The Diesel Transition
Petroleum diesel alternatives for the Australian agriculture, fisheries and forestry sector

by Acclimate Partners and the Australian Farm Institute
October 2022
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Agriculture has a significant role to play in helping the country meet the Australian Government’s target of a 43% reduction in emissions by 2030, and net zero emissions by 2050. Considered one of the hard-to-abate sectors, transformative change needs to occur across agriculture, fisheries and forestry to achieve this. Concurrently, the growing global demand for food and the Australian Government’s ambitious Ag2030 vision will increase production, undoubtably leading to an increase in the sector’s energy use.

The consumption of energy across agriculture, fisheries and forestry is heavily biased to petroleum diesel fuels, and recent price volatility and diesel fuel security concerns have highlighted just how vulnerable farmers, fishers and foresters are because of this reliance. While there are many hurdles that must be overcome to enable the transition away from diesel-powered equipment, there is also significant opportunity associated with shifting to more secure and affordable energy alternatives. Transition will require a long lead time and provisions to support incumbent systems.

To help us better understand what alternative energy options are most suitable for Australian agriculture, fisheries and forestry industries, and to comprehend what is required to support this transformational change, AgriFutures Australia engaged Acclimate Partners to review how long change might take and what regulations and policies are required to ensure industries can continue to function during the transition.

Given the complexity of moving away from diesel, this report considers the services and skills required to ensure a smooth transition, and informs industry, policymakers and all levels of government about the policy settings required.

This project has involved significant regional and industry consultation, including with other diesel-reliant industries such as mining and freight. The report considers what farmers, fishers and foresters’ current and future needs are, and the intersection with the specific regions in which they operate.

While we acknowledge a national diesel transition plan requires further development, this report provides initial priority areas for consideration, and we see it as a catalyst to engaging in sector-wide discussion about the diesel transition.

This report has been produced under AgriFutures Australia’s National Rural Issues (NRI) Program. NRI focuses on thought-provoking and horizon-scanning research to inform debate and policy on issues of importance across rural industries. Most of AgriFutures Australia’s publications are available for viewing, free download or purchase online at www.agrifutures.com.au.

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Acclimate Partners works with governments, businesses and communities to enable the transformation of industries, assets and places. Acclimate Partners specialises in place-based approaches to large-scale economic diversification and transition, focusing on financial, environmental and social outcomes for all.

The Australian Farm Institute is an independent institute leading farm policy discussions for Australian agriculture. The AFI ensures a viable future for the Australian agricultural community, delivers timely analysis and insights, and promotes evidence-based policy solutions that maximise the economic and social wellbeing of our farmers.
The transition from dependence on petroleum diesel fuels will require a coordinated approach across a wide set of stakeholders and a parallel transformation of the supporting ecosystem of fuel supply chains, equipment supply chains, financial services providers, service networks and workforce skills.
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Overview

Australia’s primary producers run on diesel. Petroleum diesel fuel is the most widely used source of energy in the Australian agriculture, forestry and fisheries sector, representing 84% of total energy consumption in 2020-2021 (DCCEEW, 2022d). Its use is ingrained as a practical, efficient, multi-purpose fuel that can be stored over long periods in a range of conditions. Stationary pumps and generators, mobile tractors and harvesting machinery, fishing trawlers, and logging harvesters, skidders and loaders, today depend on petroleum diesel fuels.

Diesel engines are particularly suited to high-torque, long-duty-cycle and on-demand applications in agriculture. Carbon monoxide and hydrocarbon emissions are generally lower in diesel engines than in petrol engines; however, diesel particulate emissions pose significant health risks, increasing further with biofuels. The risk can be reduced by increasing engine combustion temperatures, but this comes at the expense of fuel efficiency and increased nitrogen oxide (NOx) formation. This trade-off is known as the ‘diesel dilemma’ (Krafi et al, 2009; Genrofs-Nijdam et al, 2013; Bungér et al, 2000; Minutillo et al, 2009).

To avoid costly disruption and stranded assets or businesses, the sector must actively plan for a transition from dependence on petroleum diesel fuels.

Governments are now stimulating investment in alternative energy infrastructure, including battery electric and hydrogen, the latter positioned as a key component of the country’s energy landscape. Decreasing the cost of hydrogen is crucial to its uptake in the agricultural, forestry and fisheries sector and investments are being made in hydrogen roads to accommodate hydrogen (CSIRO, 2022b; APA Group, 2022). The technological challenges of hydrogen distribution into regional areas are being addressed through research, including studies on how to retrofit existing petroleum pipeline infrastructure to accommodate hydrogen (CSIRO, 2022a; APA Group, 2022).

Hydrogen shows significant promise. Australian governments at the federal, state and territory levels have identified hydrogen as a key future energy technology for the country and have produced hydrogen roadmaps to enable ‘hydrogen highways’ and ‘hydrogen hubs’, which may represent appropriate places for agricultural industries to trial new fuel technologies (Hydrogen Society of Australia and Innovate Australia, 2022). The technological challenges of hydrogen distribution into regional areas are being addressed through research, including studies on how to retrofit existing petroleum pipeline infrastructure to accommodate hydrogen (CSIRO, 2022a; APA Group, 2022).

Hydrogen has one of the highest energy density values per mass, is highly versatile and can be stored in solid, liquid or gas forms. The spectrum of hydrogen production methods and the ability to retrofit existing infrastructure and carriers to incorporate hydrogen by displacing diesel renders hydrogen a key diversification opportunity. For example, breakthroughs by CSIRO and other global equipment manufacturers have the potential to enable the use of ammonia as an economical carrier for hydrogen (Bruce, 2018). As ammonia is harnessed for fertiliser use in agriculture, hydrogen may represent an essential fuel source to decarbonise the Australian agricultural sector and act as an alternative to marine diesel oil.

Battery electric solutions are advancing in the freight and mining sectors, which may have cross-benefits for agriculture, forestry and fisheries enterprises. Peak agricultural bodies are increasingly bolstering commitments to reach net zero emissions by 2050, for example the National Farmers’ Federation (National Farmers’ Federation, 2021). Concurrently, petroleum diesel fuels face increasing supply risks, rising prices and price volatility due to unstable energy markets and geopolitical tensions. A focus on reducing emissions and switching to renewable energy and fuel sources is increasingly crucial in addressing climate change risk. Rising costs, market access due to emissions accounting and fuel security issues mean the sector must now identify transformative pathways to transition from dependence on petroleum diesel fuels.

The agriculture sector will likely be a beneficiary of the advances in technology and charging infrastructure established by the freight and mining sectors given similarities in diesel fuel demand and heavy freight and mining needs. However, greater coordination and industry-supplier engagement is required.

Key findings

Australia’s agriculture, forestry and fisheries industries are almost universally affected by the need to transition from petroleum diesel to alternative energy sources. Diesel represents 84% of energy consumption of the sector (DCCEEW, 2022d). Energy-independent farming has gained momentum with the objective of transitioning agricultural enterprises to off-grid solutions, powered by renewable energy, including generating enough green hydrogen through electrolysis to replace all diesel energy consumption (Filatoff, 2021). While advances have been made, gaps remain for products that meet the on-demand, high-torque and intense duty cycle requirements of the sector. Manufacturers are responding with low and zero carbon developments in hydrogen fuel cells, battery electric, biofuel equipment and machinery. However, demand will need to be established in Australia to enable manufacturers and distributors to create supply chains in the timeframe and scale required for a smooth transition to net zero by 2050.

Hydrogen shows significant promise. Australian governments at the federal, state and territory levels have identified hydrogen as a key future energy technology for the country and have produced hydrogen roadmaps to enable ‘hydrogen highways’ and ‘hydrogen hubs’, which may represent appropriate places for agricultural industries to trial new fuel technologies (Hydrogen Society of Australia and Innovate Australia, 2022). The technological challenges of hydrogen distribution into regional areas are being addressed through research, including studies on how to retrofit existing petroleum pipeline infrastructure to accommodate hydrogen (CSIRO, 2022a; APA Group, 2022). Hydrogen has one of the highest energy density values per mass, is highly versatile and can be stored in solid, liquid or gas forms. The spectrum of hydrogen production methods and the ability to retrofit existing infrastructure and carriers to incorporate hydrogen by displacing diesel renders hydrogen a key diversification opportunity. For example, breakthroughs by CSIRO and other global equipment manufacturers have the potential to enable the use of ammonia as an economical carrier for hydrogen (Bruce, 2018). As ammonia is harnessed for fertiliser use in agriculture, hydrogen may represent an essential fuel source to decarbonise the Australian agricultural sector and act as an alternative to marine diesel oil. Battery electric solutions are advancing in the freight and mining sectors, which may have cross-benefits for agriculture and forestry machinery. The heavy freight industry is the fastest-growing market for electric vehicles (IEA, 2021a; Electric Vehicle Council, 2022a). A report in the United States has identified the heavy duty truck market will grow at a 54% compound annual growth rate to 2030 (Businesswire, 2022). In Australia, retrofitting and freight battery swap businesses have emerged to service the opportunity. For example, Janus Electrics first electric prime mover fleet is in service today with the capacity to offer vehicle-to-grid services (Janus Electrics Ltd, 2022). Mining is also engaged in the use of electric heavy moving equipment, following an initiative by the International Council on Mining and Metals (ICMM), which launched the Innovation for Cleaner, Safer Vehicles (ICSV). The initiative brought together 27 mining companies and 19 original equipment manufacturers (OEMs) with the objective of coordinating the ramp-up and transition to next generation mining vehicles. The initiative is informed through engagement with a senior advisory group that includes mining giants BHP and Anglo American, and OEMs Caterpillar, Sandvik and Komatsu (Australian Mining, 2021). The agriculture sector will likely be a beneficiary of the advances in technology and charging infrastructure established by the freight and mining sectors given similarities in diesel fuel demand and heavy freight and mining needs. However, greater coordination and industry-supplier engagement is required.

OEMs have developed battery electric tractors and other electrified farming equipment (such as crop-spraying drones). Other electrification advances include smaller autonomous battery machines now in production, disrupting the traditional scale economics of Australia’s agriculture industries. For example, by removing the constraint of an operator, one scenario is that large diesel tractors and harvesters are replaced with multiple smaller, lower-cost autonomous battery electric tractors.

The agriculture sector is both a producer and consumer of bioenergy products. Bioenergy will play an important interim role in the energy transition as internal combustion engines are phased out over time. Biogas (biomethane) has shown significant promise as an alternative to diesel, as a transition fuel and to power production and4 tractors and harvesters. For example, the New Holland T6 Methane Power tractor and Gomselmash Palesse combine harvester. New Holland claims that with the same power as the diesel equivalent, there are benefits of up to 30% lower running costs. The company also states that the T6 Methane Power tractor produces 99% less particulate matter, reducing carbon dioxide (CO2) emissions by 10% and overall emissions by 80% (New Holland Agriculture, 2016). Gomselmash claims the 350 hp methane engine saves around 50% in costs compared to a diesel engine because the fuel is cheaper and lubricant costs can be saved (Gomselmash, 2020).
Despite advances in the adoption of hydrogen electric vehicles and bioenergy, Australian farmers and primary producers are concerned about the cost and reliability of alternative energy systems. The high upfront investment to make the switch from petroleum fuel sources to other renewable alternatives, the potential low return on investment, the uncertainty of choosing the appropriate technology and the pace of change in technology present significant barriers to transitioning the sector.

Manufacturers of engines and agricultural equipment, including but not limited to John Deere, Case IH, Kubota and New Holland, are developing prototypes of alternative fuel systems. However, manufacturers are responsive to industry demand in regional areas. Hence, establishing a roadmap for the Australian diesel transition to reduce information asymmetries and enable support for the broad product application of alternative energy sources is needed. There are advances across competing technologies and while some manufacturers have backed a technology direction, others are keeping their options open across a wide range of alternative energy sources and feedstocks.

Today, early adopters in the agriculture, forestry and fisheries sector and other sectors such as road freight, have not waited for manufacturers to ‘pick winners’ and launch production-scale products. Homegrown hybrid solutions are under trial and professional retrofitting enterprises are serving the early adopter market. Investors expect a four-to-five-year transition period followed by a rapid uptake of new technologies. Such enterprises are evident in Australia for battery-electric and hydrogen fuel-cell vehicles. With high-voltage charging and solar equipment available, the initial constraints for this growing market will primarily be in local battery swap facilities, hydrogen and biogas fuel supply and supporting services ecosystems, and skills and training within regional Australia.

**Recommendations**

The transition from dependence on petroleum diesel fuels will require a coordinated, strategic and responsive approach across a wide set of stakeholders and a parallel transformation of the supporting ecosystem of fuel supply chains, equipment supply chains, financial services providers, service networks and workforce skills. While a national diesel transition plan will require additional development, the sector must consider four initial priority areas to (i) understand and map transition barriers; (ii) align incentives and integrate planning to catalyse a coordinated change; (iii) target deployment of transition technology through ecosystem pilots; and (iv) bring supporting sectors on the journey.

**Recommendation 1: Understand and map transition barriers**

- Undertake a detailed assessment of potential constraints to transition. The analysis will vary across the sector and could be conducted on a subjective industry basis and/or by geographic region.
- Consult with machinery and equipment suppliers and the sector to identify the potential supply of machinery and equipment to Australian markets.
- Evaluate the transition impacts on supply and demand of bioenergy products in Australia, including demand from difficult-to-abate industries, and consider lessons learned from previous biofuel programs.
- Undertake a regional skills mapping activity to provide an overlay between hydrogen, bioenergy and battery electric skills demand, with regional workforce profiles and training capacity. This could inform policy and training organisations in planning.
- Identify potential regulatory or private sector/corporate policy issues that may inhibit new technology adoption and transition.

**Recommendation 2: Align incentives and integrate planning and targets**

- Identify the current set of positive and negative incentives available in the energy market to transition from diesel use, including existing policies, skills and training incentives, tariffs, excise, and rebates.
- Engage peak industry groups across the relevant sectors to identify overall transition targets and work to establish ambitious sub-targets for each transition phase to 2050.
- Promote the integration of the sector targets into existing strategic investment and planning activities, such as the national and state and territory hydrogen roadmaps and the work of rural research and development corporations (RDCs), as well as incorporation into other sector-relevant industry roadmaps.
- Considering the key constraints, develop and advocate for relevant policies, regulations and incentives required by the sectors and their suppliers for transition.

**Recommendation 3: Pilot transition technologies in key places**

- Develop the governance and institutional framework to initiate and support the national rollout of a major ecosystem pilot program. To establish diesel transition ‘nucleus zones’ that can trial implementation of energy ecosystems across different energy technologies in agricultural areas.
- Identify potential ‘nucleus zones’ in different geographic areas that align with existing policies and programming, considering locations of, for example, clean hydrogen industrial hubs, special activation precincts, renewable energy zones and drought innovation hubs.
- The pilot programs should consider coverage of a broad range of agricultural activities and seek to attract the deployment of equipment, technologies and fuel supply chains to fit with established infrastructure and early coalescing of demand from producers, as well as workforce and skills availability.

**Recommendation 4: Harness the expertise of enabling sectors**

- Identify potential existing sector expertise that may be harnessed to provide training in transition skills for agriculture groups, and identify gaps and means to procure or develop capacity in critical areas.
- Undertake an assessment of key supporting sectors, such as training, financing and insurance, and map institutional stakeholders to identify which organisations need to be involved in transition planning coupled with the timing and capacity of their respective engagement.
- Work with the financial services sector to integrate the diesel transition into environmental, social and governance (ESG) frameworks and incorporate these into sustainability-linked loan products for producers.
- Identify financial services and insurance sector risks and concerns over financing or insuring assets during the transition period.
Introduction

Petroleum diesel fuel is a staple of the Australian agriculture, forestry and fisheries sector. Its use is culturally ingrained as a practical, efficient fuel that can be stored on farm for long periods and across a range of climates. Diesel also often serves many useful purposes beyond fuel, e.g., drilling fluid, removing tree stumps or as a solvent.

Diesel engines are particularly suited to high-torque applications in agriculture. Due to its compression ignition operation, compared with petrol engines the diesel engine allows significantly higher compression ratios, which offer higher torque output. Carbon monoxide and hydrocarbon emissions are generally lower in diesel engines; however, diesel particulate emissions pose significant health risks. The risk reduces by increasing engine combustion temperatures, but this comes at the expense of fuel efficiency and increased oxides of nitrogen (NOx) emissions. This trade-off, between reducing particulate emissions while increasing NOx and vice versa, is known as ‘the diesel dilemma’ (Mikalsen, 2011).

For the Australian agriculture, forestry and fisheries sector today, the diesel dilemma is wider reaching, with pressure on the sector to reduce greenhouse gas (GHG) emissions. The sector is facing pressure to reduce its GHG emissions, which, including emissions from diesel consumption in farming machinery, was 79 Mt CO₂-e in 2019 (DCCEEW, 2021a). Concurrently, petroleum diesel fuels face supply risks, higher trending prices and price volatility. Australia is particularly vulnerable to diesel supply shock given its historic non-compliance with the International Energy Agency fuel stock rule to maintain oil reserves equal to 90 days of net imports of the previous year. This has led to the introduction of the Fuel Security Act 2021 producing a regulatory framework to establish a national fuel reserve.

While emissions from diesel fuels in agriculture of 7 Mt CO₂-e contribute to approximately 9% of the sector’s emissions (DCCEEW, 2021a), reducing petroleum diesel fuel consumption and switching to renewable energy sources is an essential activity towards addressing climate risk. Furthermore, economic drivers and fuel security risks, combined with the significance of carbon footprints as a market access risk, requires the Australian agriculture, forestry and fisheries sector to identify transformative pathways and begin transitioning from dependence on petroleum diesel fuels.

Freight movements from farm to market and on-farm energy use currently rely heavily on the use of petroleum diesel fuel. With government agencies increasing investment in alternative energy infrastructure (such as charging stations for electric vehicles), and hydrogen (such as hydrogen refilling stations) becoming increasingly prominent in Australia’s future energy landscape, it is imperative to understand what these potential transition pathways entail.

The market is anticipating growth in demand for new technology engines, and startups are exploring adapting existing machinery. For example, US company Amogy has adapted a John Deere tractor to run on ammonia fuel and hydrogen fuel cells (Amogy, 2022a). Large manufacturers are also engaged. New Holland has developed its T6 tractor to run on methane gas and has developed a prototype NH2™ tractor to run on hydrogen (New Holland Agriculture, 2016). John Deere offers production electric drive train components and has developed several dedicated electric tractor models (John Deere, 2022b).

In this context, AgriFutures Australia commissioned Acclimate Partners and the Australian Farm Institute to review the agriculture, fisheries and forestry sector requirements to move from petroleum diesel to alternative energy sources for today’s diesel-intensive machinery.

Objectives

This project aimed to reveal the opportunities and practical steps to ensure a seamless transition from machinery and equipment reliant on petroleum diesel to alternatives, such as battery electric, hydrogen fuel-cell electric or biogas-powered machinery, for agriculture, forestry and fisheries producers. It also aimed to explore the changes required to policy and regulations, skills and service requirements, and supply chain infrastructure.
Introduction

The report addresses the following questions and topics:

1. Are government interventions supporting an energy transition in agriculture? Is there a need or business case for incentivising the transition to new fuels?
2. What are the advances in technologies that will allow producers to transition away from diesel on farm/at sea, and what does the trajectory look like?
3. Will these new technologies be able to be purchased and serviced in regional areas? What other considerations are needed due to the rural, regional and remote locations of farm and fishing businesses?
4. What are the advances in technologies that will allow producers to transition away from diesel on farm/at sea, and what does the trajectory look like?
5. Will there be the skills and training for people to work on alternative fuel-powered machinery/vehicles? What considerations are needed to resource the service skills? How will repair networks, spare parts, servicing and availability of fuel be rolled out?
6. What does supply availability look like during the transition away from diesel fuels, particularly in rural areas? How will the transition occur? What infrastructure will be available to service diesel vehicles during the transition to alternatives?
7. What a realistic approach to transition is, illustrating case studies of technology adoption and insights from other industries such as freight and mining where the transition away from dependence on petroleum diesel may be further advanced.

To address the research questions and topics, this report is structured in three parts. Part 1 examines the drivers of the diesel transition, addressing question 1. Part 2 examines the opportunities for transition and identifies three technology pathways of bioenergy, battery electric and hydrogen technology. This part addresses the key questions 2 and 3. Finally, part 3 examines the transition pathways, addressing questions 4 and 5. Case studies supporting topic 6 are used throughout the document.

Scope and limitations of this report

Throughout the report, the terms ‘agriculture’ and ‘the sector’ are used in their broadest economic and Australian Bureau of Statistics industry classification definitions, and are inclusive of all agriculture, fisheries and forestry industries.

This report considers the use of diesel and its alternatives across the Australian agriculture, fisheries and forestry sector, encompassing the wide variety of industries within the sector. Not all aspects of the sector in Australia could be examined, nor the full range of conditions under which agriculture operates in Australia. While fisheries have been included the full scope of marine engine systems, ports infrastructure and alternative fuels could not be included.

This project focuses on petroleum diesel alternatives for the highest energy-consuming machinery used in the sector and what transition pathways exist for agriculture, forestry and fisheries enterprises in Australia. The project does not evaluate the merits of each technology, with examples from the major manufacturers. Instead, it explores the backdrop of the regulatory, infrastructure and service needs that will underpin a transition to new alternatives, such as electric vehicles and hydrogen or biogas-powered machinery, in the context of the broader national and global energy transition.

A significant body of work has been developed over the past decade on Australia’s energy transition, including several reports on energy-independent farms and emissions reduction pathways for the agriculture sector (Climate Action, 2011; CEFC, 2019; CEFC, 2021b). It is not the purpose of this report to rearticulate approaches for improving energy efficiency of farms, nor to explicitly discuss emissions reductions.

This report does not represent an industry consultation or position on the sector’s decarbonisation pathway or net zero transition plan. The examples of manufacturers and products included in this report do not represent an exhaustive market search nor any endorsement or recommendation to purchase.
Petroleum diesel fuel is the most widely used source of energy in the Australian agriculture, forestry and fisheries sector, representing 84% of total energy consumption in 2019-2020 (DCCEEW, 2022d). Its use is ingrained as a practical, efficient, multi-purpose fuel that can be stored over long periods across a range of climates. Stationary pumps and generators, mobile tractors and harvesting machinery, fishing trawlers, and logging harvesters, skidders and loaders today depend on petroleum diesel fuels.

Globally countries are faced with issues of ensuring a secure, equitable (affordable) and sustainable energy supply, and balancing these priority areas during a global energy transition. This is known as ‘the energy trilemma’ (Byrne, 2017). In 2021, Australia was ranked 18th by the World Energy Council’s energy trilemma index, which highlights the relatively high performance in energy security and energy equity, with environmental sustainability lagging (World Energy Council, 2021).

The agriculture, forestry and fisheries sector is facing pressure to reduce its GHG emissions, which, including emissions from diesel consumption in farming machinery, totalled 79 Mt CO₂-e in 2019 (DCCEEW, 2021a). Concurrently, petroleum diesel fuels face supply risks, higher trending prices and price volatility. Australia is particularly vulnerable to diesel supply shock given its historic non-compliance with the International Energy Agency fuel stock rule to maintain oil reserves equal to 90 days of net imports of the previous year. This has led to the introduction of the Fuel Security Act 2021 producing a regulatory framework to establish a national fuel reserve.

While emissions from diesel fuels in agriculture of 7 Mt CO₂-e contribute to approximately 9% of the sector’s emissions (DCCEEW, 2021a), reducing petroleum diesel fuel consumption and switching to renewable energy sources are an essential activity towards addressing climate risk. Furthermore, economic drivers and fuel security risks, combined with the significance of carbon footprints as a market access risk, requires the Australian agriculture, forestry and fisheries sector to identify transformative pathways and begin transitioning from dependence on petroleum diesel fuels.

1.1 Use of petroleum diesel in Australian agriculture, forestry and fisheries

Today, agricultural equipment, including tractors, harvesters, sprayers, large stationary pumps, cranes, handler loaders and excavators, rely on petroleum diesel to power the intense duty cycles and high-torque applications required by the sector. Commercial fishing vessels rely on marine diesel oil, a blend of distillates and heavy fuel oil, similar to but with higher density than diesel used in land transport. Forestry industries also require diesel to operate harvesting operations of felling, extraction and processing (Figure 1).

Many producers prefer petroleum diesel for its accessibility, storage practicality and compatibility within existing operating systems.
Why does the agriculture, forestry and fisheries sector need to transition from diesel?

Petroleum diesel fuel is the sector’s most widely used source of energy, representing 84% of total energy consumption (DCCEEW, 2022d). The sector’s overall energy consumption fell during the 2017–2020 period as the sector was impacted by drought, but recovered to a point consistent with past trends in 2021. Energy use increased by more than one-third in agriculture after the breaking of drought conditions, and grew in the residential sector as the COVID-19 pandemic increased time spent at home (DCCEEW, 2022d).

Over the past decade, petroleum diesel fuel has consistently represented more than 80% of the sector’s energy consumption (Figure 2). In agriculture industries, broadacre cropping and grazing are the most reliant on diesel, with the top four consumers of diesel being the grain, beef, sheep and cotton industries (Australian Alliance for Energy Productivity, 2021; Australian Forest Products Association, 2015).

In the agriculture sector, as drought conditions receded and favourable growing conditions returned, energy use increased markedly, growing 35% in 2020–2021 to 119 petajoules, just above the levels seen three and four years ago. Dry conditions had reduced crop and livestock production in recent years and led to lower energy use. In 2020–2021, total farm production volumes grew 12%, with crop volumes growing 40% and the area of crop cultivation increasing 18%. Numbers of cattle and sheep also increased 1% and 6%, respectively (ABARES, 2022; DCCEEW, 2022d).

Generally, irrigation and harvesting activities are the most diesel-intensive agricultural activities; however, changes in farming practices such as no-tillage can reduce consumption. Crop selection and farming practices impact diesel consumption, as illustrated in Figure 3. Energy consumption for on-farm cropping activities depends on several factors, such as tillage practices, irrigation type, water source, groundwater depth and soil type. Dryland production typically consumes less fuel than irrigated systems, and no-tillage methods consume less energy per hectare than conventional tillage. Pumping water is a significant contributor (47–86%) to energy use on irrigated crops (Maraseni et al, 2015).

Figure 1. Breakdown of energy consumption in Australian agriculture, forestry and fisheries, 2020–2021 (DCCEEW, 2022d).

![Energy consumption breakdown](image1.png)

Figure 2. Total petroleum diesel consumption in Australian agriculture, forestry and fisheries, 2010–2021 (DCCEEW, 2022d).

![Diesel consumption by agricultural product and practice type](image2.png)

Figure 3. Example of diesel consumption by agricultural product, practice type and production activity (Health, 2018).
Why does the agriculture, forestry and fisheries sector need to transition from diesel?

1.2 Drivers of change

Energy policy is a challenging area for governments today. Globally, countries are faced with issues of ensuring a secure, equitable, affordable and sustainable energy supply, and balancing these priority areas during a global energy transition. This is known as the energy trilemma (Byrne, 2017). In 2021, Australia was ranked 18th by the World Energy Council’s energy trilemma index, which highlights the relatively high performance in energy security and energy equity, although environmental sustainability is lagging (World Energy Council, 2021).

Australia’s coal-fired power generation capacity has provided a reliable, low-cost energy supply at the expense of emissions, and is in transition to renewable sources of wind and solar energy combined with storage to firm the supply stability. The Australian Government has also focused on increasing petroleum fuel security, while setting renewable energy priorities of (i) optimising transition to renewable energy; (ii) commercialising clean hydrogen; (iii) supporting the transition to low-emissions metals; and (iv) decarbonising land transport (ARENA, 2020). Australia’s agriculture, forestry and fisheries sector transition is driven by these three dimensions of secure, equitable and sustainable energy.

a) Fuel security

Fuel security is a global issue today, highlighted by the conflict in Ukraine, creating volatile energy prices and global concerns over fuel availability. Australia imports around 90% of its liquid fuels, leading to the need to build additional diesel storage capacity within the Boosting Australia’s Diesel Storage Program (DOCEW, 2022a). Ongoing geopolitical tensions, climate change and global events such as the COVID-19 pandemic highlight the precariousness of Australia’s dependence on fuel imports. To address the critical supply chain and low national reserves, the Australian Government introduced the Fuel Security Act in 2021 to provide a legislative framework for government to establish a national fuel reserve through an industry minimum state-holding obligation (DOCEW, 2022b).

Fuel security, price volatility and Australia’s recently legislated emissions reduction target of 43% and net zero emissions by 2050 (Law Council of Australia, 2022) are drivers for many sectors to begin the transition away from reliance on petroleum diesel fuels.

Slowing global economic growth and lower energy demand has softened the outlook for oil, despite the supply impacts from the war on Ukraine propelling up prices (OPEC, 2022). Oil consumption in Australia is forecast to peak this decade. Australia is developing a supply of alternative fuels and an increasing share of the energy mix is biased towards electrical power, synthetic fuels and hydrogen (Figure 4), which are expected to represent 32% of the global energy mix by 2032 and 50% by 2050 (McKinsey & Company, 2022). In Australia, the transition may become more pronounced. For example, in the electricity sector, the transition has recently accelerated. In June 2022, the Australian Energy Market Operator (AEMO) outlined its 30-year roadmap for investments in the national electricity market, stating that 60% of current coal generation will have exited by 2030 (AEMO, 2022).

Further challenges exist for petroleum diesel. Diesel engines have been the target of previous Australian governments seeking to improve air quality and reduce emissions containing particulate pollution and NOx (DITRDC, 2020). Modern diesel engines use selective catalytic reduction (SCR) technology to improve emissions, which requires a fuel additive such as AdBlue to convert oxides into gas and water vapour (Diesel Technology Forum, 2022). The AdBlue shortage in 2021 and 2022 highlighted Australia’s dependence on imported SCR additives, particularly from China and Russia, and the shortage directly risked many of Australia’s agricultural enterprises and supply chains (DoI, 2022).

b) Equitability and economic drivers

In 2018, energy expenses in the Australian agriculture industry totalled $4.56 billion, of which operators spent $3.65 billion or 80% on diesel fuels (DCCEEW, 2022d). AdBlue shortage of 2022

In December 2021, Australia faced a supply-chain crisis with the national inventory of AdBlue being depleted to critically low levels. AdBlue is a selective catalytic reduction (SCR) additive that is used in diesel vehicles to break down harmful nitrogen oxides (NOx). To meet Australian emissions standards, modern diesel vehicles require the additive. This limitation extends to diesel-run tractors and irrigation pumps (Diesel Technology Forum, 2022).

The AdBlue shortage was driven by a scarcity of synthesised urea – a critical component of the fuel additive. Urea is typically imported from Russia and China. Rising fertiliser costs prompted China, the largest producer of urea and supplier of 80% of Australia’s urea stock, to halt exports of the commodity. This caused scarcity of AdBlue and rapid price inflation (Coyne, 2021). The shortage risked a standstill in Australia’s freight and agricultural industries. The crisis was mitigated through a deal with Indonesia to supply Australia with urea, as well as $30m in financial support provided to Queensland urea producer Inocite Pivot to increase domestic production (DoI, 2022).

Why does the agriculture, forestry and fisheries sector need to transition from diesel?

There is no ‘one-size-fits-all’ economic argument for transitioning from diesel given the complexity, size and sectoral variances in its consumption. However, carbon emissions in supply chains are receiving increased attention and present a market access risk for all Australian producers. Emission reduction targets are increasingly important following the legislated emissions reduction targets within the Climate Change Act 2022.

Impacts of fuel price volatility (Figure 5) on costs of production within the agricultural sector vary across producers and industries. For example, large-scale farming enterprises may be more exposed to fuel price volatility than smaller operations with a lower rate of fuel consumption. The research presented in this report illustrates that large beef operations have a strong negative correlation between lagged diesel prices and rates of return (Chen, 2015). Large operations tend to be more mechanised and dependent on diesel while also being more efficient in terms of other production costs, meaning they are sensitive to changes in diesel prices (ABARES, 2021; Australian Institute of Petroleum, 2022).

The overall efficiency of agricultural machinery is a function of operating conditions, soils, engine design and operator practices. During the past two decades, diesel use per hectare in agriculture has slightly reduced, which may be attributed to capital equipment turnover and technological advances such as precision agriculture, longer periods of drier conditions and changes in crops (Figure 6). This trend is expected to continue as diesel engines become more efficient, delivering the same or more power output with lower fuel consumption.

The economics of large-scale production, efficient distribution networks and associated skilled workforces that support incumbent diesel producers present an inherent tension for the transition. Farmers transitioning from diesel fuel face a difficult decision between the established proven technology and a new, unproven and likely higher-priced technology. This uncertainty is compounded by multiple competing emerging technologies, such as hydrogen, battery electric and biogas, as well as the lack of skills and infrastructure in regional areas for new energy systems.

Rapid investment in the alternative energy sector means that renewable energy solutions are today more reliable and quickly becoming cost-viable. The National Hydrogen Strategy identifies hydrogen hubs as an effective means to create demand, build scale and reduce production costs by co-locating producers, exporters and users. The Australian Government is investing $464 million to develop up to seven hydrogen hubs in regional Australia (DCCEEW, 2021b).
Why does the agriculture, forestry and fisheries sector need to transition from diesel?

Case study: Road freight

Janus Electric is an enterprise in NSW that has developed a battery swap system for heavy vehicles. Their solution enables prime movers to be retrofitted with battery electric power trains, with battery swap stations on key trucking routes. To avoid the upfront capital of a large battery and a 12-hour recharge, Janus has developed its battery rental and exchange business model. The company’s service offers users a choice to pay per use or for 24-hours with a four-minute battery swap service, a quick turnaround compared with 20-minute diesel refuelling. The company undertook an initial pilot in 2020 with a converted T403 Kenworth truck and today offers a battery electric conversion service for diesel Class 8 prime movers. The solution enables a 60% reduction in maintenance and operating costs over the vehicle’s lifetime, saving ongoing costs of oil, air and fuel filters. The operating cost of battery electric (33 c/km) compares well to diesel (96 c/km) in average cost per kilometre (Janus Electric Ltd, 2022).

c) Sustainability drivers

The global transition to net zero has prompted governments and industries worldwide to set goals and targets which will inevitably cascade to have an impact on the agriculture sector. At the COP26 international climate talks held in Glasgow in 2021, six major car manufacturers including Ford, Mercedes-Benz, General Motors and Volvo, as well as 30 national governments, pledged to work towards phasing out sales of new petrol and diesel vehicles by 2040, and by 2035 in leading markets (UK Government, 2021).

Already, all diesel vehicles made before 2005 are prohibited in the city of Paris, and all diesel vehicles will be banned from the city from January 2024 onwards. Other European regions are following suit (Bloomberg, 2019). In response to the global shift from fossil fuels, manufacturers of passenger transport as well as heavy industry machinery, including construction, freight, mining and agriculture, have pivoted research and development teams into alternative fuels, hydrogen fuel-cell and battery electric engines. Australia has made international commitments to decarbonise its economy, including net zero policies and a nationally determined emissions reduction target (DFAT, 2022), while key international agreements include:

- Paris agreement – Australia is party to the Paris agreement, which came into force in 2016. It aims to hold the global average temperature increase to 1.5 °C.
- UNFCCC – United Nations Framework Convention on Climate Change (UNFCCC) nationally determined contribution commits Australia to a 43% emissions reduction on 2005 levels by 2030.
- Kyoto Protocol – Australia has committed to reducing its GHG emissions to 95.5% of 1990 levels for the Kyoto Protocol’s second commitment period (2013-2020).

The electricity sector is at the centre of Australia’s energy transition and clear pathways have been established to decarbonise the transport sector with the development of a National Electric Vehicle Strategy (Australian Government, 2022b). Under the National Electric Vehicle Strategy, the Australian Government is consulting on fuel efficiency standards as a mechanism to increase the supply of new electric vehicles into the Australian market and lower transport emissions (Australian Government, 2022b).

The ACT Government has set a nation-leading sales target that 80-90% of new vehicle sales are zero-emissions vehicles (ZEVs) by 2030, and has committed to exploring the phase-out of new light internal combustion engine vehicles by 2035 (ACT Government, 2022). Other state governments are also developing EV and EV infrastructure strategies.

The agriculture, forestry and fisheries sector GHG emissions have followed a declining trend over the past 30 years and agriculture has been a leader in developing and adopting low-emissions technologies, including bioenergy and financial products such as sustainability-linked loans and carbon offsets. The sector is also a proactive participant in environmental services markets. However, despite many gains, the sector remains a significant contributor to Australia’s GHG emissions, and is the fourth-largest emitter behind electricity, stationary energy transport, with an estimated 79 Mt CO₂-e in 2019, including emissions from farming machinery (DCCEEW, 2021a; CSIRO, 2021).

Evolutions in farming equipment, such as solar battery pumps, and new practices, such as irrigation efficiency and zero-tillage cropping, have emerged to meet the sustainability demands of producers and consumers alike. Agricultural machinery and equipment are not specifically considered under national strategies, and the supply forecasts for zero-emissions machinery for agriculture, forestry and fishing in Australia is not yet clear.

Summary

Diesel is the most widely used source of energy in the agricultural, forestry and fishery sector, representing 84% of total energy consumption. Diesel consumption across Australia’s agriculture, forestry and fisheries sector has been rising over the past decade.

The price of petroleum diesel fuels is volatile, with a recent trend towards increased prices, although impacts on cost of production vary widely across the sector.

The energy trilemma consisting of fuel security, economic and market access drivers, and sustainability concerns are key risks to the sector and are driving the need to identify a pathway to transition the sector away from its dependence on petroleum diesel fuel.

Global shifts towards electric vehicles and plans to phase out the use of cars powered by diesel engines (as soon as 2024 in Europe) have driven agricultural, construction and freight machinery manufacturers to pivot research and development into alternative fuels and battery-powered equipment. Australian governments have established a range of strategies at national and state levels, and have introduced incentives and regulations to drive industry transition towards net zero emissions. Policies are centred on the electricity sector and transport sector transition.

Australian industries are already shifting away from the use of diesel fuel and early industry adopters are already retrofitting machinery, including the freight sector, which is today retrofitting prime movers to run major routes on battery electric and hydrogen fuel-cell trucks.
The global energy transition has set the stage for a future energy mix delivered through various technologies. Battery electric solutions have gained momentum in consumer transport and residential applications, while hydrogen and ammonia have established advantages in industrial areas. Bioenergy has found applications across many sectors, complementing other low-emissions alternatives. No one-size-fits-all solution or ‘silver bullet’ fuel will meet the energy needs of a diverse set of industries and communities in Australia.

Industry and place-specific energy solutions will further develop over time. Federal, state and territory governments have enacted strategies and roadmaps to guide the transition, ranging from renewable energy to critical minerals.

For example, the Australian Future Fuels and Vehicles Strategy 2019 aims to accelerate the uptake of new low- and zero-emission vehicle technologies. The strategy is underpinned by a $2.1 billion commitment to support new vehicle technologies and related charging, manufacturing and recycling projects. Priority areas include the establishment of electric vehicle charging and hydrogen refuelling infrastructure across Australia, including in some regional areas.

The Australian Government Department of Industry has engaged in a public consultation process to produce the first National Electric Vehicle Strategy (DCCEEW, 2022c). The national strategy aims to develop the Australian EV market, drive emission reduction targets and support an orderly transition to transport electrification.

The Australian National Hydrogen Roadmap and Australia’s National Hydrogen Strategy provide the framework for commercialising hydrogen technology and aim to establish an economically sustainable hydrogen industry in Australia (Bruce, 2018; COAG Energy Council, 2019).

The Australian Bioenergy Roadmap identifies a vision for a sustainable bioenergy industry, targeting lower emissions, regional growth, energy resilience and waste management benefits for Australia. The Bioenergy Roadmap shows that bioenergy has the potential to meet up to 20% of Australia’s total energy consumption by the 2050s (ARENA, 2021).

What has been lacking is an agriculture-specific transition strategy that accounts for productivity challenges, skills needs and the complications of regional ‘tyrannies of distance’ specific to the Australian context.

This section explores the advances in hydrogen, battery-electric and bioenergy solutions from the perspective of diesel consumption in agriculture. It aims to illuminate the potential for each in supporting the sector’s transition from dependence on petroleum diesel.

2.1 Hydrogen

a) Technology overview

Hydrogen is the most abundant element in nature; it is the H in H2O. Hydrogen is positioned as an important future fuel for Australia and the world; it is versatile and can be produced without emissions. As the International Energy Agency (IEA) has observed, hydrogen is experiencing unprecedented momentum in terms of the mobilisation of political and business interest (IEA, 2021b). Hydrogen has gained traction in Europe, with plans to deploy hydrogen at a large scale for decarbonisation of hard-to-abate sectors (European Commission, 2020).

On a mass basis, hydrogen has nearly three times the energy of petroleum fuel. However, hydrogen gas requires significantly larger storage containers compared to other gaseous fuels, such as LNG. Storage of hydrogen in a gas state typically requires high-pressure tanks in the range of 5,000–10,000 psi (US DoE, 2022a). Storing hydrogen in a liquid state requires cryogenic temperatures. Hydrogen can also be stored on or within solids through an absorption method, an area of early commercialisation today (Simanullang, 2022).

Hydrogen can be produced through a variety of means, including coal gasification, electrolysis using renewable electricity, steam methane reforming and fermentation. Renewable or ‘greener’ hydrogen is commonly produced through water electrolysis using electricity from renewable energy sources, such as solar and wind turbines to produce hydrogen (CDAG Energy Council, 2019).
What are the opportunities for transition?

Renewable or ‘green’ hydrogen is hydrogen produced using renewable energy.

‘Blue’ hydrogen is produced from natural gas with carbon capture and storage (CCS).

‘Brown’ hydrogen is produced from coal-fired electricity.

Hydrogen can be used as a combustion fuel, chemically converted with oxygen to electricity using a hydrogen fuel cell, or stored with a similar storage profile to LNG. It can be used across a range of applications, including export, for transport fuel, or as an industry feedstock. Hydrogen holds the potential for deployment at scale in a wide variety of applications in both public energy infrastructure and commercial agricultural uses, as shown in Figure 7 (Advisian, 2021).

Hydrogen production using electrolysis is most effective using purified water; however, in 2019, Stanford researchers published a means to generate hydrogen directly from seawater, reducing the need for reverse osmosis water treatment (Kuang, 2019). While this is an important development for areas with lower-quality water sources, there is a range of factors that will govern viable hydrogen production sites, including proximity to relevant renewable energy sources (for green hydrogen production), access to water, electricity power lines, gas pipeline easements, access to ports, carbon capture and storage basins and proximity to industrial zones (COAG Energy Council, 2019).

Water requirements for hydrogen used in industrial settings are similar to other industrial water requirements, with the demand dependent on the specific electrolysis technology used. In general terms, it is expected that 9 kg of water is required to produce 1 kg of hydrogen using electrolysis (COAG Energy Council, 2019). Consideration will therefore need to be given to the balance between hydrogen production and other water uses, this is particularly critical in regional areas where there is water stress.

Electrolysers are a vital technology component used in hydrogen electrolysis systems. Globally, the capacity to produce hydrogen through electrolysers has doubled during the past five years. Europe has 40% of the world’s installed electrolyser capacity. However, the International Energy Agency (IEA) notes that Australia has set ambitious growth targets for the hydrogen sector that could soon rival the European market (IEA, 2021c). For example, the Gladstone electrolyser manufacturing hub will be the world’s largest electrolyser facility enabling the production of 2 GW per annum commencing in 2023 (Fortescue Future Industries, 2022).

Water supply

Wind farms

Solar farms

Hydrogen production

Hydrogen delivery

Port facilities

Dispensing

Marketing balancing and spill export

‘Green’ ammonia

Liquid hydrogen

Forklifts

Cars

Semi-trailers

Road trucks

Trains

Yachts

Container ships

Planes

Power

Remote power

Grid balancing

Feedback for industry

SNG

Alumina calcining

Steel mills

Other high-grade heats

Ammonia

Methanol

Oil refining

Power

Merchant

Industrial

Power

Feedstock for industry

CHP

Electrical

Transport

Fuel for industry

Fuel recovery

Figure 7. Hydrogen applications in Australia (Advisian, 2021).

Ammonia also has existing transportation and storage infrastructure that provides a foundation for the fuel value chain in commercial fishing vessels.

Several research institutions are investigating ammonia-to-hydrogen conversion. CSIRO has announced a breakthrough development of a new membrane that can separate hydrogen from ammonia, paving the way for bulk hydrogen to be transported in liquid ammonia and then reconverted to hydrogen (CSIRO, 2022). In 2018, CSIRO deployed the technology in Toyota Mirai and Hyundai Nexo hydrogen fuel-cell vehicles. Fortescue Metals Group has been developing a partnership with Hyundai and CSIRO to develop and commercialise the liquid membrane technology. North Western University in the US has published results of a study that enables on-demand energy through an ammonia-to-hydrogen conversion and claims the capability to skip the hydrogen phase and produce electricity directly from ammonia (Lim, 2020). The process is shown in Figure 8.

Hydrogen fuel cell vs battery electric

Today’s hydrogen fuel-cell systems are advanced, meet or exceed passenger vehicle safety standards, and are in production or are installed in passenger, commercial and industrial vehicles, and machinery. Cost-competitive production and distribution of hydrogen has presented challenges for broad adoption. Debate continues over the merits and disadvantages of battery-electric vs hydrogen fuel-cell electric engines. Battery-electric systems have strengths in distribution, well-established recharging infrastructure and reducing costs linked to economies of scale. However, battery disposal costs remain high and using critical minerals in battery construction has raised questions about sustainability. These are some reasons why investment in hydrogen technologies and engine systems continues.

3 The International Energy Agency (IEA) predicts that the global hydrogen supply from electrolysers could reach more than 8 Mt by 2030 and notes that this supply still falls below the required 80 Mt target for year 2030, which the agency has set in its roadmap to net zero.
suitable for ocean-going vessels (Amogy, 2022a). Ammonia identifies several key advantages that make it better than lithium batteries. The company also demonstrated an ammonia-fuelled engine fitted to a John Deere tractor (Figure 9).

US company Amogy has demonstrated an ammonia-fuelled tractor in 2009. It was the first tractor publicly shown by a major brand that used hydrogen fuel-cell technology. The company has since launched its NH2™ hydrogen fuel cell-powered tractor in 2009. It was the first tractor publicly shown by a major brand that used hydrogen fuel-cell technology. The concept was designed for a hydrogen storage tank on-site, connected to a compressor and dedicated filling station, so the NH2™ could operate and refuel on-farm just like a conventional tractor. New Holland claims the prototype has a top speed of 50 km/h, with pulling power comparable to that of a standard 120 hp diesel tractor. The company also identifies several key ammonia advantages that make it suitable for ocean-going vessels (Amogy, 2022a).

Other Australian agriculture supply chain projects include the Gladstone integrated abattoir, which aims to provide its own energy with 78 MW of solar capacity and a 33 MW hydrogen plant. Other projects identified by the Queensland Farmers’ Federation include green hydrogen from ammonia for a 150 MW solar-powered electrolyser at Moura and a 160 MW electrolyser at Moranbah (Queensland Farmers’ Federation, 2020). Research and development efforts focus on technologies to efficiently produce hydrogen on farm, aiming to efficiently generate hydrogen from the nitrogen and carbon compounds (e.g. ammonium) in manure. Researchers are also examining whether hydrogen can be produced using bacteria (US DoE, 2022b).

Hydrogen fuel cells powering headers are expected to lower the risk of fires during cropping season as a fuel cell-powered header converts hydrogen to electricity for the header without combustion heat. This could improve productivity by avoiding harvesting restrictions during high fire danger periods.

The Commonwealth Government has championed the development of a hydrogen industry in Australia, estimating that the Australian hydrogen industry could be worth $11b and employ over 8,000 people by 2030 (COAG Energy Council, 2019). The Australian Renewable Energy Agency (ARENA) released the Hydrogen Deployment Funding Round in 2020 to stimulate investment in hydrogen production. The Clean Energy Finance Corporation (CEFC) has also announced an Advancing Hydrogen Fund, with up to $300m in loans available for new hydrogen projects (ARENA, 2019b).

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d) How other industries and governments are responding

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**Case study: Heavy duty hydrogen trucks**

The CEFC, through the Advancing Hydrogen Fund, has invested in Ark Energy Corporation to finance the production of green hydrogen at the Townsville SunH2 hydrogen hub (CEFC, 2022). The project is constructing hydrogen production and refuelling infrastructure and five 154 tonne hydrogen fuel-cell trucks, to reduce carbon dioxide emissions by 1,400 tonnes per year over diesel equivalents. Green hydrogen will be created to power the fleet through solar energy from the Sun Metals solar farm. Sun Metals’ zinc refinery in Townsville will produce green zinc, using the trucks and hydrogen infrastructure to transport zinc ore from port to the refinery and back to the port as zinc ingots.

This investment and technology will help Sun Metals’ zinc refinery achieve its goal of becoming the first in the world to produce green zinc. The investment by the CEFC aims to demonstrate the ability of hydrogen to reduce emissions in the heavy transport sector.
What are the opportunities for transition?

2.2 Battery electric

a) Technology overview

Energy carriers, components to store and later discharge energy for use, have been a critical design feature at the centre of the global energy transition. Manufacturers cite three key advantages of battery electric technology for use in agricultural equipment: energy efficiency, precision applications and ability to use renewable energy sources (Allison, 2020). Batteries provide flexibility in response to demand for energy, supplying power in fractions of a second. Batteries can be constructed in various sizes and installed together for grid or large-scale battery storage for commercial and industrial applications (Figure 10). Investment in battery technology has seen advances in capacity and battery performance, with evolutions in battery design and the types of chemicals used. Electric batteries are distinct from hydrogen fuel cells, which combine hydrogen fuel with oxygen to produce electricity for an electric engine.

The IEA has forecast that the heavy freight sector will be the fastest-growing electrification market in the coming years (IEA, 2021a). As technology rapidly evolves to meet the power demands of prime movers, the agriculture sector will benefit from inherent technological advances.

b) Applications in agriculture

Agricultural applications require high torque, which electric engines can deliver. However, the intense duty cycles with a high power output over long periods will be the primary constraint for battery electric machinery in agriculture. To overcome battery limitations John Deere produced the GridCON concept tractor, an electric plug-in tractor powered by a 100 kW electric motor that drives the continuously variable transmission. Based on a John Deere 6210R tractor chassis, the GridCON weighs about the same as a conventional 6210 tractor, with quieter operation and twice the power. To overcome challenges with battery technology, namely capacity and duty-cycles, size, and weight, the GridCON remains connected to the grid through a 1,000 m electric cable. An additional 200 kW electric motor enables farming equipment attachments to operate. The machine uses an intelligent guidance system to prevent it from running over the 1 km plug-in cable, and a robotic arm guides the cable to prevent tangles (Karthik, 2021).

However, as batteries have advanced, agricultural machinery manufacturers have articulated a vision for future electrification of products, with John Deere, Fendt, Farmtrac and Multi Tool Trac launching full battery electric models. Multiple electric power train models have been demonstrated and OEM electric engine components, including pump drives, are available for any manufacturer to electrify their products. The major manufacturers of industrial equipment are also engaged in the electrification of products. Japanese manufacturer Kubota Corporation has unveiled prototypes of its electric tractor and excavator models, and customers are piloting the products to provide feedback for their continued development (Kubota Corporation, 2020).

Table 1. Farm gate hydrogen costs over time (CEFC, 2021a).

<table>
<thead>
<tr>
<th>Metric</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Grey’ hydrogen farm gate cost ($/kg)</td>
<td>2.20</td>
<td>2.29</td>
<td>2.29</td>
</tr>
<tr>
<td>‘Blue’ hydrogen farm gate cost ($/kg)</td>
<td>3.02</td>
<td>2.80</td>
<td>2.80</td>
</tr>
<tr>
<td>Base ‘green’ hydrogen farm gate cost ($/kg)</td>
<td>3.88</td>
<td>2.81</td>
<td>2.09</td>
</tr>
<tr>
<td>Accelerated ‘green’ hydrogen farm gate cost ($/kg)</td>
<td>3.46</td>
<td>2.29</td>
<td>1.84</td>
</tr>
<tr>
<td>Nominal ‘green’ hydrogen farm gate cost ($/kg)</td>
<td>3.88</td>
<td>2.76</td>
<td>1.98</td>
</tr>
<tr>
<td>Base ‘green’ hydrogen delivered cost ($/kg)</td>
<td>5.82</td>
<td>3.48</td>
<td>2.72</td>
</tr>
<tr>
<td>Accelerated ‘green’ hydrogen delivered cost ($/kg)</td>
<td>5.43</td>
<td>2.96</td>
<td>2.23</td>
</tr>
<tr>
<td>Nominal ‘green’ hydrogen delivered cost ($/kg)</td>
<td>5.82</td>
<td>3.42</td>
<td>2.60</td>
</tr>
</tbody>
</table>

Future Farming magazine has reported that Massey Ferguson is developing an electric tractor based on the Massey Ferguson 62 model. The company has not committed a launch date but has indicated Q4 of 2023 as a timeframe. The new electric model will be similar to a 100 hp MF 5S and aims to run for eight hours on a single battery charge (Hattum, 2022). Electrification is not limited to tractors. Among other innovations, electrified crop sprayer drones have been launched that can operate for 30 minutes on a single battery charge, with coverage for up to six hectares per hour (Figure 11).
What are the opportunities for transition?

Autonomous electric vehicles

During a press conference at global technology event CES® 2022, John Deere revealed a fully autonomous tractor that is ready for large-scale production. The machine combines John Deere’s 8R tractor, TruSet-enabled chisel plow, GPS guidance system, and new advanced technologies. The autonomous tractor will be available to farmers later in 2022. Smaller autonomous battery machinery now in production creates the potential to disrupt the traditional scale economics of today’s agriculture industries.

US manufacturer Case IH has also invested in the development of autonomous farming machinery on traditional diesel platforms. By removing the constraint of an operator, large diesel tractors and harvesters can run more efficiently over longer periods. A single capital-intensive machine may be replaced by multiple smaller and lower-cost autonomous battery electric tractors.

Legislative barriers exist in Australia that will need to be addressed before the agriculture sector can take advantage of autonomous vehicles. For example, the current regulatory landscape would need significant amendments to ensure insurance is available for agricultural producers harnessing automated vehicles. Today, a national effort is underway to identify areas of reform required for autonomous vehicles to operate legally in the country (National Transport Commission, 2022).

In the large higher-power machinery segment, in 2017, John Deere integrated a battery electric engine with the company’s 6R Series tractor chassis and fitted with a 130 kWh battery pack mated to a modified direct drive transmission that offers up to four hours mixed work capacity (Daniel, 2022). The prototype claims to be the industry’s first fully battery-powered tractor, with a high torque output expected from an electric engine and a speed range from 3-50 km/h, with a maximum output of about 400 hp (Figure 12). In addition to high-torque characteristics, the electric engines on the unit are described as ‘maintenance free’, with one powering the drive train while another operates the auxiliary systems. The company claims one battery charge lasts up to four operating hours in typical mixed mode operation or for around 34 miles of road transport work. The charging time is about three hours, with an estimated 3100 charging cycle battery life (John Deere, 2022a).

In the most recent autonomous vehicle prototype, John Deere has increased the battery capacity to 1,000 kWh, which can deliver 500 kW to the powertrain and 1,000 kW available to power implements. The company claims around 10 hours range at an 80% battery load (Daniel, 2022).

With inevitable improvements in battery technology, increased energy output in smaller footprints could be expected over time, reducing weight and offering further advantages to the agriculture sector.

Electric drivetrain components are available to OEMs today, enabling new model development or retrofitting of existing farming machinery (Figure 13). Products include electric generator pump drives and traction drives, which offer significantly higher torque specifications than diesel products at similar power output levels.
### Table 2. Cost comparison between electric and diesel fuel in the 22-tonne heavy vehicle segment (Electric Vehicle Council, 2022a).

<table>
<thead>
<tr>
<th></th>
<th>Electricity</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy requirement for 300 km range</strong></td>
<td>280 kWh</td>
<td>84 L</td>
</tr>
<tr>
<td><strong>Cost per kWh (off-peak commercial)</strong></td>
<td>$0.05-0.15/kWh*</td>
<td></td>
</tr>
<tr>
<td><strong>Cost per L ($ average)</strong></td>
<td>$1.33/L</td>
<td></td>
</tr>
<tr>
<td><strong>Cost per 100 km</strong></td>
<td>$4.67-14.00 (93.33 kWh/100 km)</td>
<td>$38.78** (28.6 L/100 km)</td>
</tr>
<tr>
<td><strong>Cost for 300 km worth of fuel</strong></td>
<td>$14-42</td>
<td>$116.34</td>
</tr>
</tbody>
</table>

* Electricity price is based on a commercial off-peak tariff for a depot-based fleet.

** including diesel cost of $37.24 (28 L/100 km) and AdBlue of $1.54.

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**c) How other industries and equipment suppliers are responding**

Transport was Australia’s third-most significant source of emissions in 2019, accounting for 19% (100 Mt CO₂-e) of total emissions. In the consumer segment, battery electric vehicles (BEV) and plug-in hybrid electric vehicles (PHEV) have seen increased sales in Australia year-on-year, with a three-fold jump in sales in 2021 over the previous year. Model availability in Australia is constrained by global supply, limiting Australian consumers’ choice of models across all vehicle segments, and a historic lack of fiscal and regulatory incentives for EV uptake.

Sectors that require specialised vehicles, such as agriculture, mining, marine and logistics, will require more time to transition. In the past six months, there has been substantial growth in the truck sector, with 21 different models of trucks, vans and utility vehicles now on the Australian market. There are eight bus manufacturers in Australia offering 11 electric bus models. For the construction sector, regulating diesel machinery in cities has accelerated the adoption of battery electric technology. Komatsu has introduced a battery electric mini excavator in Japan and has tested electrified small and medium-sized hydraulic excavators. The company is also developing electrified super-large dump trucks for mining applications (Komatsu, 2021a).

Heavy industry equipment manufacturer Volvo has also launched an electric excavator range for the construction sector. Volvo is developing its range of electric machinery alongside hydrogen fuel-cell solutions and more efficient internal combustion engine products. Volvo aims to have at least 35% of its total range of vehicles fully electric by 2030 (Volvo Group, 2022b). The Volvo ECR25 Electric (Figure 14) replaces a combustion engine with 48-volt lithium-ion batteries and an electric motor that powers the hydraulics to move the machine and attachments. The company claims that batteries store enough energy to power the machine for eight hours in typical applications, such as utility work. An onboard charger enables overnight charging via a regular household plug socket. A fast-charging option will also be available, requiring more powerful grid access. Figure 15 shows the timeline for electrification of Volvo industrial machinery in the construction sector.

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**For the construction sector, regulating diesel machinery in cities has accelerated the adoption of battery electric technology.**

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**Figure 13. Examples of currently available power train electrification components (John Deere, 2022a)**

**Figure 14. Volvo compact electric excavator (Volvo Group, 2022b).**
Case study: Replacing diesel engines with battery electric systems in mines

The 3ME Bladevolt modular battery can support a 20-tonne diesel loader in becoming fully electric. Direct emissions from powering oil, gas, mining and metal processing industries, as well as indirect emissions from powering these operations, contribute more than 25% of Australia’s total GHG emissions.

The technology from 3ME uses lithium-ion batteries specifically designed for harsh environments and heavy-duty cycles. Current machinery can be retrofitted with modular battery technology, including remote control of the battery pack cell performance monitoring and advanced safety features.

This technology aims to reduce the carbon emissions of the mining sector, with 3ME estimated to abate 735,000 CO₂-e over the lifetime of the assets, which is approximately 48,000 CO₂-e annually (CEFC, 2021c).

Case study: Electric commercial vehicles

SEA Electric’s technology called SEA-Drive allows for vans and light/medium commercial vehicles to be converted to electric by retrofitting existing chassis platforms. As the price of lithium reduces and batteries become more economically viable for vans and light/medium commercial vehicles, existing chassis and platforms of vans and light/medium commercial vehicles need to be fitted with electric systems to reduce GHG (CEFC, 2018).

SEA-Drive is SEA Electric’s power system, which is adaptable to most OEM glider chassis – from Class 3 to Class 8 (3.5 t to 29 t). This technology allows for most light/medium duty trucks and van platforms to be converted to electric. The technology suits vehicles that travel relatively fixed and pre-determined routes, and that can return to a base overnight to recharge, which takes between four and eight hours. The technology has been used in garbage trucks, tilt tray trucks, shuttle busses, passenger vans, delivery trucks, tipper trucks, rearer trucks, cargo vans and cherry picker trucks. The estimated payback period for installing the SEA-Drive technology is 2-4 years (SEA Electric, 2022).

Electricity storage is becoming more affordable and efficient, and battery technology is rapidly advancing. Lithium-ion-based batteries have also come down significantly in price, with an 87% decrease over the past decade (CEFC, 2018). Currently, a 70 hp electric tractor in the US costs US$100,000, while a similar diesel tractor costs less than half that amount (Kondinin, 2017). The cost of electric tractors is also expected to drop, following other technology pricing trends.

Duty-cycle is a key challenge for battery power in agricultural machinery. Conventional tractors typically work for 10-12 hours without refuelling, while most electric tractors today run for four hours before needing to recharge. Additionally, diesel tractors can refuel on-site in a couple of minutes.

It may take some time before Australian agriculture will benefit from electric tractors that would match the 12-hour running period of diesel tractors. However, small-sized autonomous tractors are already in production. There is a clear direction in the industry towards developing electric tractors, with tractor forestry and heavy vehicle giants investing in the technology.

Australia’s laws do not currently support the deployment of automated vehicles and are designed for vehicles with human drivers.

A policy paper developed by the National Transport Commission presents the regulatory framework to enable use of automated vehicles in Australia. The framework seeks reform across a wide set of codes, standards, regulations and laws at all levels to address more than 700 barriers to the deployment of automated vehicles in Australia. Further, the regulation of automated vehicles must be facilitated by state and territory intergovernmental agreements to support a national regulatory framework.

Continued investment in electric charging infrastructure is highlighted in state and national roadmaps. There are currently approximately 300 public fast charging stations around Australia that can deliver more than 50 kW.1

Bioenergy offers the agriculture sector opportunities to supply energy products and develop energy independence at the farm or community scale. Many bioenergy feedstocks come from agricultural activities, such as sugarcane waste and the livestock industries. Investment in bioenergy production facilities is viewed positively as supporting regional jobs and longer-term regional employment.

The Australian Bioenergy Roadmap identifies that bioenergy could meet 20% of Australia’s fuel consumption by 2050. There is a cost premium on bioenergy products, which can be as much as 1.5-3 times the cost of petroleum fuels. The Australian Renewable Energy Agency proposes that with more commercial bioenergy plants, prices will decrease in the future (ARENA, 2021). Table 3 lists the commercial-scale biofuel plants operating in Australia.

1 Fast charging is considered above 50 kW, regular charging is below 50 kW with ‘destination charging’ 7-40 kW.

NSW leads the way with more than 30% of the national installations. Over the next five years, more than 700 new fast-charging stations have been committed to with funding support from the federal and state governments.

The NSW State Government aims to ensure fast-charging points every 100 km on regional routes. State government programs aim to increase the density of fast-charging equipment deployed in remote parts of the country, in regional areas such as Fitzroy Crossing, Coober Pedy and Mount Isa, adding to the remote locations of Broken Hill, Bourke and Caiguna on the Nullarbor.

Communities and individual farmers wanting to deploy electric machinery will need to evaluate options for installing renewable energy and fast-charging solutions on-site or in shared facilities.

Situated 1,100 km east of Perth and 1,600 km west of Adelaide, the Caiguna charger site is relatively unique. Without a grid connection, the site is powered by generators using used cooking oil from the restaurant.
What are the opportunities for transition?

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Production</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manildra Group</td>
<td>Bioadery, NSW</td>
<td>Bioethanol</td>
<td>300 ML/year</td>
</tr>
<tr>
<td>United Petroleum</td>
<td>Dalby, Queensland</td>
<td>Bioethanol</td>
<td>80 ML/year</td>
</tr>
<tr>
<td>Wilmar Sucrogen</td>
<td>Sarina, Queensland</td>
<td>Bioethanol</td>
<td>50 ML/year</td>
</tr>
<tr>
<td>Just Biodiesel</td>
<td>Barnawartha, Victoria</td>
<td>Biodiesel</td>
<td>50 ML/year</td>
</tr>
<tr>
<td>EcoTech Biodiesel</td>
<td>Nanango, Queensland</td>
<td>Biodiesel</td>
<td>30 ML/year</td>
</tr>
<tr>
<td>Biodiesel Industries Australia</td>
<td>Maitland, NSW</td>
<td>Biodiesel</td>
<td>20 ML/year</td>
</tr>
</tbody>
</table>

Bioenergy is a form of renewable energy derived from organic materials known as biomass, which can produce fuels, heat, electricity and other energy products. In this report, biomass, biodiesel, biogas and biogas are discussed. Biomass is organic material often derived from agricultural activities or waste streams. Biodiesel is commonly used in Australia as a substitute for petroleum diesel and is most often a blended mixture containing a significant proportion of petroleum diesel. Biodiesel is an important intermediate transition fuel as the sector reduces its reliance on petroleum diesel; however, more significant long-term bioenergy transition options, such as biogas, are being brought to market by major equipment manufacturers (Figure 16).

Biomass can be fired or co-fired in a high-efficiency boiler to produce heat and steam for renewable energy generation. Sustainably sourced biomass material can be derived from residue or waste product from crops, grasses, and plantation timber and its processing. Gasification and pyrolysis are advanced combustion processes suited to feedstocks such as rice hulls and macadamia nut shells. Gasification can improve efficiency and produce additional outputs such as biochar, which can be used to increase soil fertility, water holding capacity and crop productivity (CEFC, 2019).

Biodiesel is a renewable, biodegradable alternative fuel made from a mix of modified vegetable oils and diesel fuel. Soybean oil is a key source of biodiesel. Alternatively, used cooking oil, algae, canola and animal tallow can be used. Most Australian states have commercial biodiesel production capacity. Biodiesel can also be produced on-site using small processing systems. Emissions and performance depend on the percentage of biodiesel blended with petroleum diesel to produce biodiesel fuels, with blends varying from 5% (B5) to 100% biodiesel (B100). The cost of biodiesel is dependent on the price of feedstock. Biodiesel carries less energy than petroleum-based diesel, which results in a small engine performance penalty.

Bioethanol can substitute petrol or diesel in vehicles and farm machinery. In Australia, most bioethanol is produced by commercial refineries, largely using feedstock from the sugar industry. A reduction of 49–55% in GHG emissions can be achieved by using bioethanol from agricultural waste (CEFC, 2019). Renewable diesel and biodiesel are not the same fuel. Renewable diesel, previously known as green diesel, is a hydrocarbon produced most often by hydrotreating, and also via gasification, pyrolysis and other biochemical and thermochemical technologies. It meets ASTM D6751 for petroleum diesel. In contrast, biodiesel is a mono-alkyl ester produced via transesterification. Biodiesel meets ASTM D6751 and is approved for blending with petroleum diesel.

Biogas is produced on farms through the anaerobic digestion of organic waste using covered lagoons or concrete or steel tanks (Figure 17). The process produces electricity, heat and a residual organic product that can be used as a fertiliser. Cost-effective biogas production generally requires an input volume of at least 25 t/day and will depend on a farm’s existing waste management practices (CEFC, 2019). There is further potential for biomethane to be used in tractors and vehicles or injected into the natural gas grid. Biodigesters are also commonly needed to process manure and biomass to produce biogas.

Figure 17. Indicative biogas cycle (Vallaey, 2022).

Bear in mind that the above is an excerpt from a larger document. For a comprehensive understanding, refer to the full report.
What are the opportunities for transition?

This report has focused on the long-run alternatives to petroleum diesel fuel using electric engines over internal combustion.

Following the development of the NH2™ hydrogen-powered prototype, New Holland has since developed the T6 Methane Power model, which has now gone into full production (Figure 18). The T6 Methane Power tractor achieves “diesel-like performance” from 100% natural gas engines that are also CNG, LNG and biogas compatible (CNH Industrial, 2019). The T6 Methane Power tractor is claimed to be the world’s first 100% methane-powered production tractor that delivers 152 kW/180 hp with 740 Nm torque through a 6.7 L engine. The model has a 7,864 kg lift capacity (Agriculture Post, 2021).

Methane gas is compressed into cylinders that fit inside the tractor chassis. This use of methane, collected from livestock waste and converted to biogas, is claimed to offset more emissions per unit of energy in its production and use cycle than it emits.

New Holland claims that with the same power as the diesel equivalent, there are benefits of up to 30% lower running costs. The company also states that the T6 Methane Power tractor produces 99% less particulate matter, reducing CO₂ emissions by 10% and overall emissions by 80%.

Roger Clothier of Wyke Farms, one of the UK’s largest cheese producers, tested the New Holland methane tractor. “We need fuel-efficient vehicles with a good power-to-weight ratio to pull heavy tanks around the farm. My first impression is that this looks and feels just like a normal tractor,” Clothier said (New Holland Agriculture, 2016).

In Belarus, equipment manufacturer Gomselmash is producing a 16,600 kg combine harvester, which has been in development since 2014 (Figure 19). The Palesse GS 4118 K and GS 4218 CNG are combine harvesters powered by a Cummins eight-cylinder engine that runs on methane. According to the manufacturer, the Palesse can run for 8-10 hours on one tank of fuel and takes approximately 10-15 minutes to refuel (Gomselmash, 2019; Gomselmash, 2020). Gomselmash claims the 350 hp methane engine saves around 50% in costs compared to a diesel engine because the fuel is cheaper and lubricant costs can be saved. Furthermore, there is less wear on the pistons and cylinder walls, extending maintenance intervals. The cost of the methane-powered machine is approximately 15% greater than the diesel counterpart (Future Farming, 2019).

c) How other industries and equipment suppliers are responding

Biodiesel will play a role in the net zero strategies for many equipment and diesel vehicle suppliers across most machinery-intensive industries. For its internal combustion engine models, Volvo has announced that biodiesel will be the fuel of choice for all machines at the Volvo Customer Experience Center in Eskilstuna, Sweden. The company uses a renewable synthetic diesel called hydrogen-treated vegetable oil, or HVO.

Ocean-going vessels generally operate on conventional diesel-mechanical engines using marine diesel oil. A study by independent Norwegian research organisation SINTEF (Gabrielli, 2020) identified alternative fuels for the fisheries industry and forecast the potential market share of each in 2050 (Figure 20):
found that emissions along the biogas supply chain were higher than for natural gas but noted that biogas remained a greener alternative to natural gas (DeCicco, 2016).

Given that the global energy transition is simultaneously impacting all sectors, it can be expected that bioenergy products will be in high demand in the short term, particularly for industries that are difficult to abate. There are concerns that developing crops for bioenergy production, such as sugarcane, palm oil, soya and maize, risks further land clearing or displacement of food production capacity. A recent study in the UK identified that biofuel crops impacted local biodiversity (Tudge et al., 2021). The UN is advocating for advances in technologies that focus on use of agricultural waste as feedstock for bio-products, reducing the competition for land use and addressing food security concerns.

Demand for biodiesel and biogas will potentially outpace supply in the transition period, causing scarcity and likely price inflation in bioenergy products. Further work is required to identify supply capacity against the potential transition demand and provide insights to bioenergy producers to manage the transition demand peaks.

Another challenge facing biofuels is the oil market. When oil prices fall, demand for renewable fuels is reduced. As one example, the Barnawartha biodiesel plant temporarily closed in 2016 when crude oil prices dropped.

Finally, biofuels can have greater fuel management requirements than petroleum diesel. Temperature controls on biodiesel storage are required as biodiesel is produced from vegetable-based products that change in nature above and below set temperatures. This requires changes in supply chains, storage and management practices at refuelling stations, as well as changes in on-farm storage and fuel management.

### Case study: Using waste and an anaerobic digestion plant to power equipment, vehicles and heating

Richgro is a garden supplies business based in Perth, Western Australia that uses an anaerobic digestion system to divert waste from landfill to create electricity and fertiliser (Richgro, 2022).

Richgro uses solid and liquid organic food waste from processors, breweries, supermarkets and fruit and vegetable producers to feed into its anaerobic digester. Bacteria breaks down the waste into biogas, which creates electricity that powers the entire operation at Richgro, with the excess sold to the power grid.

Digestate is a material left over after the anaerobic digestion process that is used as an organic fertiliser. Excess heat from the process is transferred to hothouses on the property and used to produce of out-of-season blueberries for the export market.

Richgro powers its operation through electricity created using the digester and estimates that the surplus exported to the grid is enough to power 1,800 households in Western Australia. The project is estimated to abate 140,000 t CO₂-e over a 20-year lifespan and has so far diverted 95,000 tonnes of waste from landfill (CEFR, 2016).

### Summary

Battery electric tractors and other electrified equipment such as crop-spraying drones have been developed for farming industries. Demand will need to be established in the Australian market to enable manufacturers and distributors to plan product launches and ensure supply of battery electric farming equipment to the Australian market.

The consumer transport sector is experiencing rapid adoption of electric vehicles. National and state roadmaps and strategies are focused on establishing charging infrastructure, including a focus on regional charging infrastructure. According to the IEA, the heavy freight industry is the fastest-growing market for electric vehicles and battery electric prime movers are in service today. The agriculture sector will be a beneficiary of the advances in technology and charging infrastructure established by these early adopter industries.

Manufacturers supplying machinery to the construction and mining sectors have published indicative five and 10-year timetables for electrification of heavy vehicles, including large excavators and heavy earthmoving equipment.

For on-farm equipment, communities and individual farms will need to evaluate options for installing renewable energy and fast charging solutions on-site or in shared facilities.

The agriculture sector is a producer and consumer of bioenergy products. Biodiesel will play an important interim role in the energy transition, as internal combustion engines are phased out of service over time. Concerns have been raised over the carbon emission benefit claims for biodiesel and it may struggle to achieve a long-term position in the alternative fuel mix. Production and use of biomethane has shown significant promise as an alternative combustion fuel during transition, and production tractors and harvesters have been produced that are claimed to deliver performance suitable for farming applications.

Hydrogen shows significant promise as a future fuel and alternative carrier to petroleum diesel for the agriculture sector. The technology challenges of distribution into regional areas are being addressed through research and breakthroughs by CSIRO and other global equipment manufacturers have the potential to enable use of hydrogen through an ammonia form.
How will the sector transform?

Australia is ranked 35th in the Global Energy Transition Index (Figure 21) developed by the World Economic Forum (WEF, 2021). This index measures national energy transition progress across 115 benchmarked countries based on their current energy system performance and preparedness for transition. The global average of the index in 2021 was 59, with 58 countries performing above average. The top three countries were Sweden, Norway and Denmark.

Opportunities exist for Australia to learn from international best practices across all areas of transition, particularly in areas where Australia is below the world average. Even though Australia (65) is performing above the Global Energy Transition Index average, the framework identifies a need for further attention to environmental sustainability, human capital, consumer participation and energy system structure.

Implementing a whole-of-sector transformation across the diverse and multi-scale enterprises and industries of the agriculture, forestry and fisheries sector is a complex undertaking that extends beyond the scope of a single industry, technology, service network or supply chain. Considering factors of each regional community, the transformation will require multi-stakeholder engagement, planning and a dedicated transition coordination mechanism to align both supply and demand sides of the sector. This includes for both government and industry activities.

Figure 21. Australian standing in global energy transition index benchmarking (WEF, 2021).
How will the sector transform?

3.1 Transition lessons

Broadly, economic transitions have traditionally concentrated around activities in three priority areas, evolving in different ways and over different timeframes, with diverse leadership and governance models (Briggs and May, 2000; Coenen, Campbell and Wiseman, 2018). Identifying the need for transition is the first priority. This generally occurs in one of three ways that respond to declining or changing market demand:

- Industry identifies changes in the technology, regulatory and market landscapes and takes a proactive approach to engagement with suppliers and customers; or
- Local, state or national governments anticipate changes in an economic sector that will have a major community impact and plan for the change; or
- Unanticipated market changes leading to industry collapse, or failure of companies to be proactive resulting in government stepping in to mitigate the social and economic impact.

The second priority area is to build transition roadmaps. Roadmaps are developed at multiple levels, with place-based community-level planning at the core:

- Industry and assets: Companies or state-owned operators will plan transitions for and with their business, customers, employees, unions, supply chains and investors. Where multiple businesses are affected, joint ventures and marketing may be adopted within and between regions, in collaboration with research organisations, to pursue innovations.
- Places: Councils, industry and other local businesses, government service providers and community organisations will collaboratively develop a vision for their community. This generally involves economic diversification to minimise impact on the local economy and jobs, and optimise opportunities.
- State and national: Government policies and programs, such as net zero targets, energy strategies, planning frameworks and regional development policies and initiatives provide the governance framework with which roadmaps must comply. These are often adapted to remove barriers to investment and inclusive diversification.

The third priority area is to attract investment and implement transition:

- Public and private investment is needed to stimulate inclusive economic growth and jobs around transition points.
- Effort is needed to attract new service providers and transition supply chains to new technology and skills. Clear points of entry – usually through a government or co-funded authority – are necessary to coordinate investment attraction efforts.

3.2 Conditions for transition

The impacts of the global energy transition are familiar across the Australian agricultural sector. Agribusinesses are sensitive to energy costs, and the sector has been a driver of energy innovation through producing and applying renewable energy. The on-demand, duty-cycle and reliability requirements of the sector have not been fully met by alternative energy solutions today, and cost remains a formidable barrier. An efficient diesel transition will require a transformation of the energy system and its ecosystem. In addition to consistent market demand for new products and services, and a capacity to supply products, pre-conditions need to be met in regional areas concerning infrastructure and energy supply chains, and workforce capacity and skills to deliver demanded services, such as servicing equipment or producing fuels. Furthermore, enablers such as financial services and insurance will be required and regulatory issues require redress; for example, the need for certification of workers, equipment, and permits for local production or movement of energy and storage of new fuels.

Today, early adopters in agriculture, forestry and fisheries, and other sectors such as road freight, are not waiting for manufacturers to launch production-scale equipment. Homegrown hybrid solutions are emerging in places, however professional retrofitting businesses will serve the early adopter market for the initial four-to-five-year transition period. Such businesses have already emerged in Australia for both battery electric and hydrogen-powered vehicles. With high-voltage charging and solar equipment available, the initial constraints for this growing market will primarily be in local battery swap facilities, hydrogen and biogas fuel supply, and supporting services ecosystems for regional Australia.

a) On the demand side

In 2017, Agriculture Victoria published a survey of farmers’ concerns over energy and the barriers to investment in energy-efficient technology (Figure 22). The cost of energy was highlighted as the primary concern, and reliability also featured. These findings are consistent with the findings from interviews conducted as part of this diesel transition study.

What are the main energy-related concerns for farmers?

<table>
<thead>
<tr>
<th>Cost</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ for 75% of gas users</td>
<td>100% for 35% users</td>
</tr>
<tr>
<td>$66% of diesel users</td>
<td>21% of diesel users</td>
</tr>
<tr>
<td>$59% of electricity users</td>
<td></td>
</tr>
</tbody>
</table>

What are the biggest barriers to decreasing on-farm energy costs?

<table>
<thead>
<tr>
<th>Impact</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>High up-front cost of investment</td>
<td>73.5%</td>
</tr>
<tr>
<td>Low return on investment</td>
<td>63.2%</td>
</tr>
<tr>
<td>Unsure of how to choose appropriate technologies</td>
<td>31.8%</td>
</tr>
<tr>
<td>Technology changes too quickly</td>
<td>28.2%</td>
</tr>
<tr>
<td>Unsure of how to implement appropriate technologies</td>
<td>27.7%</td>
</tr>
<tr>
<td>Need to see others in my industry succeed first</td>
<td>10.1%</td>
</tr>
<tr>
<td>Lack of interest</td>
<td>8.1%</td>
</tr>
</tbody>
</table>

Figure 22. Energy-related concerns of farmers (Agriculture Victoria, 2020).
How will the sector transform?

High upfront costs coupled with a rapidly changing technology landscape and uncertainty over how to select appropriate technology is a significant impediment for the sector’s energy transition. There are alternatives to diesel, but these have not been viable for the Australian agriculture sector to date. Although there are early adopters of petroleum diesel alternatives, many in the sector have yet to engage in the transition. Reducing and replacing non-renewable energy sources, such as petroleum diesel, requires a degree of certainty over the direction of the energy ecosystem for regional areas.

Without a coordinated approach underpinned by government policy and incentives, early adopters would wear higher risk and likely go to great lengths to build or import equipment and machinery while creating small-scale local solutions for biogas, hydrogen fuel or battery charging without fiscal incentive. The early costs of establishing an on-farm or equivalent set-up would be high for the individual. They may also encounter barriers in all aspects of the investment, including insurance, warranty, servicing and availability of energy infrastructure. Coordination in local regional communities is important to aggregate demand and build local infrastructure, skills and energy supply chains.

Establishing transition zones in regions

The energy system transition is a chicken-and-egg problem. Farmers are unlikely to invest in new equipment if it’s unclear which technology manufacturers they will use in the long term or if refuelling and servicing capacity is unavailable locally. On the other hand, equipment providers are unlikely to invest in new products and the associated fuel supply chains are unlikely to develop in regional areas if there is no established demand.

One potential approach is to establish ‘nucleus zones’ in different geographic areas that align with existing policy and programming. These zones would consider locations of and build on, for example, clean hydrogen industrial hubs, special activation precincts, regionalisation loci, renewable energy zones and drought innovation hubs.

As a comparable initiative, the Future Fuels Program, the Federal Government has sought expressions of interest for low and zero-emission vehicle fleet demonstrations (ARENA, 2022). The funding for this program is intended to support charging infrastructure for light and heavy vehicle fleets, as well as partly cover some of the upfront costs for heavy vehicle fleets. The commitment to nucleus zones for the agriculture, forestry and fisheries sectors would enable demand aggregation and community coordination with suppliers and fuel supply chains for monitored product trials.

b) On the supply side

Major and boutique manufacturers have already developed battery electric, hydrogen, ammonia and methane-powered prototypes of commonly used agricultural machinery. In many cases, diesel alternatives outperform their counterparts, and some have entered production. The global shift to a net zero economy has resulted in several major equipment manufacturers publishing 2050 technology roadmaps and transition plans. For example, Volvo has published an indicative technology composition by engine types, phasing in battery electric, hydrogen fuel cell and alternative fuels in a declining internal combustion engine (ICE) market (Volvo Group, 2022a). Figure 23 shows Volvo’s market forecast of new engine technology from 2020–2050.

The Volvo roadmap highlights manufacturers’ uncertainty over which energy carrier technology will dominate future sales; battery electric or fuel-cell electric. The market share of internal combustion engines is also uncertain. However, manufacturers have consistently identified that it will decline significantly and be a small proportion of future vehicle sales over the next two decades. Biogas and other biofuels, as well as hydrogen combustion, are expected in the engine combustion cycle in the future.

Japanese manufacturer Komatsu produces heavy vehicles for the forestry, construction and mining sectors. Komatsu has presented its 2050 technology roadmap (Figure 24), giving insights into the progression of heavy industry machinery towards carbon neutrality (Komatsu, 2021b). Komatsu has forecast the introduction of hydrogen fuel cells with the on-site generation of hydrogen fuel, as well as battery electric technologies as the key contributors to the overall reduction in CO₂ emissions from the company’s products.

Figure 23. Volvo market forecast of new engine technology, 2020–2050 (Volvo Group, 2022a).

Figure 24. Komatsu Roadmap for Carbon Neutrality, 2020–2050(Komatsu, 2021b).

It will be important for the sector to coordinate with machinery suppliers to understand planned product release schedules and market forecasts for Australia. The inclusion of fuel supply chains will also be important. Working with the supply side could assist machinery distributors in identifying demand clusters and focus on developing business cases for launching prototypes or early market trials of new products in Australia.

A coordinated transition scenario would rely on establishing partnerships between equipment suppliers, local communities and all actors in the ‘energy ecosystem’. This scenario would require an intervention such as an advance market commitment that could kick-start clusters of activity around specific technologies in regional areas.
c) Skills

The agriculture, forestry and fishing sector has seen an evident shift in structure over the past 20 years, with a decline in workforce of two percentage points. The Australian Industry Skills Committee (AISC) identified that the agriculture sector was impacted by technology factors that have shaped the demand for skills (AISC, 2022). Across all sectors, the most prominent technology factors identified in the National Industry Insights Report 2021 were automation and robotics (including drones), and digitisation (DESE, 2022). The rise of digital transformation in the agriculture sector has driven greater demand for technology skills in regional Australia. The renewable energy transition (Rutovitz, 2021) is also a key driver of skills demand – the types of jobs expected to support the renewable energy industry range across all skill levels (Figure 25).

The Queensland Government’s Hydrogen Industry Development Roadmap has identified core skills that are required across the different stages and types of hydrogen projects, including plumbing, electrical work, process operations and engineering. These skills are also shared with bioenergy projects and are transferrable from LNG projects. Construction skills will be required to support regional energy infrastructure projects (DEST, 2022).

Strategies for developing a hydrogen workforce have been launched, focusing on key actions over the short, medium and long term. For the agriculture, fisheries and forestry sector, the development of local skills pipelines should be a priority, focusing on:

- Developing capacity in the workforce for skilled, adaptable workers suitable for emerging opportunities in regional hydrogen production and services.
- Matching training with skills demand around local employment opportunities.
- Establishing knowledge-sharing practices to support hydrogen skills development, training and safety outcomes.
- Taking an adaptive approach, using data insights to plan for the workforce needs of the sector over time.

Another initiative is through the ASC, which has approved a Battery Electric Vehicle Repair project. This includes a new qualification and updated skill sets and competencies. Through the ASC process, new training products will be available for delivery by registered training organisations (RTOs).

As initiatives are established, a regional skills mapping activity would provide an overlay between the demand for hydrogen, bioenergy and battery electric skills, with regional workforce profiles and training capacity. This could inform policy and training organisations in planning and selecting regional areas for new initiatives.

Summary

Lessons from other transitions in Australia and around the world demonstrate the importance of (i) identifying the need to actively transition; (ii) developing roadmaps at national, state and local levels; and (iii) determining the means to coordinate and drive investment into the transition.

Australian farmers are concerned about the cost of energy and the reliability of alternative energy solutions. The high upfront cost of investment in switching to alternative energy solutions, the potential low return on investment, the uncertainty of choosing the appropriate technology and the pace of change in the energy technology space are significant concerns for farmers and barriers to transitioning the sector.

The Australian Government through a portfolio of strategies has identified hydrogen as a key future energy carrier for the country. Advances have been made in developing means to economically transport hydrogen in the form of ammonia, which is an important step in unlocking the potential of hydrogen for Australian agriculture, including for use as an alternative to marine diesel oil.

Manufacturers of engines and agricultural equipment have been developing prototypes of alternative fuel systems, and products have been developed to use hydrogen fuel cells, as well as ammonia, battery electric and methane.

However, farmers are unlikely to invest in new equipment if it’s not clear which technology manufacturers they are going to use in the long term or if refuelling and servicing capacity is not locally available. Equally, equipment providers are unlikely to invest in rolling out new products, and the associated fuel supply chains are unlikely to develop in regional areas, if there is no established demand.

Traditional diesel engines enjoy an advantage in the economics of scale, proven performance and reliable supply chains that have been established for them over a long history in the market. An inherent tension exists for new equipment buyers between the reducing costs and improved performance of traditional diesel engines, against the higher costs and unproven performance of new alternative fuel technologies.

Transition from dependence on petroleum diesel fuels will require a coordinated approach across a wide set of stakeholders and a sector-scale simultaneous transformation of the entire system of fuel supply chains, equipment supply chains, financial and insurance services providers, service networks and workforce skills.
Recommendations

The transition from dependence on petroleum diesel fuels will require a coordinated approach across a wide set of stakeholders and a parallel transformation of the supporting ecosystem of fuel supply chains, equipment supply chains, financial services providers, service networks and workforce skills. While a national transition plan will require additional development, the sector must consider four initial priority areas to (i) understand constraints; (ii) align incentives and integrate planning to catalyse a coordinated change; (iii) target deployment of transition technology through ecosystem pilots; and (iv) bring supporting sectors on the journey. Government, industry groups or manufacturers may need to intervene to overcome barriers to adoption, capacity constraints and financial viability gaps. An initial understanding of constraints and short-term impacts on transition commodities, including biofuels, is required to establish a detailed sector transition plan.

Recommendation 1: Understand and map transition barriers

- Undertake a detailed assessment of potential constraints to transition. The analysis will vary across the sector and could be conducted on an industry basis and/or by geographic region.
- Consult with machinery and equipment suppliers and the sector to identify the potential supply of machinery and equipment to Australian markets.
- Evaluate the transition impacts on supply and demand of bioenergy products in Australia, including demand from difficult-to-abate industries, and consider lessons learned from previous bioethanol programs.
- Undertake a regional skills mapping activity to provide an overlay between hydrogen, bioenergy and battery electric skills demand, with regional workforce profiles and training capacity. This could inform policy and training organisations in planning.
- Identify potential regulatory or private sector/corporate policy issues that may inhibit new technology adoption and transition.

Creating a catalyst for change could involve a combination of government regulation and market incentives. Adoption incentives from equipment suppliers are another potential avenue. However, it is likely that in the early stages of the transition, manufacturers may not prioritise the Australian market. The system of incentives will need to be balanced to ensure all aspects of the ecosystem can transition at the same pace while meeting expectations on both the supply and demand sides of the market.

Recommendation 2: Align incentives and integrate planning and targets

- Identify the current set of positive and negative incentives available in the energy market to transition from diesel use, including existing policies, skills and training incentives, tariffs, excises, and rebates.
- Engage industry groups across the sector to identify overall transition targets and work to establish ambitious sub-targets for each transition phase to 2050.
- Promote the integration of the sector targets into existing strategic investment and planning activities, such as the National Hydrogen Roadmap and the work of RDGs, as well as incorporation into other sector–relevant industry roadmaps.
- Considering the key constraints, develop and advocate for the set of policies, regulations and incentives required by the agriculture, forestry and fisheries sector and its suppliers for transition.

While several energy technology options are emerging to replace petroleum diesel fuel, there isn’t a clear winner at this stage. A mix of technologies may be required across the sector. Small nucleus pilots will be required to assist in planning across different emerging energy technologies, with collaboration required between machinery suppliers and producers. Pilot programs must establish infrastructure and an energy ecosystem, including technology-related workforce skills. Each pilot should focus on a technology direction and allow agriculture, forestry and fisheries industries to test the most suitable energy supply chains and machinery. Solutions could vary by industry, scale of operation and regional area.

Recommendation 3: Pilot transition technologies in key places

- Develop the governance and institutional framework to initiate and support the national rollout of a major pilot program: To establish diesel transition ‘nucleus zones’ that can trial implementation of energy ecosystems across different energy technologies in agricultural areas.
- Identify potential ‘nucleus zones’ in different geographic areas that align with existing policies and programming, considering locations of, for example, clean hydrogen industrial hubs, special activation precincts, renewable energy zones and drought innovation hubs.
- The pilot programs should consider coverage of a broad range of agricultural activities and seek to attract the deployment of equipment, technologies and fuel supply chains to fit with established infrastructure and early coalescing of demand from producers, as well as workforce and skills availability.

Key considerations are:

- Commonwealth engagement with states and territories to establish expectations of the major pilot program, including financial, administrative and coordination support expectations. This could be part of a capital investment process in one or more states and territories. This discussion would inform budget processes at Commonwealth and state levels.
- Undertake a market sounding with manufacturers, distributors, research organisations and producers to be involved in developing technology demonstrations and trials for key technologies to establish viability.
- Develop local empowerment roadmaps and engage potential co-funders to enable and guide communities to lead local efforts through a two or three-stage competitive call for proposals nationally to design and implement energy ecosystems in each potential zone and attract equipment suppliers and supporting energy ecosystems.

- Consider a place-based approach to workforce development and establish a workforce development and extension framework for market support services to be developed.

Working with enabling industries, notably the financial services and insurance sector, will be an important consideration for transition. Identifying potential barriers to transition from financial and insurance products will require early engagement and involvement of key institutions in the early pilot programs.

Recommendation 4: Harness the expertise of enabling sectors

- Identify potential existing sector expertise that may be harnessed to provide training in transition skills for agriculture groups, and identify gaps and means to procure or develop capacity in critical areas.
- Undertake an assessment of key supporting sectors, such as training, finance and insurance, and map institutional stakeholders to identify which organisations need to be involved in the transition planning and the timing of engagement.
- Work with the financial services sector to integrate the diesel transition into ESG frameworks and incorporate these into sustainability–linked loan products for producers.
- Identify financial services and insurance sector risks and concerns over financing or insuring assets during the transition period.

To avoid costly disruption and the stranding of assets or businesses, the agricultural, forestry and fisheries sector must actively plan for a transition from reliance on petroleum diesel. While current barriers are not insurmountable, they are significant. It is up to industry bodies, research institutions and governments to create the supporting ecosystems described in the recommendations above. By doing so, Australians can collectively improve efficiency and productivity, and hasten the pace of climate change mitigation efforts to shore up the sector’s natural capital.
Appendix A

National blueprints

Australia’s Bioenergy Roadmap, 2021
(ARENA, 2021)
The roadmap identifies the bioenergy sector’s role in Australia’s energy transition, opportunities for regional development and role in helping Australia further reduce emissions. The roadmap indicates the bioenergy investment will support long-term regional employment, providing additional revenue streams for farmers and ultimately national economic growth. The Bioenergy Roadmap will:
• Enable market opportunities in hard-to-abate sectors: renewable industrial heat, sustainable aviation fuel and renewable gas grid injection. These opportunities currently have limited low-emissions alternatives.
• Enable market opportunities where bioenergy can complement other low-emissions alternatives: in the road transport and electricity markets.
• Support resource development: Australia has a significant bioenergy resource potential. However, there is insufficient clarity and detail on the viability and sustainability of these resources.
• Build supportive ecosystems: An enduring and successful bioenergy industry will require concerted efforts beyond those relating to markets and feedstocks. It will be necessary to harness an ecosystem linking the bioenergy industry’s diverse parts to facilitate its growth.

Australia’s Long-Term Emissions Reduction Plan, 2021
(Department of Industry, Science, Energy and Resources, 2021a)
The plan is designed to achieve net zero emissions by 2050. The plan focuses on practical and responsible technology that will take advantage of new economic opportunities while continuing to serve ways of living, traditional markets, jobs and prosperity in the current economy. Further, the plan prioritises technologies that will cut emissions while creating jobs and growing the economy. The plan outlines how to:
• Drive down the cost of low-emissions technologies
• Deploy these technologies at scale
• Help regional industries and communities seize economic opportunities in new and traditional markets
• Work with other countries on the technologies needed to decarbonise the world’s economy.

Future Fuels and Vehicles Strategy, 2021
(Department of Industry, Science, Energy and Resources, 2021b)
The strategy emphasises the importance of the government working with the private sector, increasing the uptake of hybrid, hydrogen, electric and bio-fuelled vehicles. The strategy will make it easier to roll out future fuel technologies and generate awareness among consumers and better information. The strategy also focuses on ensuring electricity grids are ready for more electric vehicles across the country. The strategy will:
• Promote consumer choice in vehicles
• Develop local industries and jobs
• Reduce emissions
• Improve health outcomes and increase fuel security.

Technology Investment Roadmap: A strategy to develop and deploy low-emissions technologies, 2020
(Department of Industry, Science, Energy and Resources, 2020)
The roadmap sets a strategy and a process to develop and deploy low-emissions technologies in Australia by focusing on government investment. The roadmap aims to reduce the cost of new low-emissions technologies about the same as existing high-emissions technologies. The roadmap will:
• Deliver low-cost, clean and reliable energy to households and industry
• Increase productivity, create jobs and substantially reduce emissions from Australia’s primary industries
• Expand Australian manufacturing and capture new export markets for low-emissions commodities, and help Australia store carbon dioxide in soils, plants and underground reservoirs.

Australia’s National Hydrogen Strategy, 2019
(Indigenous Energy Council, 2019)
The strategy sets a vision for a clean, innovative, safe and competitive hydrogen industry in Australia that is a major global player by 2030 and that benefits all.
• The hydrogen strategy:
  • Explores Australia’s clean hydrogen potential.
  • Considers future scenarios with wide-ranging growth possibilities.
  • Outlines an adaptive approach that equips Australia to scale-up quickly.
  • Includes showcases from each state and territory, and details nationally coordinated actions involving governments, industry and communities.

Australia’s energy transition: a blueprint for success, 2019
(Wood, 2019)
Developed by the Grattan Institute, the blueprint promotes a future energy mix of renewables, batteries, electric vehicles, hydrogen and novel uses of fossil fuels with carbon capture and storage.

National Hydrogen Roadmap, 2018
(Bruce, 2018)
The roadmap provides a comprehensive strategy for turning emerging technologies that support a hydrogen economy into bankable assets as a foundation for building an economically sustainable industry and realising the opportunity for a hydrogen industry in Australia. The roadmap provides information on investment across the hydrogen value chain. It also includes electricity/energy storage, heat, transport and industrial uses. The authors undertook detailed techno-economic assessments for each application for hydrogen in the energy sector. To create the roadmap, 20-plus organisations representing government, research and local and global industries participated. They developed an investment framework that outlined the commercial models, policy/ regulations and RD&E investment required to allow hydrogen utilisation to become competitive in local and global markets.

Queensland Government Hydrogen Workforce Development Roadmap
2022–2032
(Department of Employment, Small Business and Training, 2022)
The Queensland Government is working in industry skills and training providers, universities and regional bodies to look ahead, anticipate the skills needs of the hydrogen industry and plan a path to supporting a hydrogen-ready workforce.

The roadmap identifies short, medium and long-term actions focused around:
• Building a pipeline of skilled workers for the hydrogen industry
• Sharing knowledge and supporting hydrogen for training and safety
• Local approaches to skills, training and workforce development
• Leveraging data insights to plan for workforce needs over time.
Example on-farm petroleum diesel avoidance and efficiency measures

Interim measures can be taken to reduce petroleum diesel consumption as the agriculture energy ecosystem transitions, with new fuels becoming available in regional areas, new equipment coming to market and new skills being developed across the workforce.

The focus of this report has been on the end-state of a transition away from petroleum diesel fuels, concentrating on the three major alternative fuels for the sector of (i) hydrogen and ammonia; (ii) battery electric; and (iii) bioenergy.

There are many reports published on technologies that improve farming energy efficiency. Many resources have also been made available on farming practice changes that can avoid or minimise consumption of petroleum diesel fuels (Figure 26). The research team recommends the CEFC joint publication with the NFF titled Transforming Australian agriculture with Clean Energy, which serves as a practical guide to identifying and implementing new clean energy and efficiency practices.

Substantial reductions in operating costs can be achieved through implementing change in practice. One example of this is the introduction of zero-tillage practices. Conventional tillage is assumed to be on dry land and typically involves a sequence of soil tillage, such as ploughing and harrowing, to produce a fine seedbed and remove most of the plant residue from the previous crop. Tractors consume a large amount of diesel in this process, with wheat crops requiring the largest amount of diesel fuel as wheat has the highest amount of secondary tillage.

This report does not promote recommendations for particular practice changes, rather it highlights that there are examples and resources available for agribusinesses that have potential to reduce diesel costs. For example, robotics can automate many tasks in agriculture, such as fruit picking, weed spraying and phenotyping. Energy savings depend on the application. A solar-powered plant-monitoring robot could lead to lower overall energy consumption by reducing fuel use associated with visual inspections. Many other examples of innovations to improve on-farm energy efficiency exist, including those listed in Table 4.

Reduced machinery use through practices, e.g. precision farming, zero-tillage

- Improved engine efficiency in new models
- Hydrogen-hybrid conversions
- Diesel fuel substitution, e.g. biodiesel, synthetics, ethanol
- Engine substitution with electric and hydrogen fuel cells (long term)

Reducing consumption through irrigation efficiency measures

- Hydrogen-hybrid conversions, solar/battery pumps
- Bioenergy heating and generation solutions
- Diesel fuel substitution, e.g. biodiesel, synthetics, ethanol

Shifting activities to alternative technology, e.g. drones where possible

- Replacing with electric vehicles

Figure 26. Example approaches to avoid or reduce on-farm diesel consumption.

Table 4. Example innovations for reducing petroleum diesel fuel consumption.

<table>
<thead>
<tr>
<th>Innovation Description</th>
<th>Innovation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless communications for smart monitoring and control</td>
<td>Long-range wireless communication can control gates, pumps and other equipment remotely over long distances, and sensors or nodes can remotely detect water availability, soil health and plant health. Long-range systems can transmit information over up to 40 km, reducing fuel costs associated with direct monitoring and controls, and improving operational efficiency.</td>
</tr>
<tr>
<td>Variable speed drives</td>
<td>Variable speed drives are a cost-effective improvement to energy efficiency in motorised pumps. A variable speed drive, also known as a variable frequency drive or an adjustable speed drive, has been claimed to save up to 60% on energy costs compared to regular pumps.</td>
</tr>
<tr>
<td>Scroll compressors</td>
<td>A scroll compressor is claimed to save dairy farmers 15-20% on energy costs against traditional reciprocating compressors. This technology also works for any farmer who depends on refrigeration to preserve their product, including fruit and vegetable farmers.</td>
</tr>
<tr>
<td>Steiger tractor</td>
<td>Developed by Case IH using SCR emissions technology, these petroleum diesel tractors set fuel efficiency records at the Nebraska Tractor Test Laboratory, with compelling results in horsepower and maximum pull while consuming less fuel. It is claimed that farmers can expect to save about US$1,000 per year from lower fuel costs and reduced maintenance expenses. These tractors can go 600 operating hours without an oil change. They also have no particulate filter and require no regeneration period.</td>
</tr>
<tr>
<td>Automatic in-row weeder</td>
<td>The in-row weeder uses sensors and a spike to impact the ground surrounding each plant, killing any weeds growing there. This device improves farm efficiency by increasing yield and reducing losses, helping to produce greater quantities of healthy, marketable crops. This device can quickly harvest carrots, saving farmers labour costs.</td>
</tr>
<tr>
<td>Airhead potato harvester</td>
<td>Built by Advanced Farm Equipment, the Airhead harvester solves the problem of mass-harvesting potatoes without bruising, and uses less fuel than other equipment built for the same purpose. It cuts energy costs as well as labour costs, resulting in savings, especially for large farms.</td>
</tr>
<tr>
<td>Driverless tractors</td>
<td>Driverless tractor concepts built by the large tractor manufacturers are based on technologies such as GPS auto-steer, variable rate application, continuously variable transmission and drive-by-wire functionality. The potential benefits of driverless tractors include reduced labour costs, increased productivity and equipment utilisation rates, alongside the more precise application of farming inputs.</td>
</tr>
<tr>
<td>Unmanned aerial vehicles</td>
<td>Unmanned aerial vehicles (UAVs) are used in agriculture for surveillance of farm assets, crops and livestock, and drone-mounted sensors can identify weeds and diseases. Drones can reduce fuel consumption by reducing the need for physical inspections using a vehicle.</td>
</tr>
</tbody>
</table>
Appendix C

Australian Fuel Tax Credit Scheme

Fuel excise was introduced in Australia to fund public roads. However, since its introduction, successive governments have changed the fuel excise rate (including indexation) and hypothesisation of funding\(^8\) solely for investment in roads. Despite this, today, vehicles or machinery solely used on private roads benefit from a fuel tax credit (FTC) that offsets the excise. FTCs provide a significant benefit to agribusinesses based in rural, regional and remote Australia, where fuel is an essential input for a range of activities.

The fuel tax credits scheme ensures agribusinesses are not disadvantaged by paying excise on the off-road use of diesel in the production of goods and services. Farming and fisheries industries can access a rebate to the 44.2 c/L excise on diesel for off-road use. The tax credit rates have increased from 39.5 c/L in 2016 to 44.2 c/L in 2022.\(^9\) The mining sector claimed more than $3 billion in fuel tax credits between 2019-2020 while the agriculture sector claimed less than $900 million (DCCEEW, 2022a).

The NFF has expressed that any cut to the rebate would damage Australia’s agriculture competitiveness, as most farmers use diesel.

Historically, the mining sector represents the highest value of fuel tax credit claims; however, the agricultural sector represents the most claims (Table 5, Figure 28).

Biodiesel and fuel ethanol are also subject to rates of excise duty, which are being phased into the Australian market. An excise duty of 32.77% on fuel ethanol was applied in Australia from 1 July 2020, and 50% on biodiesel will be applied from 1 July 2030 (ATO, 2020). Any potential market distortion effects on investment and adoption of new energy technologies from excise and credit schemes are outside the scope of this report.

Table 5. Fuel tax credit claims and value among agriculture subsectors (DCCEEW, 2022a).

<table>
<thead>
<tr>
<th>Rank</th>
<th>Subsector</th>
<th>Number of fuel claims</th>
<th>Value of fuel claims ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sheep, beef cattle and grain farming</td>
<td>195,150</td>
<td>513</td>
</tr>
<tr>
<td>2</td>
<td>Fruit and tree nut growing</td>
<td>20,755</td>
<td>74</td>
</tr>
<tr>
<td>3</td>
<td>Dairy cattle farming</td>
<td>19,863</td>
<td>51</td>
</tr>
<tr>
<td>4</td>
<td>Other crop growing</td>
<td>15,682</td>
<td>53</td>
</tr>
<tr>
<td>5</td>
<td>Agriculture and fishing support services</td>
<td>13,671</td>
<td>46</td>
</tr>
<tr>
<td>6</td>
<td>Fishing</td>
<td>11,116</td>
<td>51</td>
</tr>
<tr>
<td>7</td>
<td>Mushroom and vegetable growing</td>
<td>10,052</td>
<td>37</td>
</tr>
<tr>
<td>8</td>
<td>Other livestock farming</td>
<td>8,868</td>
<td>36</td>
</tr>
<tr>
<td>9</td>
<td>Forestry and logging</td>
<td>4,984</td>
<td>14</td>
</tr>
<tr>
<td>10</td>
<td>Nursery and floriculture production</td>
<td>3,475</td>
<td>9</td>
</tr>
<tr>
<td>11</td>
<td>Poultry farming</td>
<td>2,471</td>
<td>7</td>
</tr>
<tr>
<td>12</td>
<td>Aquaculture</td>
<td>1,955</td>
<td>5</td>
</tr>
<tr>
<td>13</td>
<td>Forestry support services</td>
<td>845</td>
<td>4</td>
</tr>
<tr>
<td>14</td>
<td>Hunting and trapping</td>
<td>407</td>
<td>0.284</td>
</tr>
<tr>
<td>15</td>
<td>Deer farming</td>
<td>99</td>
<td>0.024</td>
</tr>
</tbody>
</table>

Table 5. Fuel tax credit claims and value among agriculture subsectors (DCCEEW, 2022a).

- Rank Number of fuel claims Value of fuel claims Value ($m)
- Subsector Number Subsector Value ($m)
- Sector Number of fuel claims Value of fuel claims ($ million) (2019-2020)
- Number of fuel claims by industry (2019-2020)
- Value of fuel claims by industry (in $ million) (2019-2020)


\(8\) i.e. dedication of revenue to a particular expenditure purpose.

\(9\) For six months from 1 April to 1 October 2022, the fuel excise was reduced in the Federal Budget to 22.1 c/L for all road fuels.

**Figure 28. Fuel tax credit claims by industry, value and number (ATO, 2020).**