and price variability, driven by growing conditions and global market imbalances. There is also seasonal variation driven by planting and harvesting – for example canola is typically a winter crop in Australia, with harvesting and crushing occurring from October to January.[1] This necessitates careful storage management to ensure constant supplies for fuel production.

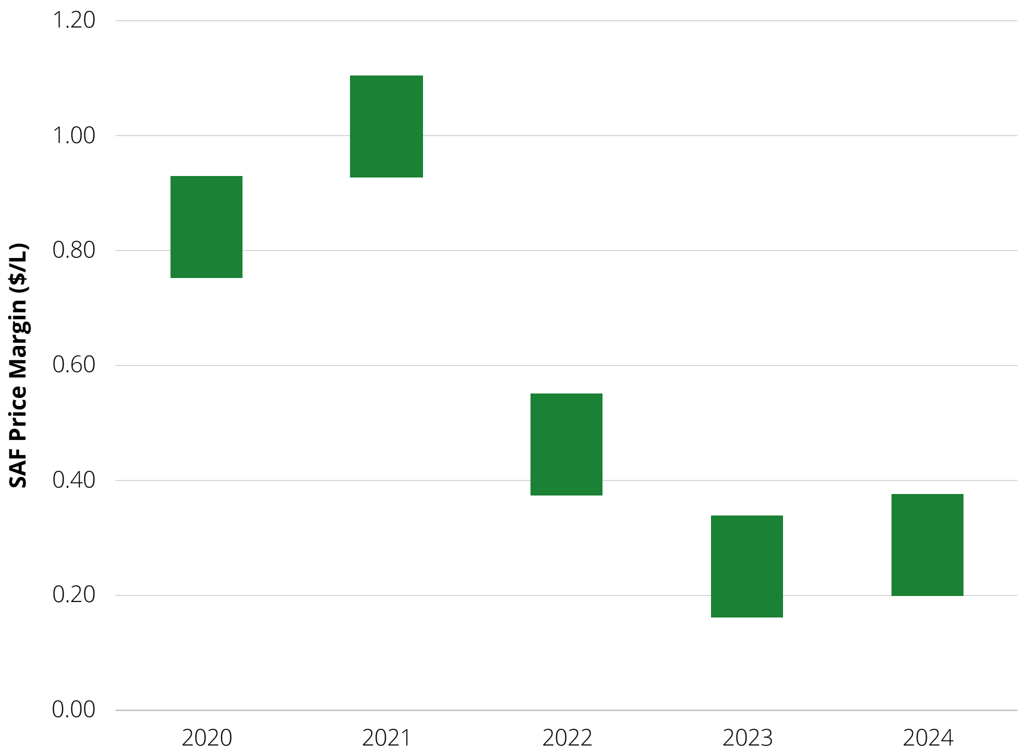
Given the materiality of feedstock costs to the overall LCLF cost stack, the inherent volatility of feedstock availability means that swings in feedstock prices can significantly impact refining margins. Figure 60 presents a stylised analysis of this process – historical tallow prices[1] are used to estimate the annual production cost of a HEFA plant, and a sale price range is assumed based on variability in the US Argus SAF across 2024.[2] The resulting margin varies significantly over the assessment period – LCFS and RIN credits are currently helping maintain positive (if low) margins.

Investment Implications: Prospective investors will need mitigants for feedstock volume risk and seasonal variability, which is likely to require refineries to secure multiple feedstock suppliers or suppliers with the ability to manage volume and price risks. In addition, should a refinery be seeking debt finance, the feedstock contracting arrangements, including duration of the supply contract, supplier size, and creditworthiness, will have an impact on the tenor of debt able to be achieved.

Feedstock suppliers will face different incentives to engage on these challenges. For example, existing operators selling onto global feedstock markets may be cautious about signing long-term supply agreements given the relative immaturity of LCLF as an end-use market in Australia and potential competition from other end users. However, feedstock suppliers scaling production or incurring capex associated with new processing capacity may find a longer dated offtake agreement helps to derisk their investment and provide predictable cashflows.

Mature market participants have developed sophisticated sourcing platforms to manage feedstock risks, diversifying supply across feedstock types and geographies. Some fuel producers have made direct acquisitions in feedstock collection and aggregation businesses – primarily for tallow and UCO – to draw benefits from vertical integration.[3] Other prospective producers are entering into joint development agreements with significant feedstock suppliers.[4] Consistently strong supply chain governance and certification processes are used to ensure compliance with international standards.

Figure 60: Theoretical US refining margins based on historical tallow prices and high/low Argus SAF price[1,2]



Sources: 1. MLA, Australian Co-Products Rendered Products, 2025. 2. Argus, 2025 based on Airlines for America. 3. For example, Neste has acquired Crimson Renewable Energy, Mahoney Environmental, Agri Trading, and IH Demeter, Annual Report 2023; Shell acquired EcoOils in 2022 – Argus Market Update 2022, Darling Ingredients, a JV partner of Diamon Green Diesel, acquired Valley Proteins and FASA, Platts Jet Fuel, Market Update 2022. 4. Graincorp, Media Release, 2024

Risk #4 – Technology Risk: Newer production pathways lack standard risk mitigants raising financing complexity

The Challenge: There are less than 100 operational renewable fuel refineries globally[1], with a number of these retrofits of existing brownfield refineries, and almost all leveraging HEFA production technologies. There are clear limits to reliance on HEFA as a production technology, and clear competition consequences.

A function of the scale up pathway of alternative production technologies is the absence of a mature construction ecosystem. As Figure 61 and 62 show, HEFA represents the vast majority of operational and announced projects. FT, AtJ, and PtL projects are a much smaller share of the pipeline. Because of HEFA's significant operational footprint, there are multiple creditworthy technology suppliers and multiple experienced EPCs. In contrast, only one commercial scale AtJ facility has been built, using LanzaJet's technology.

Investors typically manage construction and technology risks with mitigants such as:

- **EPC wraps,** where the construction contractor bears the risk of on time and on budget delivery. EPC contracts typically contain liquidated damages for construction delays up to a liability cap linked to the contract value.
- **Equipment performance guarantees,** where the technology supplier retains financial liability for technology underperformance. These typically feature liquidated damages provisions which compensate the project if performance obligations are not met (e.g. minimum uptime or output hurdles).

A key challenge for non-HEFA based pathways is that the risks of a newer technology could mean that these products may not be available.

Investment Implications: Investors will bias towards HEFA production, where the operational performance of technology has been derisked and mechanisms to manage both technology and construction risks have been normalised.

In contrast, the additional financial structuring needed to derisk alternative pathways adds to their risk premium, financing costs and due diligence timeframes. These instruments will develop over time but currently serve as a financing impediment. They can be overcome – for example LanzaJet was able to strike fixed-price EPC agreements for construction of Freedom Pines Fuels and manage costs via a modular approach to construction.[1] Two USD $50m grants from the Microsoft Climate Innovation Fund and Breakthrough Energy Catalyst further derisked construction.[2] Specialty insurance products can also manage technology risk.[3]

Figure 61: Technology split across operational and planned LCLF plants[4]

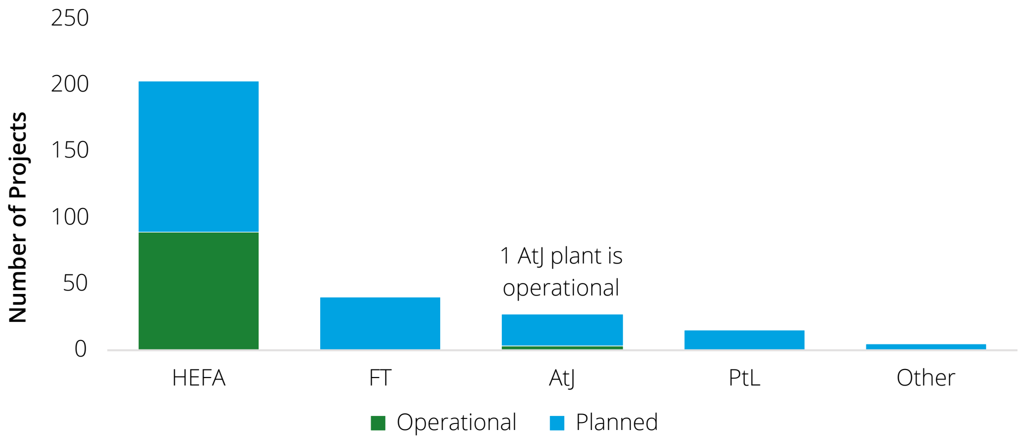
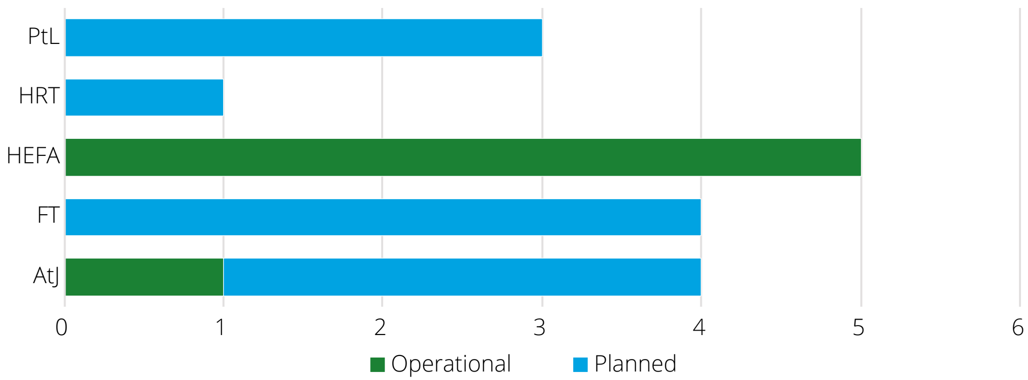


Figure 62: Number of LCLF technology providers across sample of 94 operational and planned projects[5]



Sources: 1. LanzaJet Media Release, 2021. 2. LanzaJet Media Release, 2022. 3. Such as those offered by New Energy Risk, Ariel Green, Munich Re, and Matrix. 4. Deloitte LCLF Project Database. 5. Deloitte Analysis of Technology Provider company reports and announcements.

Risk #5 – Policy Risk: Uncertainty over market integrity rules and ease of international interoperability impacts valuations

The Challenge: The value of LCLFs to the customers of end fuel users is primarily the abatement attribute that allows them to reduce scope 3 emissions. This means that the value of LCLFs are inextricably tied to the carbon accounting regimes of different markets. LCLF projects will need consistent, transparent and certain carbon accounting methodologies to price and value fuels. Typical chain-of-custody information necessary to underpin LCLF abatement benefits include certification of feedstock, fuel tracking, a credit registry, and claiming and reporting of fuel use.[2] To minimise transaction costs and maximise market access, methodologies ideally remain consistent across borders.

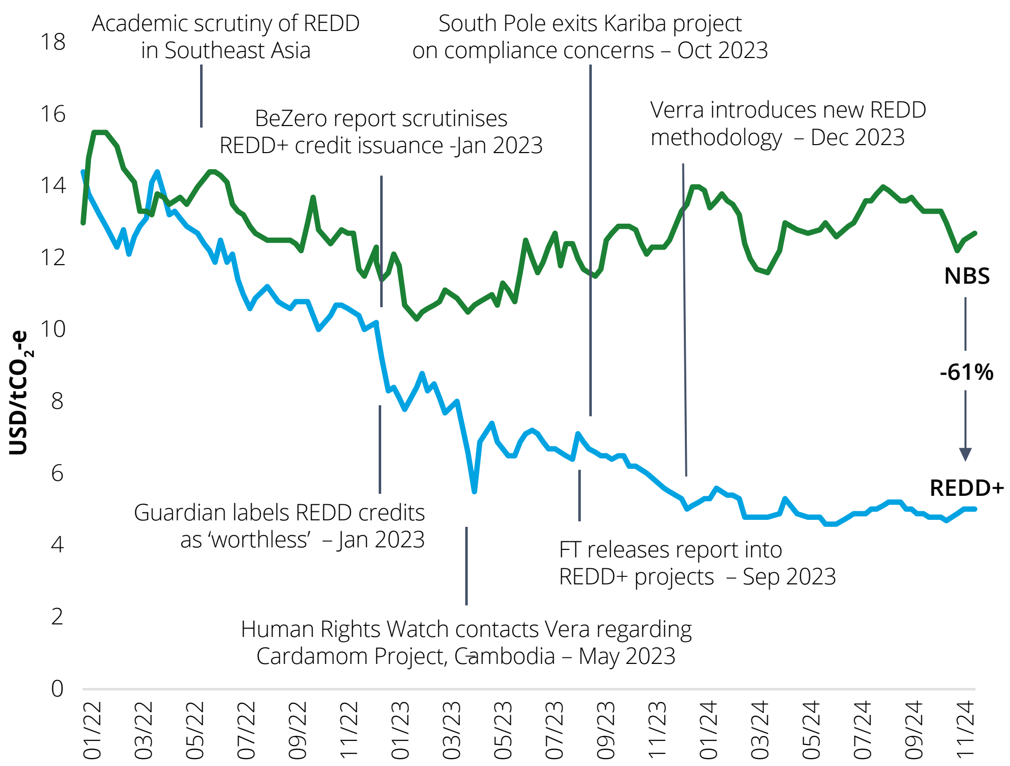
Policymakers understand that stable market pricing hinges on the credibility and integrity of carbon accounting methodologies. There are clear lessons from the adjacent carbon market which underscores the centrality of integrity to pricing. Figure 63 shows the evolution of voluntary carbon credit prices for REDD+ and Nature Based Solutions (NBS) credits. A series of exposes between 2022 and 2023 dramatically undermined confidence in the abatement basis of REDD+ which were credits for avoided deforestation. Demand for this type of credit evaporated which led to a sustained price correction. The fall stabilised after a new methodology was formalised in early 2024, but the credits now trade at a structurally lower price to NBS credits and face reduced demand from leading corporates.

It is not in the interests of project developers, fuel users or investors for a repeat of the experience of the voluntary carbon market. In 2023, concerns were raised with labelling of biodiesel and biodiesel feedstocks from Asia which led to significant price reductions in Europe.[3] This raises the importance of feedstock certification, verification and monitoring.

Investment Implications: Greater certainty regarding market rules would aid valuation of projects and improve market competitiveness. Investors may value alignment with international carbon accounting frameworks given an expected export leaning for initial Australian projects and the depth of comparable transactions in more mature markets. However, there is recognition that some investment opportunities (e.g. in feedstocks) are contingent on recognition of Australian-specific emissions factors.

In the Australian context, the Government has announced an intention for abatement to be validated via a Product GO certificate.[4] Draft feedstock criteria are also included in the draft Australian Sustainable Finance Taxonomy,[5] and observations are included in CSIRO's most recent work.[6]

Figure 63: Anatomy of a scandal – lessons from the voluntary carbon market[1]



Sources: 1. ClearBlue Markets, 2025. 2. See for example IATA, SAF Accounting, 2023. 3. ISCC, Media Release, 2023. 4. DITRDLG Media Release, 2024. 5. ASFI, Sustainable Finance Taxonomy Consultation, 2024. 6. CSIRO, Opportunities for LCLF, 2025.

The five investment risks are more pronounced for newer LCLF production pathways, with HEFA the most commercial technology

A review of the investment risks across the production pathways suggests that HEFA is most advantaged. Relative to other pathways, HEFA projects have common risk mitigants for technology risk based on the number of operation facilities. The number of operational facilities also provides more datapoints for fuel producers to manage price risk. The lack of demand certainty, feedstock risk, and policy uncertainty remain significant barriers for HEFA.

AtJ could gain momentum from the recently completed Freedom Pines Fuels but faces significant challenges. The AtJ pathway is slightly less exposed to investment risk than FT and PtL. This is primarily because the first commercial scale reference plant exists, and because near-term dynamics in the ethanol market could form a tailwind for AtJ project developers. However, because AtJ remains at a cost disadvantage relative to HEFA, demand uncertainty, price risk, and policy uncertainty all present material investment hurdles.

With no reference projects, FT will face investment challenges, but some feedstocks remain attractive. Similar to AtJ, FT remains at a disadvantage relative to HEFA. The absence of food vs fuel challenges and expected price stability of some feedstocks could manage some investment risks.

PtL is likely to remain the most challenged pathway. Limited availability of green hydrogen price points and the absence of a deployment ecosystem will remain structural barriers to investment for PtL.

Figure 64: Mapping investment risks across technology pathways

Key: Lower Risk → **Higher Risk**

	Demand Uncertainty	Price Risk	Feedstock Risk	Technology Risk	Policy Uncertainty
HEFA	• Policy actions required to bridge the cost gap and promote domestic offtake • Export only viable route, but requires outcompeting producers in other markets	• Benchmark prices increasingly feasible based on feedstock indices and LCLF price indexes	• Multiple viable waste & oilseed feedstocks • Significant emerging feedstock price competition • Material feedstock price voliatility	• 90+ operational facilities • Multiple experienced EPC contractors • Multiple proven technology providers	• Well-understood lifecycle emissions and some Australia-specific LCAs • Historic evidence of some integrity issues from Asian feedstock suppliers (with indirect land use change implications)
FT	• Policy actions required to bridge the cost gap and promote domestic offtake • Higher cost base than HEFA makes it challenging for projects to export	• Some price discovery may be possible if European or American projects are developed • Management of price risk challenging in absence of a revenue certainty mechanism	• Feedstock volumes scale with population • Some feedstock competition from W2E and biomethane • Feedstock costs are stable, but pretreatment costs linked to heterogeneity of feedstock	• No operational facilities • No experienced EPC but transferable knowledge from W2E • 4 emerging technology providers	• No food vs fuel challenges for waste-based feedstocks
AtJ			• First generation feedstock growing in availability • Competition for first generation feedstock reducing as road transport electrifies	• 1 small operational facility • 1 EPC with experience • 3 emerging technology providers	• Relative LCA of Australian feedstocks against global competitors still to be understood
PtL			• Dependent on green hydrogen and biogenic or captured carbon • Feedstock variability driven by weather	• No operational facilities • No experienced EPCs • Wide range of emerging technology providers	• Clear Product Go expectations for green hydrogen

7: How can Australia scale up the LCLF market?

Investment challenges manifest differently depending on the stage of market development. Unlocking export-led growth will require a focus on access to export markets and scaling Australian feedstocks. At the same time, efforts could focus on increasing visibility of market data to underwrite policy development for the domestic market. Transitioning to domestic demand requires a pivot, with a strong demand signal coupled with efforts to develop a competitive and efficient market the priority.

Seven accelerators can scale up the Australian LCLF market, with specific actions determined by the stage of market development:

1. Increasing Australia's **market access** to LCLF offtakers, new markets for feedstocks, and access to tech suppliers and EPCs
2. Offering **new risk mitigants** for financing challenge: including concessional finance, grant programs, insurance products, and revenue certainty mechanisms
3. Reducing **market frictions** by levelling the playing field for technologies and standardising contract terms
4. **Underwrite initial demand** volumes, including via longer term offtake agreement or through regulation
5. Reducing **information asymmetry** by developing benchmarks, publishing forward expectations of demand, supply, and feedstocks
6. Leveraging **innovation** to put downward pressure on costs, largely through feedstocks and by increasing fuel yields
7. Supporting **alignment of interests** through commercial models, vertical integration and partnerships.

Investment challenges manifest differently depending on the stage of market development

The scenario analysis earlier in this paper highlighted the likely progression through four phases of LCLF market development. Importantly, investment risks manifest differently across the stages – suggesting that each sequential phase of market development will require different mitigants to unlock.

Figure 65 steps out preliminary objectives for each phase of market development mapped to investment risks. What emerges are a set of sequential objectives to guide action in each phase. Broadly:

- **Phase 1:** Unlocking export-led growth will require a focus on access to export markets and scaling Australian feedstocks. At the same time, efforts could focus on increasing visibility of market data to underwrite policy development for the domestic market.
- **Phase 2:** Transitioning to domestic demand requires a pivot, with a strong demand signal coupled with efforts to develop a competitive and efficient market the priority.
- **Phase 3:** As the market begins to mature and supply diversifies, investors will want to know new facilities can remain competitive. This will require a focus on transparency & clear price signals.
- **Phase 4:** By phase four, risk mitigation turns to managing the impacts of potentially structural transitions in the market on investment returns.

Figure 65: Potential objectives to manage investment risks mapped to stage of market development

	Phase 1: Export-led growth	Phase 2: Emergence of domestic demand	Phase 3: Supply diversification	Phase 4: Consolidation
Demand Uncertainty	Secure access to prospective export markets to scale up initial Australian projects	Develop credible underpinning for domestic demand expectations	Clearly signal market balance and emerging shortfalls necessitating new feedstocks or technologies	Manage declining demand if it eventuates
Price Risk	Increase transparency of factors driving market pricing	Facilitate price discovery to ensure efficient pricing	Manage competition between pathways to put downward pressure on abatement costs	Manage emergence of PtL into the market
Feedstock Risk	Scale Australian feedstock supply chains	Fairly divert Australian feedstocks onto the domestic market	Scale Australian feedstock supply chains	Manage feedstock stranded asset risk if PtL emerges
Technology Risk	Attract HEFA development ecosystem	Seed non-HEFA development ecosystem	Derisk novel production pathways	
Policy Uncertainty	Provide policymakers data on trade-offs to inform robust policy	Embed high integrity rules into emerging Australian market		

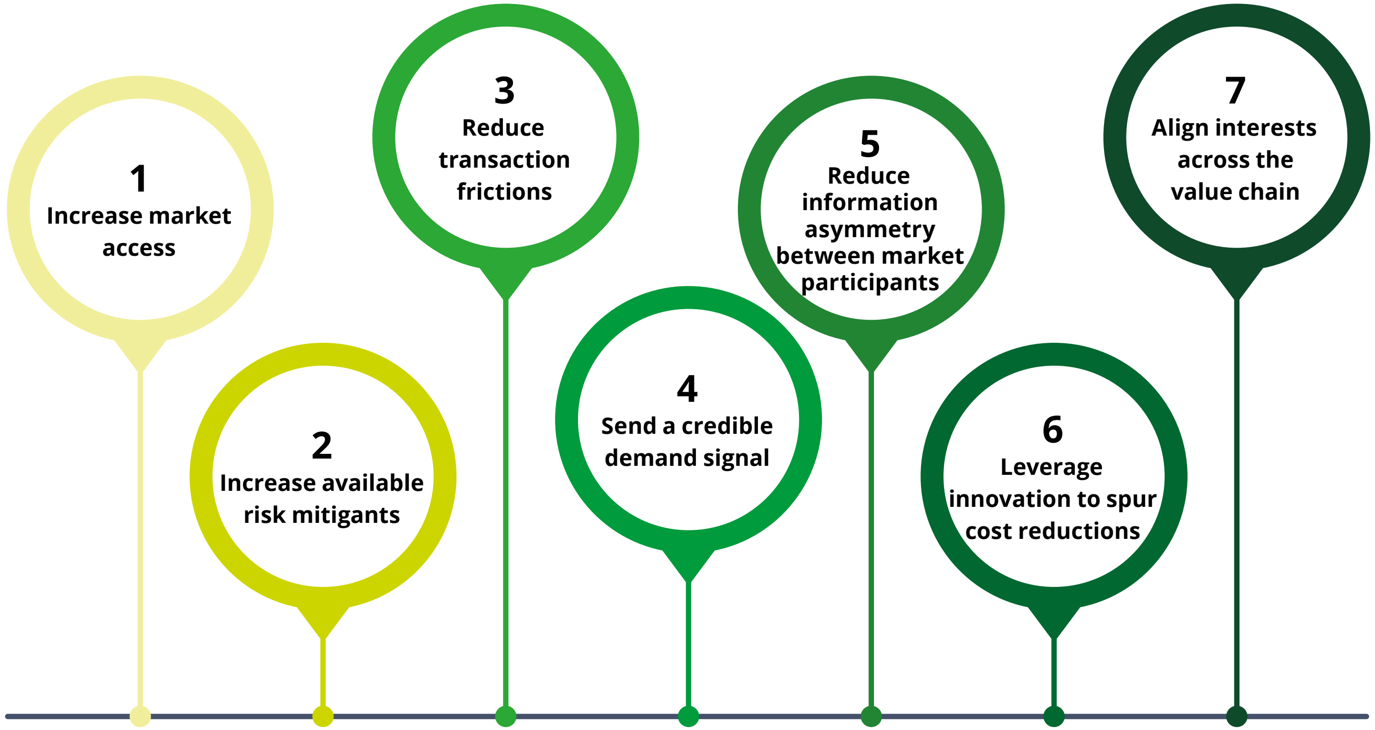
Seven accelerators can scale up the Australian LCLF market, with specific actions determined by the stage of market development

There are a broad range of potential actions which actors across the LCLF value chain can take to manage investment risks and scale the market. A long list of actions by risk and value chain stage (producers, fuel users, investors, and policymakers) is included at Appendix D.

Common themes for coordinated action emerged from this long listing process. These have been summarised in Figure 66, which sets out the **seven accelerators** to scale up Australia's LCLF market:

1. Increasing Australia's **market access** to LCLF offtakers, new markets for feedstocks, and access to tech suppliers and EPCs
2. Offering **new risk mitigants** for financing challenge: including concessional finance, grant programs, insurance products, and revenue certainty mechanisms
3. Reducing **market frictions** by levelling the playing field for technologies and standardising contract terms
4. Underwrite **initial demand** volumes, including via longer term offtake agreement or through regulation
5. Reducing **information asymmetry** by developing benchmarks, publishing forward expectations of demand, supply, and feedstocks
6. Leveraging **innovation** to put downward pressure on costs, largely through feedstocks and by increasing fuel yields
7. Supporting **alignment of interests** through commercial models, vertical integration and partnerships.

Figure 66: Seven accelerators for the Australian LCLF market



Coordinated near-term action is needed to leverage Asian mandates to lay the foundation for a scaled Australian value chain

Australia is already benefiting from global interest in LCLFs through exports. As mandates are introduced and enforced globally, Australia's supply chain has the benefit of a growing market to sell into. This will initially drive an uptick in feedstock exports and can be leveraged to build out more sophisticated domestic feedstock supply chains which would facilitate faster scale up of LCLF production as domestic demand emerges.

To capture a growing share of Asian LCLF demand, Australia will need to prioritise market access and speed. Australia is not the only potential trade partner for Asian offtakers. A coordinated approach will be needed from Australian projects and policymakers to facilitate discussions and potential partnerships. Ensuring market access is critical, as is ensuring Asian LCLF producers can recognise the high integrity emissions reduction benefits of Australian feedstocks.

In parallel, market actors can invest today in initiatives that are demand agnostic – primarily in innovation and market transparency. The early stage LCLF market remains opaque and illiquid. Participants across the Australian value chain could swiftly improve coordination and support publication of market benchmarks to improve transparency. Similarly, feedstock providers are already scaling R&D to improve the benefits of Australian feedstocks. Policymakers could support this by ensuring international recognition of the carbon benefits of Australian feedstocks.

Figure 67: Options for coordinated action to unlock export-led LCLF growth

	Objective	Enablers
Demand Uncertainty	Secure access to prospective export markets to scale up initial Australian projects	01 **Market access:** Australia could leverage trade policy to scale Asian LCLF demand, with high integrity rules that favour Australian feedstocks 01 **Market access:** Feedstock suppliers and project developers could directly engage with Asian LCLF offtakers
Price Risk	Increase transparency of factors driving market pricing	05 **Resolve information asymmetry:** Investors or fuel users could develop and regularly publish market benchmarks for feedstock costs, fuel costs, and contract terms 06 **Drive innovation:** R&D investments could prioritise pathways to increase fuel yields from Australian feedstocks
Feedstock Risk	Scale Australian feedstock supply chains	02 **Increase available risk mitigants:** Governments could consider introducing grant programs to support the build out of feedstock collection and processing infrastructure 03 **Reduce frictions:** Fuel producers and feedstock providers could invest in definitive Australian lifecycle carbon assessment reports to underpin feedstock exports 06 **Drive innovation:** R&D investments could target carbon intensity reduction pathways for Australian feedstocks, crop yield improvements and advances in feedstock processing and collection. Increasing rotational oilseed crops could also have supply and soil carbon benefits
Technology Risk	Attract HEFA development ecosystem	03 **Reduce frictions:** Governments could consider streamlining permitting and approvals for projects in the pipeline to lower entry points for Australian LCLF projects
Policy Uncertainty	Provide policymakers data on trade-offs to inform robust policy	01 **Market access:** Australia should ensure recognition of the emissions reduction benefits of Australian feedstocks in international markets 03 **Reduce frictions:** Governments could continue to clarify LCLF standards and regulatory requirements (e.g. fuel standards, minimum stockholding obligation, etc)

Australia will need to manage the transition from export-led production to delivering domestic decarbonisation

Australia will need a managed transition from an export-led production model. The first implication is that domestic LCLF demand when it emerges will be coupled to global prices from day one, as it will need to divert feedstock or fuel from existing customers. Second, Australia will need to navigate long-term offtake contracts which could lock up a majority of supply for export markets for at least five years.

A credible demand signal will be needed to begin the managed transition, coupled with actions to reduce the cost gap. The scenario analysis was clear that in the absence of a demand signal, limited volumes of LCLF will be uplifted in Australia. Market participants could send a signal with a collective tender as has been the case in the US and Europe. Similarly, governments could act to underwrite demand. Simple actions including LCLFs in scope of the Fuel Tax Credit can also reduce the cost gap.

Laying the foundations for market scale up will be critical at this point, with price discovery and increasing feedstock supply essential. Price discovery would be best achieved through sale of LCLF on a spot market and aided by standardisation of sale contract terms. Feedstock supply will naturally seek to respond to a price signal but could be accelerated through the increasing availability of risk mitigants.

Figure 68: Options for coordinated action to unlock emergence of domestic demand

	Objective		Enablers
Demand Uncertainty	Develop credible underpinning for domestic demand expectations	03	**Reduce frictions.** Australia could recognise RD and SAF under the fuel tax credit to level the playing field between fossil fuels and LCLFs
		04	**Demand signal:** Fuel users could aggregate demand through collective offtake tenders mirroring successful tenders in the US and Europe
		04	**Demand signal:** The Australian Government could signal detailed design options for demand-side intervention that will be evaluated under a regulatory impact analysis process
Price Risk	Facilitate price discovery to ensure efficient pricing	03	**Reduce frictions:** Market participants could develop model clauses to standardise key offtake contract terms including premiums for fuel carbon intensity and risk allocation
		05	**Resolve information asymmetry:** Policymakers could consider options for direct price discovery for directly supported projects (e.g. requiring spot sales of a fraction of LCLFs)
Feedstock Risk	Fairly divert Australian feedstocks onto the domestic market	02	**Increase available risk mitigants:** Market participants could explore viability and demand of feedstock insurance
		07	**Align value chain interests:** Fuel producers and feedstock providers could explore co-investments or value sharing arrangements to directly align commercial interests. Efforts could also focus on innovative supply and offtake with revenue sharing optionality
Technology Risk	Seed non-HEFA development ecosystem	01	**Market access:** Project developers could support market entry for new technology suppliers and facilitate local EPCs to leverage international LCLF knowledge
		03	**Reduce frictions:** Governments could directly facilitate trials and deployment of newer production pathways (e.g. via CSIRO, ongoing ARENA grant programs, access to credit enhancements)
Policy Uncertainty	Embed high integrity rules into emerging Australian market	03	**Reduce frictions:** Policymakers will need to expedite Product GO certification for LCLF producers to commodify scope 3 benefits for end consumers

Ensuring a competitive market in the future will require near-term decisions to be balanced with the enablers of long-term efficiency

Consumers would be disadvantaged by a market with limited competition. The scenario analysis is clear that in order for LCLFs to deliver scaled abatement, multiple technology pathways are needed. Abatement costs for consumers only reduce if competition between production pathways eventuates and drives innovation. However, it is also clear that investment risks are more substantial for these newer production pathways than for HEFA.

A competitive market will turn on the rules established during the emergence of domestic demand, which will cast a long shadow. Careful consideration will need to be given to both contracting norms and policy settings to avoid limiting future competition between production pathways.

Competitive markets require resolution of information asymmetry and mitigants for risk. Projects using non-HEFA pathways will struggle to secure finance without offtake arrangements, and in turn these will hinge on market consensus expectations on the future balance of supply and demand. Clear publication of these expectations would facilitate decision making.

Similarly, structural efforts to address risks associated with non-HEFA pathways are likely to be needed. Options include revenue certainty mechanisms, grant programs targeting feedstock business models, credit enhancements and novel insurance products.

Figure 69: Options for coordinated action to unlock supply diversification

	Objective	Enablers
Demand Uncertainty	Clearly signal market balance and emerging shortfalls necessitating new feedstocks or technologies	05 **Resolve information asymmetry:** Market participants should facilitate publication of forward expectations of market supply and demand, similar to the way AEMO publish the ESOO and GSOO
Price Risk	Manage competition between pathways to put downward pressure on abatement costs	02 **Increase available risk mitigants:** Policymakers may need to consider introduction of a revenue certainty mechanism to support non-HEFA production pathways to compete in the market
Feedstock Risk	Drive cost reductions across feedstock supply chains	02 **Increase available risk mitigants:** Governments could consider introducing grant programs to support new feedstock business models – such as regional hub and spoke models disadvantaged in the early market 05 **Resolve information asymmetry:** Market participants should facilitate publication of feedstock availability forecasts and seasonal outlooks
Technology Risk	Derisk novel production pathways	02 **Increase available risk mitigants:** Investors should work with governments to increase access to credit enhancements and novel insurance products (e.g. technology performance insurance) for commercial scale non-HEFA production pathways
Policy Uncertainty		Risks associated with policy uncertainty have been resolved by this stage

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