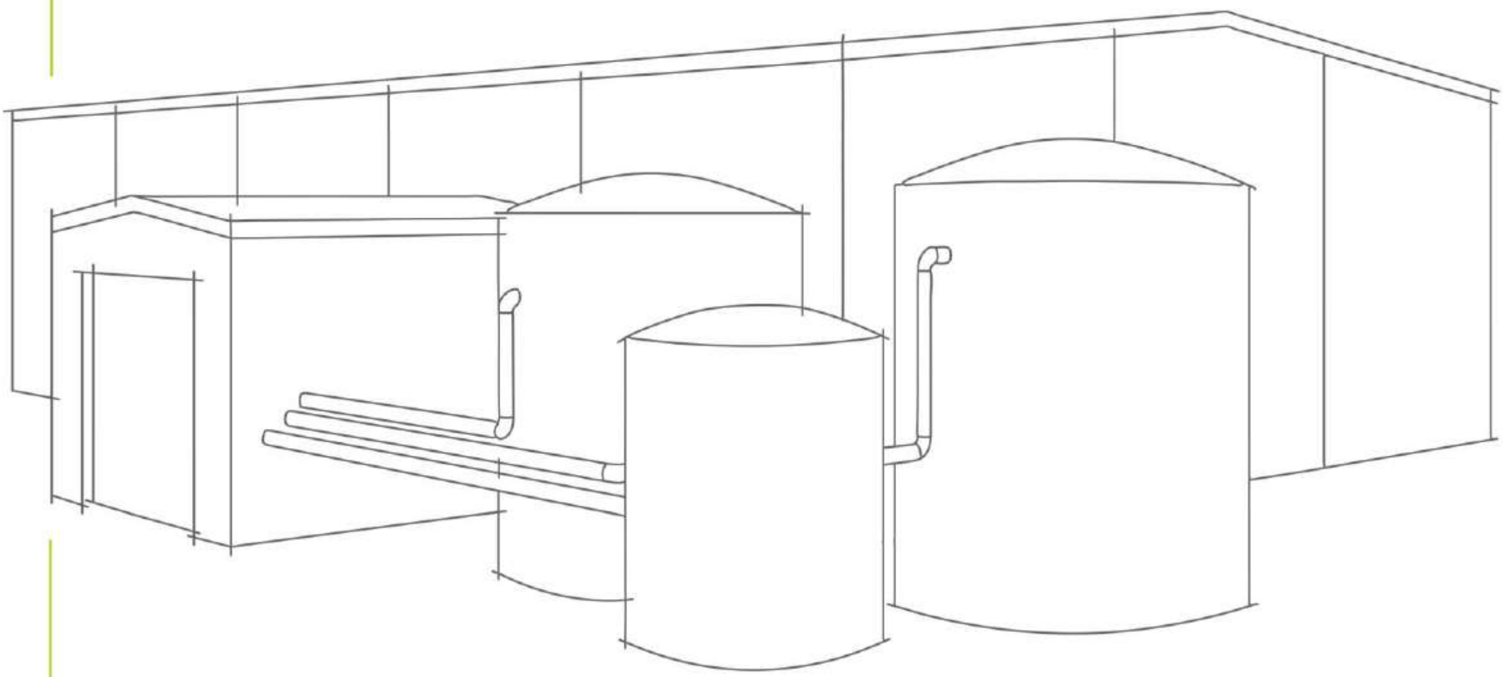
WHITEPAPER

LOW EMISSION VEHICLES - AN AUSTRALIAN PERSPECTIVE PART 3



Project Group

CREATE · PLAN · DELIVER

PROJECT MANAGERS | PLANNERS | DESIGNERS | ENGINEERS

WHITEPAPER

Low Emission Vehicles - An Australian Perspective Part 3

Sustainable Liquid Fuels - The Transition from Liquid Fossil Fuels

TFA CONTACT: Keith Sharp
keith.sharp@tfa.com.au
Mob: 0417 712 706

Document Control

REVISION	DATE	PREPARED BY	REVIEWED BY	COMMENTS
B	23-Aug-23	L.Ponton	K.Sharp	For Internal / External Use
A	13-July-23	L.Ponton	K.Sharp	For Internal / External Use

TABLE OF CONTENTS

FIGURES

AT A GLANCE

- This paper explores the feasibility of transitioning from fossil fuels to sustainable liquid fuels that can be distributed and used in existing infrastructure and vehicles.
- Hydrogen and electric vehicles are unlikely to achieve net zero by 2050 in the transport sector. Some sectors such as road vehicles depend on consumers bearing the cost of purchasing much more expensive vehicles as well as the long-term transition to renewable electricity generation and recharging infrastructure. Using hydrogen and electric vehicles for sectors such as aviation and marine is considered less viable.
- Renewable petrol, diesel (RD) and sustainable aviation fuel (SAF) can be generated from a diverse range of renewable feedstocks such as waste and biomass (vegetable oil, fat, agricultural residues, municipal solid waste [MSW] etc.), as well as carbon dioxide (CO_2) emissions from industry and carbon dioxide stored within the atmosphere today. By utilising renewable hydrogen and renewable electricity, the emissions associated with the fuel production can be significantly reduced.
- Similar greenhouse gas reductions can be achieved with renewable fuels to those achieved via electric vehicles running on renewable electricity or fuel cell vehicles operating on renewable hydrogen.
- Australia currently possesses ample renewable feedstocks to produce sufficient sustainable liquid fuels to meet the projected 2050 future demand for all liquid transport fuels.
- There are additional opportunities to further expand biofuel production for export utilising crops that are suitable for planting on non-arable land and algae.

1.0 INTRODUCTION

This white paper builds upon the two-part series previously published by TfA Project Group (TfA), which examined the existing landscape of electric and hydrogen-powered vehicle technology in Australia.

Part 1 identified that electric vehicles sales are growing and likely to dominate the passenger vehicle fleet by 2050.

Part 2 discussed hydrogen which has many applications and great potential. However, Australia's hydrogen industry today is not green. Approximately 530,000 tonnes per annum of grey hydrogen is produced for industry via steam methane reforming which alone generates millions of tonnes of CO_2 per annum. This creates a dilemma for the generation of new green hydrogen to be used for alternate purposes when it would appear logical to replace existing grey hydrogen first. Progress in the application of hydrogen for transport has been slow to date. Five years on from the release of Australia hydrogen roadmap there are very few hydrogen cars on the road and only a few refuelling facilities installed. Notably modelling in Europe recently identified that FCEVs are not expected to reach more than 10% market share in trucks before 2050 [1]. It appears likely that hydrogen in transport is likely to be long term at best and is considered unlikely to have a significant impact by 2050.

So the key issue is addressing transport emissions in Australia between now and 2050.

Notably, the rest of the world has embraced biofuels which provide 3.6% of the world liquid fuels market. There are effective mandates in over 60 countries, 175 billion litres (BL) of production per year and hundreds of plants in operation [2]. Whilst the IEA Net Zero by 2050 Roadmap predicts the continued expansion of biofuels through to and beyond 2050, the industry has stalled in Australia with a widespread perception that we do not have sufficient renewable feedstocks to support the effective replacement liquid fossil fuels. For the purpose of this paper, we will refer to biofuels and e-fuels produced from renewable resources as sustainable liquid fuels.

Part 3 of this series aims to provide a comprehensive overview of Australia's potential and capability in supplying sufficient feedstock for the production of sustainable liquid fuels to replace existing fossil fuels. This serves as a crucial step towards facilitating Australia's transition away from fossil fuel-based liquid fuels in the transportation sector.

2.0 LIQUID FUEL DEMAND IN THE TRANSPORTATION SECTOR

Transportation is a significant contributor to carbon emissions in Australia, accounting for 19% of national emissions and currently predicted to increase to 26% by 2035 [3] [4]. While it is essential to decarbonise the transport sector swiftly, the task of replacing or upgrading trucks, trains, cargo ships, and planes is complex and costly compared to electrifying passenger cars and light commercial vehicles which contribute to 60% of total transport emissions [5].

In Australia, several states and territories have set ambitious goals, aiming to achieve 100% of new passenger vehicle sales as zero emission vehicles by the 2030's [5]. However, this is ambitious and will not result in the overnight conversion of the Australia passenger car fleet. In 2022, only 3.1% of new vehicle sales [6] were electric vehicles. This is still significant given consumers are bearing the cost of paying to a significant premium above the cost of a conventional comparable vehicle. The Australian Electric Vehicle Market Study [7] predicts 50-60% of the Australian passenger car fleet will be electric by 2040 and 90-95% by 2050. Subsequently, petrol sales will not disappear quickly and renewable liquid fuel alternatives for petrol will be required over the long term. Ernst and Young predict we sill still need 5-10 billion litres per annum of petrol in 2050.

The application of electric and hydrogen fuel cell engines for truck, rail, maritime, and aviation transport is limited, making it challenging to fully decarbonise. Electrification of aviation and shipping is not technically viable today and biofuels are the only commercially ready potential alternative. Considering the relatively modest fuel requirements of the maritime and aviation sectors and the implementation of other decarbonisation strategies in the future, the overall demand for diesel, jet fuel, and bunker fuel in 2050 is projected to be similar to or slightly lower than the current levels across various scenarios, as depicted in Figure 1. It is likely that a potential biofuel demand of 30-40 BL per annum will be required to replace fossil-based liquid fuels by 2050 subject to government policy and the rate of technology advancement and adoption.

Numerous international governments have established emissions reduction targets, and these mandates drive the need for low-emission alternatives in the transportation sector. For instance, in the European Union (EU), fuel suppliers are required to ensure that sustainable aviation fuel (SAF) sales reach 2% by 2025, increasing to 6% by 2030, 20% by 2035, and ultimately aiming for 70% by 2050 [8].

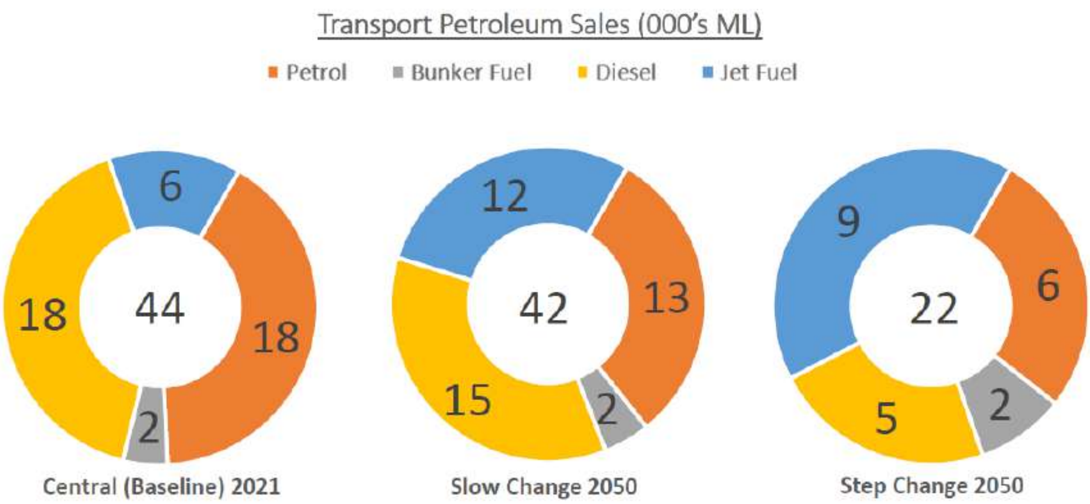


Figure 1: Estimated transport liquid fuel demand from 2021 to 2050 (approximate) [9]

To achieve the overarching net-zero emissions target, it becomes imperative to develop low-emission renewable liquid fuel substitutes for petrol, and in particular diesel and jet fuel where there will be a long-term demand in industries where electrification is more challenging.

3.0 BIOFUEL TECHNOLOGIES

Over the last 15 years, the range of viable technologies to produce sustainable liquid fuels has expanded significantly.

3.1 CONVENTIONAL BIOFUELS

Conventional biofuels, known as first-generation (1G) biofuels, are primarily sourced from feedstocks associated with the human food chain. This includes biodiesel from vegetable oils, animal fats, and ethanol derived from sugar or starch [3]. Notably, 1G ethanol can still be sustainable without affecting the food chain in Australia. For example, Manildra produce ethanol from waste starch from their flour and gluten plant and Wilmar utilise low grade molasses C. The use of grains used for cattle feed can also be sustainable, by only utilising the starch component which has low nutritional value and producing a high protein and fibre feed which is highly valued by feedlots.

These biofuels typically have higher levels of oxygen and moisture content compared to traditional fuels and are commonly used as a blend with petroleum-based fuels.

3.2 ADVANCED SUSTAINABLE LIQUID FUELS

Advanced biofuels, comprising second, third, and fourth generation biofuels, are derived from non-food feedstocks. Typical feedstocks for advanced biofuels consist of cellulose-rich materials like agricultural residues such as wheat straw, stover and bagasse, and various waste streams such as municipal solid waste. Carbon monoxide (CO) and carbon dioxide (CO_2) can now also be used as a feedstock for biofuels, either captured as direct emissions from industry or via direct air capture (DAC).

The significant advantage of advanced biofuels lies in their compatibility with existing fuel infrastructure, allowing for seamless displacement of conventional fossil-based fuels. Due to the diversity of the feedstock, advanced biofuels can be produced via various pathways.

3.2.1 HEFA

Most of the 6 billion litres (BL) per annum of renewable diesel (RD) and SAF today are primarily produced via the hydro processed esters and fatty acids (HEFA) process. The main feedstock for this process is vegetable oils, tallow, used cooking oil and fats. Both Ampol and BP in Australia are currently performing feasibility studies on the implementation of this technology in their refineries. One of the challenges of this technology is the availability of feedstocks for expansion.

Figure 2: Neste Singapore HEFA Plant

3.2.2 Fischer Tropsch

The Fischer-Tropsch (FT) process is currently in use by Fulcrum in Sierra, Nevada USA to process syngas from gasified municipal solid waste (MSW) into synthetic crude oil that can be co-processed into renewable diesel and jet fuel in a conventional refinery.

US company Twelve, formerly known as Opus 12, a recognized world leader in CO_2 electrocatalysis, has further developed their carbon transformation technology. After working with Lanzajet to convert CO_2 into carbon monoxide for gas fermentation, they have adapted FT to produce e-jet sustainable aviation jet fuel directly from carbon dioxide and water with 90% lower lifecycle emissions compared to conventional fossil-based fuels.

3.2.3 HTL

Australian company Licella pioneered catalytic hydrothermal liquefaction (HTL) of biomass and MSW into synthetic crude oil that can be processed in conventional refineries. This provides a key sustainable alternative to produce conventional fuels and the many non-fuel products that are produced from crude oil. Licella are constructing a plant in Canada with Canfor utilising wood residues to be processed in the adjacent conventional oil refinery.

3.2.4 Gas Fermentation

LanzaTech has developed the production of ethanol from industrial waste gas emissions from existing manufacturing plants such as CO_2 and CO via gas fermentation which has a CO_2 conversation rate of around 60% [10]. LanzaTech have three existing plants in China converting steel mill emissions into ethanol. This technology also has the potential to increase the production of conventional ethanol plants by approximately 50%.

The application of this technology has now been extended to process syngas from the gasification of waste biomass and MSW.

3.2.5 Lignocellulosic

This process uses enzymes or acids to break down cellulosic material in waste biomass such as straw, stover and bagasse into C5 and C6 sugars that can be processed via conventional fermentation. The production of C5 sugars requires the development of custom yeast strains. The process has been under development at commercial scale for over ten years. Whilst successful at pilot scale, commercial plants have struggled to scale up the process. Most recently Praj appear to have had success at commercial scale with the IOCL 30 ML per annum plant at Panipat Haryana, India constructed in 2022.

Figure 3: Praj IOCL 2G ethanol bio-refinery, Panipat Haryana, India

3.2.6 AtJ

Gevo, Biogy and LanzaJet, a subsidiary of LanzaTech, have been developing an alternate scalable method of manufacturing renewable diesel and sustainable aviation fuel known as the Alcohol to Jet (AtJ) process which uses renewable ethanol as a feedstock [11]. This process uses a combination of proven processes that are widely used in the oil industry and has the potential to make ethanol the crude oil of the future as this process can also produce ethylene as a feedstock for the plastics industry. Several demonstration plants are in operation and the first commercial plant has recently been constructed at Freedom Pines, Georgia, USA by Lanzajet. Several more are currently under development. TfA are currently engaged on the feasibility study for the Jet Zero project proposed for Queensland.

3.2.7 E-FUELS

E-fuels, otherwise known as power to liquids, are another low-emission fuel option that can generate renewable petrol for existing vehicles. They are made by combining CO_2 with renewable hydrogen, utilising renewable electricity in the process. An overview of the E-fuel production process is shown in Figure 4. Depending on the specific production process, E-fuels have the potential to be carbon-neutral or even carbon-negative when compared to synthetic fuels derived from natural gas, when considering the Well-to-Wheel (WTW) emissions [12].

HIF Global have built the first E-Fuels demonstration plant in the world in Chile processing CO_2 and hydrogen from electrolysis using wind power to produce 350 tonnes per annum of e-methanol and 130kL per annum of e-gasoline [13]. They are working on a proposed 700 ML per annum plant in the USA which is currently in FEED phase. HIF Global have announced a proposed Australian plant to be built in Burnie, Tasmania with a capacity of 100 million litres (ML) per annum of e-fuels recycling 260,000 tonnes of CO_2 per annum [14]. This equates to processing 3.5 tonnes of CO_2 per tonne of e-fuel.

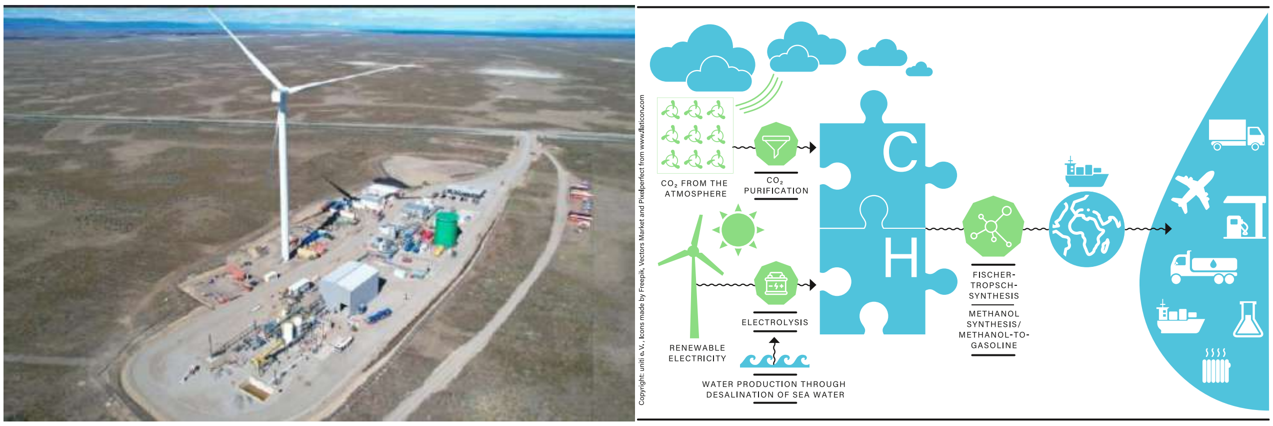


Figure 4: HIF Chile plant and E-Fuel Production Process [15]

3.2.8 Emerging Technologies

There are still more technologies under development such as pyrolysis and the Mercurius REACH process supported by QUT with a demonstration plant at Mackay.

4.0 LIFE CYCLE ANALYSIS

The life cycle greenhouse gas (GHG) emissions of biofuels and E-fuels can vary greatly depending on factors such as the source of electricity, the origin of the feedstock, and the specific production process. In the case of E-fuels, the production process can be energy-intensive, especially when utilising DAC, CO_2 and hydrogen from electrolysis. Therefore, the choice between renewable electricity and fossil fuel electricity plays a crucial role in determining the overall GHG emissions associated with E-fuel production. It is also important to consider the carbon emissions related to the production of feedstock crops. This includes the energy used for farm collection, fertilisers applied, water consumption, transport, and other related processes. These aspects contribute to the overall carbon footprint of biofuels and E-fuels throughout their life cycle.

One of the key challenges is to make progress quickly. Realistically, not everything has to be net zero to make a significant impact on reducing emissions. The European Union has set targets that renewable technologies must achieve a minimum of 60% lower emissions than the fossil fuel equivalent.

In general, biofuels demonstrate significantly lower life cycle GHG emissions compared to fossil-based fuels, as depicted in Figure 5. However, it is worth noting that first generation technologies are not as effective as subsequent generations in reducing life cycle GHG emissions .

Many of the technologies described above make substantial reductions close to net zero.

- Gas fermentation can achieve 67% utilising steel mill furnace gas emissions and up to 98% with gasified biomass such as crop stover and straw or forest residues [16].
- Cellulosic technologies use waste biomass can achieve 93%.
- FT processing of gasified MSW to produce renewable diesel can achieve 593% [17].
- HTL processing of wood residues can achieve up to 82% [18].

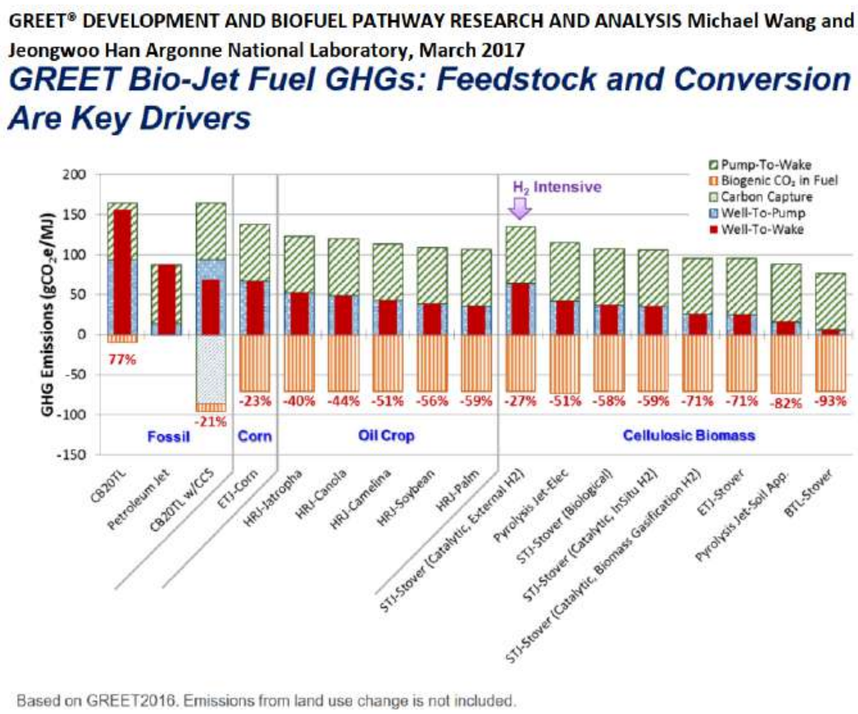


Figure 5: GREET® Development and Biofuel Pathway Research and Analysis [19]

5.0 OPPORTUNITY TO MANUFACTURE SUSTAINABLE LIQUID FUELS IN AUSTRALIA

There are now many pathways to manufacture liquid biofuels. The best path for Australian Industry depends on both the resources available and the processing cost. Presently, only 1G biodiesel and bioethanol have commercial examples within Australia. Manildra and Wilmar produce both fuel-grade and higher-value ethanol in the order of 360 million litres (ML) per annum. There are also three biodiesel production facilities operating in Australia, which use tallow and used cooking oil as their feedstock produced approximately 15 ML per annum of biodiesel in 2022 [20].

Whilst several biofuels projects are currently progressing through feasibility, the establishment of a strong biofuels industry in Australia will rely on the establishment of government incentives and policy comparable to that in the USA and Europe.
Given Australia's land mass and large agricultural industry, it is interesting to note that, at face value, many other countries are accelerating the production of biofuels, whilst there is a popular belief in Australia that we do not have the feedstocks to support biofuels.

5.1 FEEDSTOCKS

Many studies and comments have focused on a single source of feedstock such as conventional crops or biomass, however today the options are much broader.

5.1.1 Conventional Biofuel Feedstock

Australia is one of the most food secure nations, with a significant portion of its agricultural products being exported. For instance, 86% of the sugar, 71 % of the wheat, and 72% of the canola produced in Australia are exported [21].

Most of Australia's sugar production takes place in Queensland, and sugar milling is one of Australia's largest rural industries. However, the sugar market faces tough international competition, particularly from countries like Brazil, India, and China, resulting in low sale prices for sugar. Consequently, many sugar mills in Queensland have been forced to shut down. The utilisation of surplus sugar production for biofuel production presents a potential opportunity to address this challenge.

Whilst canola is considered a food crop, which is quickly frowned upon as a biofuel feedstock, 60% [21] of the 1.8 million tonnes (Mt) of canola exported to the European Union is currently utilised for biodiesel production. Interestingly there is little comment on land use considerations when Canola is exported for biofuel use, but it is one of the first comments if one is to suggest its use for this purpose in Australia. At typical production rates, this represents approximately 720,000 hectares [22] of land dedicated to biofuels feedstocks for the benefit of Europe.

Beef tallow used to be considered a waste product and was used to support the development of eight biodiesel plants in Australia. However, international biofuel policy has resulted in the value of tallow doubling, making it unaffordable for Australia plants. Only 1.4% of the 510,000 t/year produced is utilised for domestic biodiesel production with the rest exported for biodiesel production abroad.

We estimate reallocation of these feedstocks to Australian biofuel production could potentially generate up to 1.5 BL per annum of renewable diesel and SAF.

5.1.2 Advanced Biofuel Feedstocks

According to estimates by CSIRO, Australia has significant biomass resources for bioenergy production, predicted to reach approximately 80 Mt/year by 2030 [23]. These include crop stubble, grasses, wood residues, sugar cane bagasse and organic MSW. Today, many farmers burn wheat straw residues in the field. These waste residues can be processed via a number of technologies with a potential yield of up to 14 BL of renewable diesel and SAF per annum based on typical published yields.

Figure 6: Wheat straw, sugar cane bagasse, wood residues

A potential non-food oil seed feedstock for HEFA plants is Brassica Carinata which can be used as a break crop for Canola and similar crops. BP have an agreement in place with Nuseed for the use of this crop in Australia.
GHG emissions such as carbon monoxide and carbon dioxide are now potential feedstock for biofuels production, with commercial plants already in operation. Sources include emissions from industry, transport and manufacturing or the carbon dioxide already in the atmosphere. Both are plentiful.

Australia was reported to have produced 526 Mt CO_2 equivalent in 2022 [24], adjusted to a net of 487 Mt in Figure 7 to account for offset reductions due to land use change and forestry. Notably 68% of these emissions are in the form of CO_2 with much of the remainder being methane. A substantial proportion of methane is released as leaks into the atmosphere, known as fugitive emissions, from coal mines (62%) and LNG plants(22%).

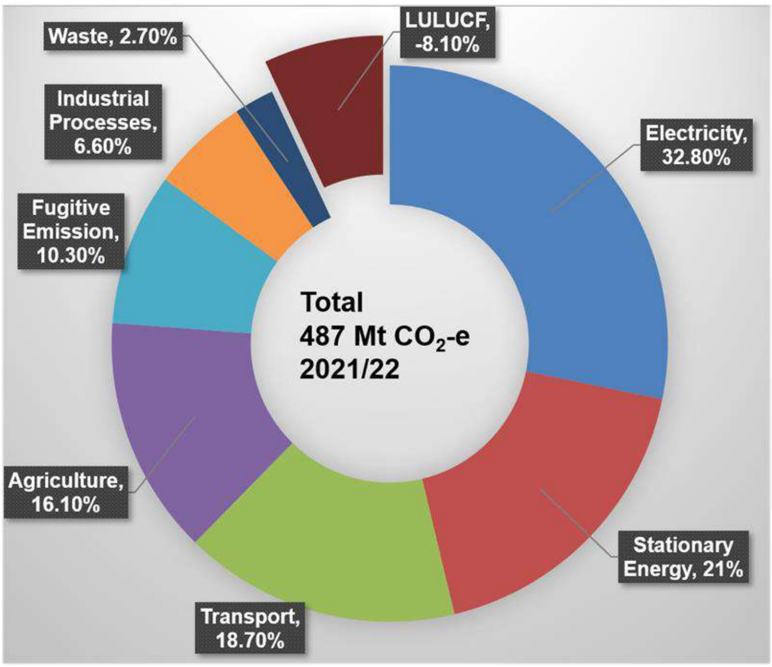


Figure 7: Share of total emissions by sector, for the year to March 2022 [25]

Australia's Safeguard Mechanism applies to industrial facilities emitting more than 100,000 tonnes of carbon dioxide equivalent (CO2-e) per annum. There are 219 Safeguard facilities, across the mining, manufacturing, transport, oil, gas and waste sectors that must report their emissions [26]. Collectively they produce around 28% of Australia's greenhouse gas emissions [27]. Under the mechanism, they will be required to reduce emissions by 4.9% per annum to 2030.

Some facilities such as the Gorgon LNG project on Barrow Island, (WA) already capture CO_2 via CCS for underground injection and permanent storage. Notably CCS is very expensive and has an ongoing cost with no return on investment. Additionally not all CCS projects have met performance expectations. Converting emissions into renewable liquid fuels offers an alternate method for existing industries to mitigate emissions and generate an income stream.

We have considered a conservative scenario excluding fugitive emissions, mining, and transport operations. Focusing only on major industrial plants such as LNG, aluminium, steel mills, ammonia, cement and refining where emissions are likely to be more concentrated, there is a potential of 70 Mt of CO_2 emissions per annum. This represents approximately 50% of CO_2 emissions from plants subject to the Safeguard Mechanism or 13% of our total emissions. On this basis, up to 24.5 BL of renewable diesel and SAF could be produced from these emissions.

A secondary already purified stream of CO_2 is also generated from ethanol plants using liquid fermentation from either first generation or second generation lignocellulosic feedstocks. Processing the CO_2 emissions would facilitate a further increase in production of ethanol by 50%. This is estimated to potentially produce up to a further 6.4 BL of renewable diesel and SAF.

Several E-fuels plants processing CO_2 via direct air capture from the atmosphere are currently being developed. DAC is also being installed at the existing HIF Global Chile E-fuels plant. The proposed HIF Global plant for Tasmania has a planned production of 0.1 BL per annum. This sector is virtually unlimited for feedstock in its expansion capacity, however it is energy intensive and requires a source of renewable electricity.

5.1.3 Potential Feedstocks

So far, all the options discussed are based on existing land usage in Australia. However Australia has one of the largest areas of any country with 768 million hectares of land. We have extraordinary food security, utilising only 4% of our land for crops whilst still exporting 71% of all agricultural production.

Given the limitations imposed by temperature and precipitation, only a small percentage of the country's land is suitable for conventional crop production. Over 45% of Australia is allocated as grazing native vegetation. Much of this land is non-arable and infested with weeds such as woody weed. A feasibility study is currently in progress to identify the potential to utilise woody weeds as a biofuel feedstock as a means of control.

Crops such as Pongamia and Agave offer a unique opportunity as they can thrive in high heat and drought conditions, allowing them to be cultivated on traditionally infertile land. The sugar and biomass found in the agave plant and the oil derived from Pongamia seeds can be utilised as a feedstock for biofuel production.

Pongamia can yield 9 T/ha of oil seed with an oil yield of 3,600 L/ha/yr [28]. In context it is estimated planting Pongamia on 1% of Australia's land area (2.2% of the current area allocated as grazing native vegetation) could yield 23 BL/year of RD and SAF.

Figure 8: Pongamia trees and Agave Plants

Agave is a drought tolerant plant that outperforms current first generation biofuel crops in water-related impacts, including Freshwater Eutrophication (96% lower than corn and 88% lower than sugarcane), Marine Ecotoxicity (59% lower than corn and 53% lower than sugarcane) and Water Consumption (46% lower than corn and 69% lower than sugarcane). It is widely grown in Mexico to produce Tequila. In recent years MSF Sugar planted 50,000 agave plants on the Atherton Tablelands. Trials have demonstrated that it can achieve an impressive ethanol yield of 7,414 L/ha/year [29]. In context it is estimated planting Agave on 1% of Australia's land area (2.2% of the current area allocated as grazing native vegetation) could yield 31 BL/year of RD and SAF.

One of the most productive feedstocks for biofuel production is microalgae. They offer several advantages over traditional crops, such as rapid growth and significantly higher oil yield per unit of land used. The oil derived from microalgae can be readily utilised for biofuel production. Notably, microalgae as a biofuel feedstock have been found to have one of the lowest ecological footprints, making them an environmentally sustainable option [30].

Microalgae company Algenol has successfully achieved a microalgae yield of 9.1 g/m^2/day [31]. Based on this yield, it is projected 1% of Australia's land area (2.2% of the current area allocated as grazing native vegetation) could yield 220 BL/year of RD and SAF.

Harvesting algae is currently much more expensive than other options, however this highlights the extraordinary potential of microalgae as a biofuel feedstock, as it allows for the production of substantial quantities of RD and SAF while utilizing a relatively small fraction of the existing land resources.

6.0 CHALLENGES

The following challenges are present for large scale commercialisation of biofuels in Australia:

Overseas Biofuels Policies and Incentives

- Government incentives play a crucial role in the successful commercialisation of biofuel projects. Currently it is more attractive for Australian farmers to export feedstocks overseas to support biofuels in the USA and Europe than for their use for biofuels production in Australia. The Australian government needs to put in place comparative policies that are competitive.

Logistics

- While lignocellulosic biomass feedstocks are abundant, plants need to be located regionally close to the feedstock to minimise logistical costs for collection and transportation to production facilities.

Technology Readiness

- The technologies for some advanced biofuel technologies such as E-fuels are still in their early stages at small scale. Larger plants at commercial scale are required to satisfy investors in order to widely expand their use and commercialisation.

Microalgae Production is Expensive

- Microalgae has by far the highest yield and lowest land utilisation. However further research is required to reduce the cost of harvesting and extracting algae oil.

Carbon Capture Using Direct Air Capture is Expensive

- The utilisation of renewable H_2 and CO_2 from direct air capture (DAC) significantly increases the cost of biofuel production. It is much more economic to collocate with an existing industrial source of concentrated CO_2 emissions.

7.0 DISCUSSION

Sustainable liquid fuels offer a viable alternative to fossil-based fuels and can play a significant role in helping Australia achieve its net zero emissions target. They also contribute to energy security, reducing the country's reliance on imported liquid fuels in both the short and long term.

The transition to sustainable liquid fuels presents a cost-effective solution compared to switching to electric or hydrogen-powered fleets. One key advantage is their compatibility with existing fuel infrastructure, which significantly reduces the need for costly infrastructure modifications. Moreover, unlike the production of lithium batteries and hydrogen electrolysers, the production of biofuels and E-fuels offers an advantage by not relying on precious metals and rare earth minerals, which are limited in availability and facing supply challenges. Additionally, existing refinery infrastructure can be repurposed for sustainable liquid fuels production, utilising the already established facilities. These enable a smoother and more affordable transition, making sustainable liquid fuels an attractive option for meeting sustainable energy needs while minimising the overall investment required.

Several private companies have already expressed their interest in expanding the sustainable liquid fuels industry in Australia, showcasing the growing momentum in this sector:

- Qantas and Airbus have partnered to invest in a sustainable liquid fuels production facility in Queensland. This facility aims to produce up to 100 ML/year of SAF and RD using bioethanol and renewable energy sources.

- Renewable.bio is investigating a new facility in Western Australia. This facility will utilise renewable residue feedstocks to produce renewable ethanol, RD, and SAF. It is proposed to begin operations by 2026.
- The Burnett-Mary Regional Group has plans to utilise Pongamia seed oil to produce SAF. Production is proposed to commence in 2029.
- BP's Kwinana energy hub is performing a feasibility study on a HEFA SAF and renewable diesel plant.
- Ampol is partnering with Eneos to perform a feasibility study for a HEFA SAF and renewable diesel plant at the Lytton refinery.

Although sustainable liquid fuels currently face challenges in terms of cost competitiveness compared to fossil-based fuels, it is important to consider the limitations and high costs associated with other low-emission fuel alternatives for transportation, such as battery-powered electric vehicles (EVs) and renewable hydrogen. As discussed above, both EVs and hydrogen fuel cell vehicles require substantial investments in new vehicles and infrastructure to support widespread adoption. Additionally, the cost of renewable hydrogen production and distribution is significant. In contrast, biofuel technologies, as well as some E-fuel technologies, have reached a level of maturity and can be readily integrated into existing industrial practices.

One of the main hurdles for sustainable liquid fuels is the production cost, which can be attributed to the lack of sufficient government support when compared to EVs and renewable hydrogen. Australian sustainable liquid fuels policy lags well behind the USA and Europe where effective policies have resulted in large viable industries.

However, with adequate policy support, Australia has the potential to meet its entire liquid fuel demand by utilising its current waste resources alone. Furthermore, any gaps in fuel demands can be filled by utilising feedstocks like carbon dioxide, Pongamia and microalgae.

8.0 CONCLUSION

This paper examines the potential production of sustainable liquid fuels using diverse available and potential feedstocks within Australia.

The overall conclusion is that Australia possesses an ample supply of feedstocks to meet the nation's entire liquid fuel requirements through sustainable liquid fuels production without any significant change in land use.

In addition:

- Direct air capture combined with renewable power can produce virtually unlimited additional sustainable liquid fuels.
- If only 1% of Australia’s land area (45% of which is currently classified as grazing native vegetation land) was to be utilised for feedstocks such as Agave, Pongamia or Algae, we estimate Australia could potentially export 30-200 BL pa of sustainable liquid fuels.

However, to encourage the widespread adoption of sustainable liquid fuels, increased government support is necessary. The USA and Europe have well developed policies that have created over 300 sustainable liquid fuels plants, which has resulted in Australia exporting large quantities of biofuel feedstocks overseas for processing.

Australia needs to establish similar policies to drive the development of a local industry to support our own economic development, GHG emissions reduction and fuel security.

Considering these factors, sustainable liquid fuels should be recognised as achievable and sustainable options for low-emission transportation fuels.

9.0 ABOUT TFA

TfA Project Group is a national design and engineering consultancy which has been in operation for close to 30 years, specialising in the liquid fuel and energy industry and which has been involved in renewable energy projects since the early 2000s. TfA has been a leading consultancy on many key renewable energy and biofuels projects including Australia's first grain to ethanol facility (Dalby Bio-refinery) developed in 2007 and more recently, on two of Australia's first scalable truck hydrogen refuelling facilities in Victoria. TfA is actively engaged as the lead engineer on the current Jet Zero feasibility study for what will be Australia's first Sustainable Aviation Fuel (SAF) facility.

With multiple technologies available to produce sustainable liquid fuels from the same feedstock, TfA's industry expertise can assist you to evaluate and compare technologies and establish the feasibility of your project. For a confidential discussion, contact keith.sharp@tfa.com.au.

10.0 REFERENCES

[1] The International Transport Forum, “Decarbonising Europe’s Trucks How to Minimise Cost Uncertainty,” ITF OECD, Paris, 2022.

[2] IEA, “Biofuel production by country/region and fuel type, 2016-2022,” 11 May 2021. [Online]. Available: https://www.iea.org/data-and-statistics/charts/biofuel-production-by-country-region-and-fuel-type-2016-2022. [Accessed 24 June 2023].

[3] GHD, “Biofuels and Transport: An Australian opportunity,” ARENA and CEFC, 2019.

[4] DEECCW, “Australia’s emissions projections 2022,” Commonwealth of Australia, Dec 2022.

[5] Australian Government, “National Electric Vehicle Strategy,” 2023. [Online]. Available: https://www.dcceew.gov.au/sites/default/files/documents/national-electric-vehicle-strategy.pdf.

[6] Federal Chamber of Automtive Industries, “FCAI releases 2022 new car sales data,” 5 January 2023. [Online]. Available: https://www.fcai.com.au/news/index/view/news/787. [Accessed 22 June 2023].

[7] Energia, “Australian Electric Vehicle Market Study,” Energia, May 2018.

[8] K. Abnett, S. Kar-Gupta and J. Plucinska, “EU agrees binding green fuel targets for aviation,” Reuters, 26 April 2023. [Online]. Available: https://www.reuters.com/business/sustainable-business/eu-council-european-parliament-reach-provisional-deal-decarbonising-aviation-2023-04-25/.

[9] E. &. Young, “Stakeholder Presentation of Domestic Opportunities for Future Fuels Modelling for DISER,” Dec 2022.

[10] CCU News, “Commercial CCU Plant using LanzaTech Technology Receives RSB Advanced Products Certification,” 11 02 2021. [Online]. Available: https://ccu-news.info/commercial-ccu-plant-using-lanzatech-technology-receives-rsb-advanced-products-certification/. [Accessed 2023].

[11] Deloitte, “Transitioning Australia's Liquid Fuel Sector: The Role of Renewable Fuels,” 2022.

[12] G. Zang, P. Sun, A. Elgowainy, A. Bafana and M. Wang, “Life Cycle Analysis of Electrofuels: Fischer-Tropsch Fuel Production from Hydrogen and Corn Ethanol Byproduct CO2,” *Environ. Sci. Technol.,* vol. 55, no. 8, pp. 3888-3897, 2021.

[13] HIF Global, “Haru Oni Demonstration Plant,” [Online]. Available: https://hifglobal.com/location/haru-oni/. [Accessed 23 June 2023].

[14] HIF Global, “HIF Tasmania eFuels Facility,” [Online]. Available: https://hifglobal.com/region/hif-asia-pacific/. [Accessed 23 June 2023].

[15] eFuel Alliance, “What are eFuels?,” 2022. [Online]. Available: https://www.efuel-alliance.eu/efuels/what-are-efuels#:~:text=How%20are%20eFuels%20produced%3F,production%20steps%2C%20electricity%20is%20required.. [Accessed 15 June 2023].

[16] S. e. a. Handler, “Life Cycle Assessments of Ethanol Production via Gas Fermentation:Anticipated Greenhouse Gas Emissions for Cellulosic and Waste Gas Feedstocks,” *Industrial & Engineering Chenistry Research,* 2015.

[17] Lifecycles, Australia. , "Greenhouse gas and sustainability footprints of emerging biofuels for Queensland," Lifecycles, Australia. , Sept 2018.

[18] Y. N. etal, "Life-cycle assessment of transportation biofuels from hydrothermal liquefaction of forest residues in British Columbia," *Biotechnology for Biofuels,* 2018.

[19] M. W. a. J. Han, "GREET® DEVELOPMENT AND BIOFUEL PATHWAY RESEARCH AND ANALYSIS," Argonne National Laboratory, 2017.

[20] Z. Biki, "Biofuels Annual," USDA and GAIN, 2022.

[21] ABARES, "Snapshot of Australian Agriculture 2023," Australian Bureau of Agriculture and Resource Economics and Science, 2023.

[22] GRDC, "GRDC Grownotes - Canola," GRDC, August 2015.

[23] D. Crawford, M. O'Connor, T. Jovanovic, A. Herr, R. Raison, D. O'Connell and B. Tim, "A spatial assessment of potential biomass for bioenergy in Australia in 2010, and possible expansion by 2030 and 2050," *GCB Bioenergy,* vol. 8, no. 4, pp. 707-722, 2015.

[24] Department o Climate Change, Energy, the Environment and Water, "Australia's greenhouse gas emissions: March 2022 quarterly update," Austarlian Government, 31 Augest 2022. [Online]. Available: https://www.dcceew.gov.au/about/news/australias-greenhouse-gas-emissions-march-2022-quarterly-update. [Accessed June 2023].

[25] Department of Climate Change, Energy, the Environment and Water, "Quarterly Update of Australia's National Greenhouse Gas Inventory: March 2022," Augest 2022. [Online]. Available: https://www.dcceew.gov.au/sites/default/files/documents/nggi-quarterly-update-march-2022.pdf.

[26] Clean Energy Regulator, "Safeguard facility reported emissions 2021-22," Australian Government, 31 March 2023. [Online]. Available: https://www.cleanenergyregulator.gov.au/NGER/The-safeguard-mechanism/safeguard-data/safeguard-facility-reported-emissions/safeguard-facility-reported-emissions-2021-22. [Accessed 11 July 2023].

[27] Department of Climate Change, Energy, the Environment and Water, "Safeguard Mechanism Reforms," May 2023. [Online]. Available: https://www.dcceew.gov.au/sites/default/files/documents/safeguard-mechanism-reforms-factsheet-2023.pdf. [Accessed 2 July 2023].

[28] Agrifutures Emerging Industries, "A technical and economic appraisal of Pongamia pinnata in northern Australia," Agrifutures Emerging Industries, August 2021. [Online]. Available: https://agrifutures.com.au/wp-content/uploads/2021/08/21-085.pdf. [Accessed 4 July 2023].

[29] X. Yan, K. R. Corbin, R. A. Burton and D. K. Tan, "Agave: A promising feedstock for biofuels in the water-energy-food environment (WEFE) nexus," *Journal of Cleaner Production,* vol. 261, 2020.

[30] N. A. Sasongko, C. Thorns, I. Sankoff, S. T. Chew and S. Bista, "Transitioning to sustainable use of biofuel in Australia," *Renewable Energy and Environmental Sustainability,* vol. 2, 2017.

[31] Viridos, "Viridos Technology," [Online]. Available: https://www.viridos.com/technology/. [Accessed 4 July 2023].

[32] H. Ababneh and B. H. Hameed, "Electrofuels as emerging new green alternative fuel: A review of recent literature," *Energy Conversion and Management,* vol. 254, 2022.

[33] ENEA and Deloitte, “Australia’s Bioenergy Roadmap: Appendix - Production Pathways,” ARENA, 2021.

[34] SOR and SYNBIO, “Renewable Fuels Pilot Plant Knowledge Sharing Report,” 2018.

[35] M. Sheather, “Biofuels: Australian farmers’ untapped resource,” NSW Farmers, October 2018. [Online]. Available: https://www.nswfarmers.org.au/NSWFA/Posts/The_Farmer/Innovation/Biofuels_Australian_farmers_untapped_resource.aspx. [Accessed 19 May 2023].

[36] atmosfair gGmbH, “atmosfair FairFuel: Power-to-Liquid kerosene production,” 2021.

[37] atmosfair, “Fairfuels,” Niedersachsisches Wasserstoff-Netzwerk, [Online]. Available: https://www.wasserstoff-niedersachsen.de/en/fairfuels/. [Accessed 2023].

[38] R. A. Lee and J.-M. Lavoie, “From first- to third-generation biofuels: Challenges of producing a commodity from a biomass of increasing complexity,” *Animal Frontiers,* vol. 3, no. 2, pp. 6-11, 2013.

[39] Australian Oilseeds Federation, “Australian Canola and the EU Biodiesel Market,” September 2022. [Online]. Available: http://www.australianoilseeds.com/__data/assets/pdf_file/0006/38571/AOF_education_factsheets-biodieselWEB20221025.pdf. [Accessed 2023].

[40] Australian Export Garins Innovation Centre, “Australian Canola,” [Online]. Available: https://aegic.org.au/wp-content/uploads/2021/03/AEGIC-Grain-Note-canola_LR.pdf.

[41] R. Seepaul, S. Kumar, J. E. Iboyi, M. Bashyal, T. L. Stansly, R. Bennett, K. J. Boote, M. J. Mulvaney, I. M. Small, S. George and D. L. Wright, “Brassica carinata: Biology and agronomy as a biofuel crop,” *GCB Bioenergy,* pp. 582-599, 2021.

[42] A. v. Herwaarden, R. Bennett, T. Potter, C. Lambrides, N. Gororo, H. Krakowski, V. Arief, W. Leveque and P. Salisbury, “The Performance and Feasibility of Carinata in Australia,” in *Agronomy Australia Conference*, Toowoomba, 2022.

[43] A. Elgowainy, J. Kelly and M. Wang, “Life Cycle Greenhouse Gas Emissions for Small Sport Utility Vehicles,” US Department f Energy, 2020.

[44] Southern Oil, “Our Refineries,” 2017. [Online]. Available: https://www.sor.com.au/what-we-do/oil-refineries/. [Accessed 15 June 2023].

[45] L. Life Cycle Associates, “Life Cycle GHG Emissions,” Life Cycle Associates, LLC, Dec 2015.

[46] Grains Research & Development Corporation, “Break Crop Benefits Fact Sheet,” March 2011. [Online]. Available: https://grdc.com.au/__data/assets/pdf_file/0022/117274/grdcfsbreakcropbenefitswestpdf.pdf.pdf. [Accessed 4 July 2023].