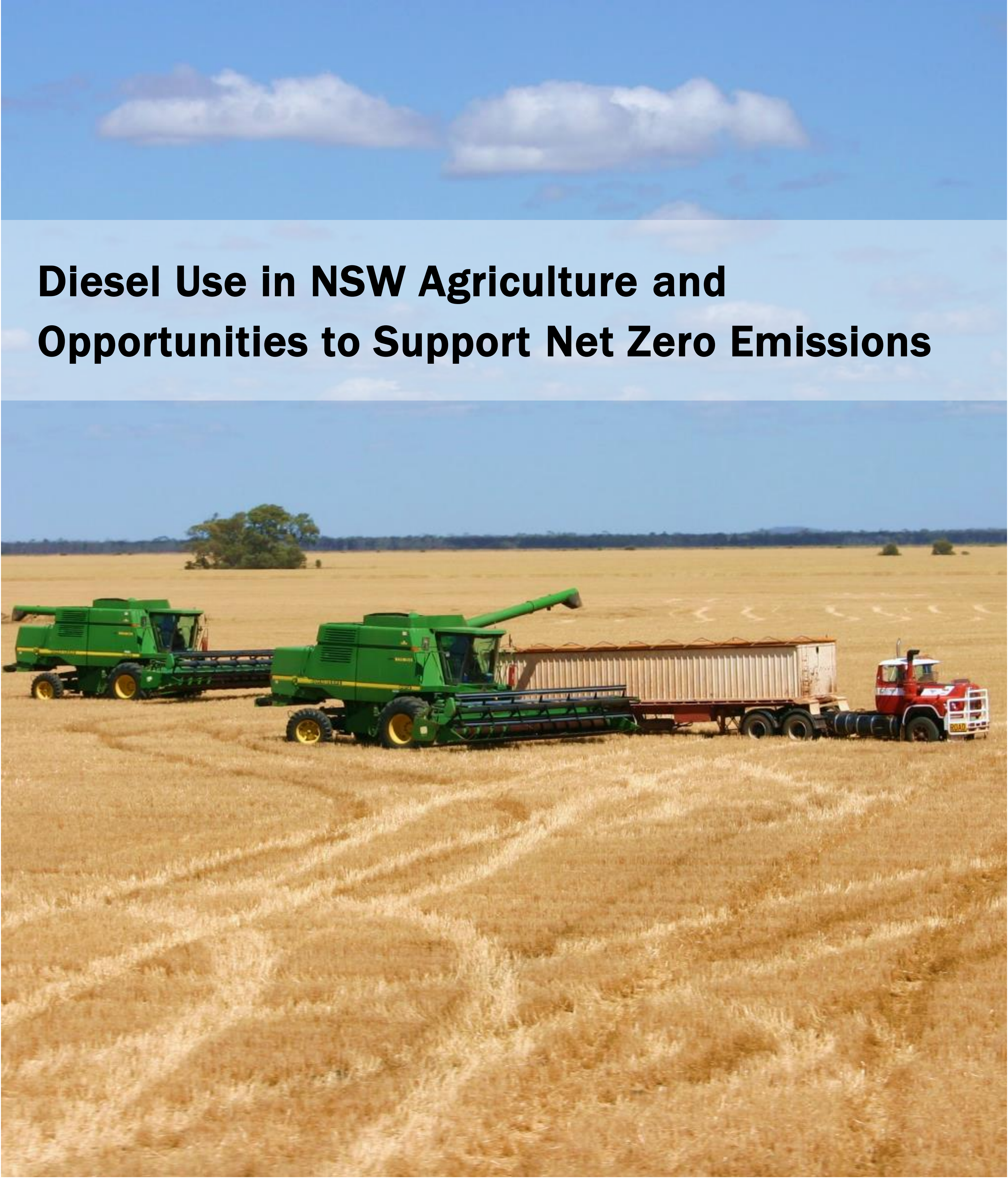
Diesel Use in NSW Agriculture and Opportunities to Support Net Zero Emissions



MOVEMENT transport energy environment

NSW GOVERNMENT Department of Primary Industries

AUSTRALIAN ALLIANCE FOR ENERGY PRODUCTIVITY

AUTHORSHIP OF THIS REPORT

This research was commissioned and managed by the Australian Alliance for Energy Productivity (A2EP) for the NSW Department of Primary Industries. The work was funded through the Climate Change Research Strategy (Project 1: Clean energy solutions). The team at MOV3MENT [mov3ment.com.au] researched and wrote the report. A2EP wishes to acknowledge the contributions and advice received from Cathy Waters, Michael Cashen, John O'Connor and Liz Hutton at the Department during the work.

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CLIMATE CHANGE RESEARCH STRATEGY

To ensure the continued growth of NSW Primary Industries, and safeguard the future of the regional communities, the sector needs to be resilient and adaptable to changes in economic and environmental conditions. Supported by an investment of $29.2 million from the NSW Climate Change Fund, the Strategy invests in project and program areas that could support the primary industries sector to adapt to climate change.

The Strategy seeks to identify through research, and innovation, energy supply and demand solutions, carbon opportunities and climate resilience building programs to enable our primary industries to prepare for the challenges and opportunities climate change presents. The results of this research will be useful in informing forward work programs and policy to support the long-term sustainability of primary industries for NSW. More at dpi.nsw.gov.au

DISCLAIMER

ABOUT A2EP

A2EP is an independent, not-for-profit coalition of business, government and research leaders helping Australian businesses pursue a cleaner and more successful future by producing more with less energy.

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EXECUTIVE SUMMARY

Following previous reports on energy use in intensive agriculture, this report looks at extensive agriculture where diesel is the primary energy source. The amount of diesel used by different sub-sectors of agriculture varies widely, but beyond individual case studies, little data exists on how and where it is used.

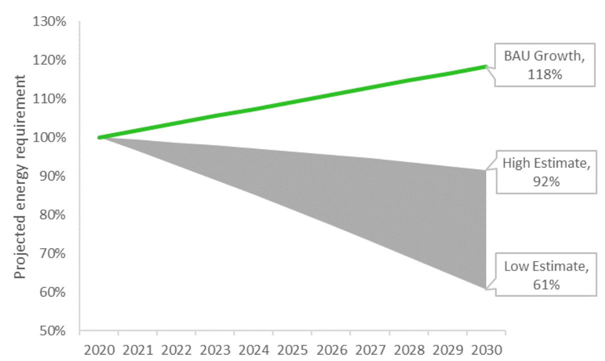
Although diesel represents over 80% of the energy consumed by agriculture in NSW, it is not the major source of its GHG emissions. In fact, diesel represents only 8% of agriculture's GHG contribution. Animal husbandry and crop production make up most of the remainder. Diesel can contribute to net zero carbon emissions in agriculture, but the other 92% will still need addressing with other options.

The main two pathways explored by this paper are improvements in energy productivity, and fuel switching to lower carbon energy alternatives. Diesel machines were split into two groups: stationary off-grid machinery such as bore pumps; and mobile machinery such as tractors, headers and support vehicles.

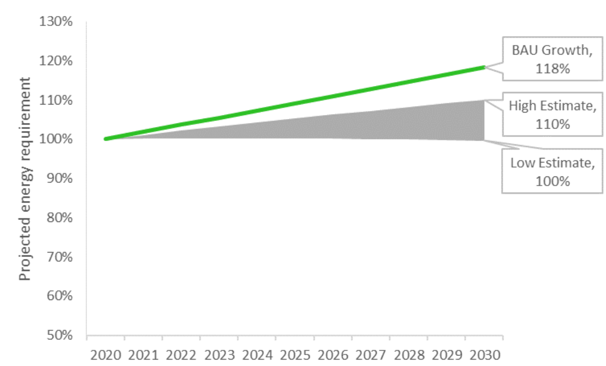
Actions to improve diesel machine efficiency have a triple benefit: reducing emissions from existing operations, cutting on-farm costs, and reducing the amount of alternative energy that eventually needs to be found to replace diesel. A lot of efficiency information has been made available by government, but its uptake has been hampered by farmers' preference for learning face-to-face from trusted persons.

The efficiency of machines alone has been steadily improving for decades and will continue to do so. A key future enabler of efficiency will be partial electrification, in the same way a hybrid car that is still powered by petrol/diesel, but the electric motor and small battery enable energy recovery and efficient driving. Electric motors will increasingly take over particular functions on complex agricultural machines because they are simply better suited to the task. Where necessary (such as in large mobile machines) a fuel such as diesel, hydrogen or gas will generate the required electricity, providing much higher efficiency than direct fuel use.

Increasing levels of agricultural production will require more energy unless productivity can be improved to counter the energy demand. The federal government's Ag2030 vision for $100bn of agricultural production by 2030 would likely require 40% more energy in 2030 than the business-as-usual situation of today, negating some, if not all, of the benefits from efficiency improvements.



Off-grid stationary machinery (efficiency & electrification)



Mobile machinery (efficiency alone)

For stationary off-grid machinery, the most promising pathway is replacing diesel with electric motors:

- In grid-connected situations electric motors are already a known and trusted technology.
- Solar and wind electricity generation is starting to be understood and trusted on farm.
- Where continuous supply is required, batteries or hybrid systems with diesel backup can be used.
- A small proportion of systems which require high power but are only used very occasionally are likely to stay diesel for the foreseeable future.
- Use of both fossil gas and biomethane require diesel machines to be replaced. Fugitive emissions are a big risk to achieving emissions reductions. On balance, this path is seen to be of little benefit.
- Hydrogen fuel cell systems are an immature alternative to battery storage. Even if systems are commercially available by 2030, real benefits are unclear.
- The production and use of biodiesel or renewable diesel will benefit GHG emissions. This has the added benefit of reducing emissions from legacy (in-service) equipment, not just new products.

For mobile machinery:

- There is no easy replacement for diesel in large vehicles. Smaller support vehicles may start a transition to battery electric in the medium term.
- Battery electric systems won't be capable of powering a large machine for a 12 hour shift within the 10 year time period assessed.
- Hydrogen fuel cell systems are similarly immature and will not be available on a commercial scale in this timeframe.
- Use of both fossil gas and biomethane require diesel machines to be replaced – but the risk of fugitive emissions makes this switch less beneficial.
- Mobile machines are very capital intensive and used for many years. Even when new technology and fuel is available, any change that requires vehicle replacement will have a very small and slow impact on the industry's GHG emissions.
- The only practical way to rapidly reduce emissions in the 2030 timeframe is to rapidly ramp up biodiesel or renewable diesel production and use as an interim combustion transition fuel, while building capacity and confidence for the non-combustion future alternatives.

Key actions for government are to address the barriers to adoption of both cleaner combustion fuels and the non-combustion future alternatives. These barriers mostly relate to market confidence, high costs, and lack of fuel/energy infrastructure.

Short-term actions (1-2 years) that could accelerate the emissions reductions by specifically focussing on energy productivity as a foundation for future work. Actions could also support improving baseline data and information (particularly with demonstration projects and peer-to-peer knowledge sharing); supporting on-farm efficiency assessments (like Victoria); benchmarking and defining best practice.

Medium-term actions (2-5 years) could include more support for the production of biofuels and renewable diesel, financial support to reduce switching costs, a focus on reducing the user price, as well as promotion/education about the viability of these fuels in broadacre applications (i.e. large machines). Government could also work with equipment suppliers to understand and map the path of future technologies (electric and hydrogen) to market. Investigating regional energy hubs to both take and supply low carbon fuels might also support an accelerated transition.

Over the longer-term (5-10 years), supporting manufacturers to bring more electric and hydrogen models to market could provide greater choice to farmers who are often aligned with one manufacturer for specific products. Enabling farmers who over-achieve to monetise their emissions reductions could also open up additional revenue opportunities and position them as leaders in the fight against climate change.

GLOSSARY

BEV	Battery Electric Vehicle (Motive power by electricity only)
PV	Photovoltaic system to generate electricity from sunlight
PTO	Power Take-Off
CTF	Controlled Traffic Farming
CNG	Compressed Natural Gas
LNG	Liquefied Natural Gas
RNG	Renewable Natural Gas
RoI	Return on Investment

1 Introduction

Diesel is the dominant input cost for many farms. It fuels tractors and other vehicles, pumps, machinery and remote electricity generators. The following sections examine how choices in both mobile and stationary off-grid machinery can reduce the volume of diesel used on the farm. Both short-term low-cost strategies for reducing diesel are examined, and longer-term higher cost solutions are also discussed. Future fuel options and the role of government are also analysed before concluding with comments and observations on the various technologies and trends and their likelihood of reducing the amount of diesel used on-farm.

As Figure 1 below shows, extensive agriculture that is the focus of this study, such as the broadacre cropping and grazing sectors, is more reliant on diesel than are the intensive farming sectors such as dairy, horticulture and poultry. Intensive farm types tend to use more electricity for their stationary energy applications, as was noted in a previous study focussed on the opportunities in those sectors (A2EP, 2019).

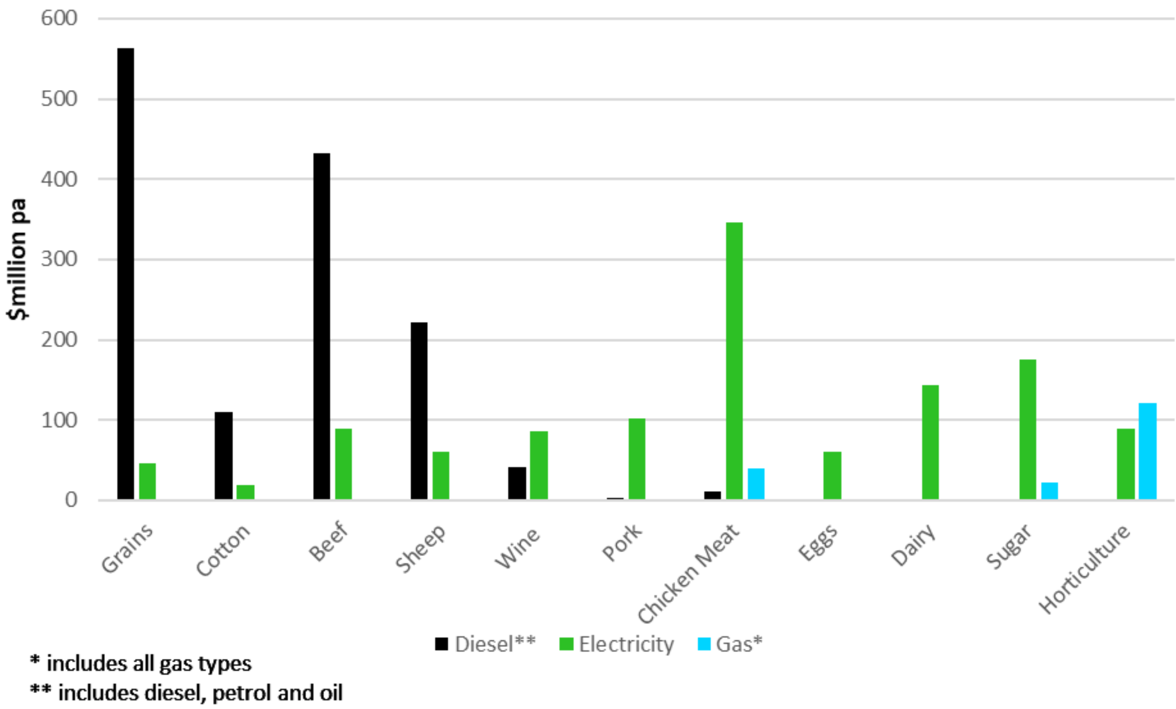


Figure 1 Cost of energy sources to each sector. Derived from (Australian Farm Institute, 2018).

2 How much diesel is used and where?

In 2019, Australian agriculture consumed 85.9 PJ of diesel, equivalent to 2,225 ML (ABS, 2020), (DISER, 2020). Over 80% of the energy consumed by agriculture in NSW and nationally, is in the form of diesel.

The amount of diesel used by different sub-sectors of agriculture varies widely. Understanding the distribution of diesel use across farm/commodity types, locations, and activities is important in identifying trends over time, modelling potential opportunities, and focussing on priority areas. However, the limited data that exists is fragmented and non-standardised. A compilation of available data found in this study, showing the relative use of diesel for different activities (columns) by various farm/commodity type (rows), is shown in Table 1.

The last column shows the overall average diesel intensity for the different farm types. It is clear that cotton is by far the most diesel-intensive farm type, with 4 to 5 times the diesel usage per hectare than the next sub-sector (wheat). It can also be seen that, on farms where they are used, tillage and pumping are major fuel users.

Table 1 Estimate of Australian on farm diesel usage (Approximate)

	Tillage	Planting	Fertilizer application	Harvest	Spraying & Mobile irrigation	Pumping & stationary irrigation	Support vehicles	L/ha
Dairy	21%	0%	0%	35%	0%	0%	44%	52
Wheat	66%	8%	8%	10%	8%	Not included	0%	64
Wheat (no-till)	0%	15%	15%	15%	50%	Not included	0%	33.1
Wheat (irrigated)	0%	7%	7%	19%	20%	47%	0%	69.9
Cotton	10%	1%	5%	27%	6%	51%	0%	290
Sheep/wool	0%	0%	66%	NA	44%	0%	0%	4.2

Sources: (Chen, 2015), (Australian Farm Institute, 2018), (Chen, 2015)

2.1 Cotton

On highly mechanised cotton farms, diesel represents up to 90% of the total energy consumption (Foley, 2015), with half of this used for irrigation pumps. Bore irrigation requires higher energy than river irrigation (CottonInfo, 2018). Tractor use during ground preparation (10.3%), harvesting (13.8%), and post-harvest crop destruction (13.2%) are the next largest diesel consuming activities. Median direct energy use per hectare was estimated at 290 L/ha (Foley, 2015).

2.2 Grain

On grain farms, diesel comprises 85% of the total energy consumption (Australian Farm Institute, 2018) – almost as high as cotton.

In the northern wheat region (NSW and Southern QLD) on non-irrigated land, each hectare of wheat grown required 64 L of diesel. Of that, 42 L (66%) was used just for the tilling (conventional tillage). Comparable figures for other grains vary. Sorghum and barley were quoted at 23.3 L/ha and 51.8 L/ha respectively (Chen, 2015).

Wheat grown in the same region under irrigation (with mostly diesel-powered pumps) averaged 69.9 L/ha (Chen, 2015). Irrigation similarly increases diesel use for sorghum (77.7 L/ha) and barley (95.8 L/ha (Chen, 2015).

2.3 Wool and Sheep

In the research for this report, no information was found to quantify energy inputs and the energy cost impact on producers and processors across the wool supply chain in Australia. This is an important knowledge gap for the wide range of sheep farming and wool processing systems (Australian Farm Institute, 2018). Furthermore, data for wool and sheep energy use is not separated within individual farming practices because the co-production of wool and meat in one flock is complex, as both products are often jointly produced from the same sheep flocks (Chen, 2015).

2.3.1 Wool

A Victorian wool study (on a no-till farm) found fertilizing (0.81 L/ha) and spraying (0.65 L/ha) were the biggest consumers of diesel. Diesel use totalled 1.46 L/ha, or around 96% of all on-farm direct energy use (Biswas, 2010).

On-farm energy use is greater again if irrigation is involved. An energy case study of a large (45,834 hectare) 18,000 head merino farm (with some grain cropping) north of Conargo in the Western Riverina district of NSW revealed that diesel comprised 85% of on-farm energy use at 6.4 L/ha. Of that figure, 80% was used for irrigation pumping, with the rest for tractor and heavy vehicle use (again without additional breakdown data) (Flores, 2014).

2.3.2 Sheep

The most detailed look at the lamb/sheep meat industry is a life cycle analysis of Australian sheep production at multiple sites countrywide (Wiedemann, 2016). Energy demand varied widely, depending on location, farm size and other factors, but fossil fuel use was found to be heaviest on farm rather than at processors. Although the study did not provide a detailed breakdown of the use of diesel and other energy sources, it showed the diesel heavy demand ranged from 0.06 to 0.18 L/kg liveweight and averaged 4.24 L/ha for the average of farms studied in Eastern NSW.

2.4 Beef

Although beef farming is NSW’s second largest agricultural sector after wheat, detailed data about on-farm fossil fuel consumption is poor, with no breakdowns of diesel use by farming operation. (Australian Farm Institute, 2018). However, there are still clear trends. Just as in the sheep sector, fossil fuel energy consumption on beef properties was found to vary widely depending on farm size, soil and pasture type, location and operating methods. In this sector though, unlike sheep, energy consumption was higher in downstream processing operations rather than on the farm - where mean fossil fuel demand typically ranged between 0.14 – 0.21 L/kg liveweight (Wiedemann, 2014)

These figures are similar to the sheep sector, as are fuel costs as a portion of total costs (around 6%); however, the diesel intensity in litres per hectare are not available for the beef sector (Chen, 2015).

2.5 Dairy

Diesel’s portion of energy used for dairy farming in NSW is much smaller than in other industries, as electricity is the dominant power source. Chen found that electricity use makes up 67% of the total direct on-farm energy consumed, including 47% for irrigation water pumping and 20% for shed operations; while diesel fuel used for tractor field operations contributes 30% (Chen, 2015).

No data was found for disaggregating the work performed using different types of diesel equipment. However, by extrapolation: Harvesting forage for future use appears to be the greatest usage of diesel (at approx. 35%); followed by soil tilling/cultivation of that same forage crop; with the rest of the diesel consumed by vehicles engaged in hay/silage dropping and miscellaneous farm operations.

For the hypothetical 'average' 150 ha dairy farm, typical diesel consumption is approx. 52 L/ha (Chen, 2015).

2.6 Summary

It impossible to develop a thorough understanding of the distribution of diesel use across farm/commodity types, locations, and activities without better data than currently exists. This brief examination does however reveal that diesel use is high throughout the major broadacre sectors. The equipment in which diesel is used includes both stationary off-grid machinery and mobile machinery.

- Diesel use is particularly high in the cotton and grain sectors.
- Cotton uses very large amounts of water which are traditionally pumped by diesel pumps.
- Grain farming with conventional tillage sees tractors consume large amounts of diesel.
- Grain farming on irrigated land also uses a high proportion of diesel for pumping.
- Dairying, although on smaller parcels of land, is very energy intensive and uses substantial amounts of both diesel and electricity.
- Livestock farms, although not as energy intense as the other sectors, still rely on diesel to provide the bulk of their on-farm energy requirements.

2.7 Gaps

There is little on-farm data of sufficient depth and breadth to understand how much energy individual equipment or processes are consuming in extensive farms. More granular data could provide guidance on the biggest energy consuming activities, and areas of greatest potential policy impact. For example:

- The Energy Efficiency Information Grants program (EEIG) ran from 2012 to 2015. It included some energy audits and published case studies. Although a lot of advice has been published on the associated AgInnovators website, no summary statistics of the audits have been found.
- More recently, Business Victoria has gathered useful data in its recently closed Agriculture Energy Investment Plan, where it has offered free on-farm energy audits (Business Victoria, 2020). Depending on the level of follow-up carried out, aggregated results of this work could provide valuable insights into areas of opportunity or concern in Australia.

3 Why reduce reliance on diesel?

As indicated in the figures above, diesel is often the largest operating expense for extensive agriculture farmers, or the second largest behind labour cost. But there are other reasons beyond costs to reduce on-farm use of diesel. These include:

- reducing the commercial risk farmers are exposed to from oil price fluctuations.
- increasing the energy security of the Agriculture industry and Australia as a whole, due to its reliance on imported fuel
- reducing the amount of greenhouse gases (GHG) emitted from burning fossil fuels – which may have the associated benefits of improving social licence to operate and securing future markets.
- strengthening rural communities and supply chains with a more resilient agricultural industry.

Beyond these reasons, there are also practical benefits such as saving time. Steam Plains sheep farm, which was using 300,000 litres of diesel each year, found investing in a solar powered bore pump on a remote paddock did not just save on diesel use: "The business decision was enhanced by halving the number of trips by farmhands to this paddock to maintain and refuel diesel pumps" (Flores, 2014). By freeing up time for other tasks or reducing the need for labour, the overall productivity of the operation can be improved.

3.1 Reducing Commercial Risk

By relying heavily on diesel, farmers are vulnerable to any fluctuations in the global oil price. Price volatility is a significant issue because of the commercial uncertainty (and financial risk) it creates in long-term business planning. This is particularly relevant because it adds uncertainty in input costs, on top of existing uncertainty in revenues due to trading their output commodities on world markets.

The price of diesel is driven by global oil market dynamics and the relative value of the Australian dollar. Figure 2 shows that year to year diesel price variations of 15-25% are common. The 2020 year to date value is still recovering from the COVID-19 induced oversupply early in 2020, where the unexpected worldwide demand crash caused the price to drop close to 30% below 2019s average.

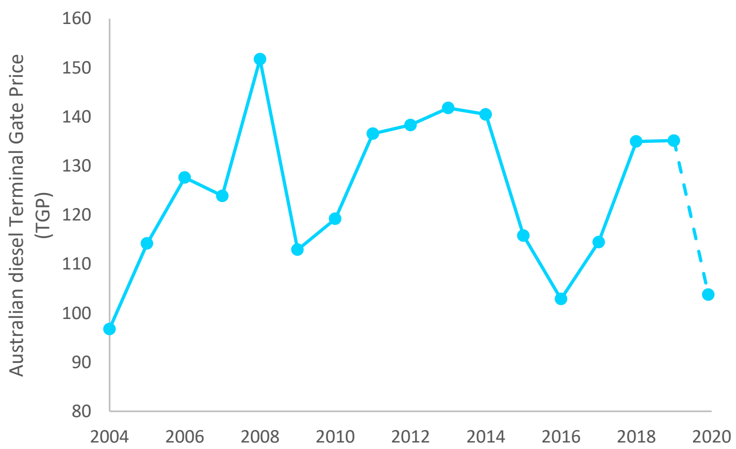


Figure 2 Historic diesel price (AIP, 2020)

Figure 3 shows the EIA's long-term projection of oil prices. Although a major recovery is expected in 2021 and beyond, the effects of COVID reducing oil demand are expected to be permanent with changes in consumer behaviour following the short-term economic disturbance (Nagle, 2020). It is unclear how this will affect world oil prices, but reductions in production to match demand mean the price may not remain low. If prices do trend higher for whatever reason, the diesel dependent agricultural sector will face rising operational costs that can test the resilience of individual operators.

Any energy savings from farmers can increase business resilience by reducing exposure to price shocks and lowering the effect of volatile inputs in the business structure. Energy savings can translate to increased business profits and lower prices for consumers.

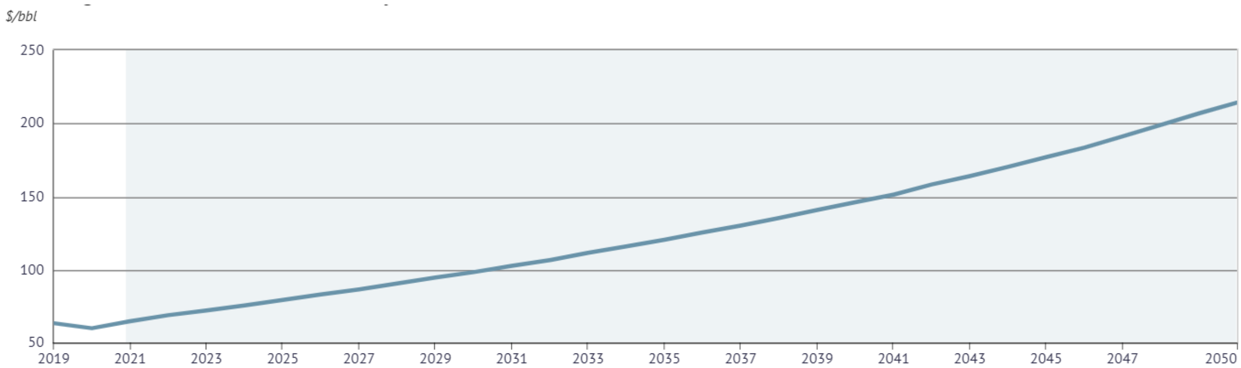


Figure 3 EIA Pre-COVID projected oil price (USD) (Knoema, 2020)

3.2 Energy Security

Most energy for Australian farming comes from a single fossil fuel (oil). This has serious implications for energy security. Self-sufficiency of diesel is declining rapidly as domestic oil production falls, refining capacity closes, and the country faces an increasing import bill to keep the nation moving. This means Australia is heading towards almost total reliance on imported liquid fuels for transport and other diesel-using activities, despite being a significant energy exporter overall.

In 2009-10 Australia was producing 83% of the diesel it uses. In 2019-20 the figure was only 47% (A Tillet, 2020). In a relatively stable and mature global fuels market, this should not be a problem; however, any disruption to the fuel supply chain could have significant implications for economic and social stability (Blackburn 2014). Agriculture is highly sensitive to disruption and fuel security has been a concern for some years. Even though Australia currently has onshore fuel reserves for around 30 days' supply, agriculture is guaranteed only 3 days' supply in a national emergency.

Even without national supply constraints, events like rain could cause demand surges, stressing rural supply chains (Marshall, 2020). East coast floods and cyclones in the last decade have shown the vulnerability of the logistics supply chain to extreme weather (Lenzen, 2019). Any such disruption could delay sowing, harvesting, or interrupt necessary spraying operations. Reduced yield, quality or failed crops could have a significant impact on the Australian economy.

If Australia moves further towards meeting the IEA's 90-day stockpile target, reducing agriculture's reliance on diesel would reduce the cost of providing this additional stockpile.

3.3 Environmental Benefits

There are two major environmental impacts from diesel combustion. One is the focus of this study: GHG emissions. The other is the (human) health impact arising from air pollution caused by diesel exhaust.

In terms of air pollution, diesel exhaust was classified as carcinogenic by the World Health Organisation in June 2012. This Particulate Matter produced by diesel engines is a well-researched health issue (Commonwealth of Australia, 2016). However, unlike CO2, which is a global issue, diesel exhaust pollutants (PM, NOx, THC, CO) primarily impact humans close to their source (DIRD, 2016). As a result, health costs are much more significant for vehicles and equipment in urban areas than in broadacre farming.

Considering the low number of people and (in most cases) high levels of ventilation in extensive farming, the health impact of modern diesel exhaust pollutants is generally minimal when compared to the GHG and energy security impacts.

In the case of greenhouse gas emissions, agriculture is a large contributor in Australia, contributing 76 Mt CO2-e of GHG in 2020 (DISER, 2020). But not all Agricultural emissions come from diesel usage. Figure 4 shows that diesel is a small proportion of agriculture's total emissions, dwarfed by animal husbandry. Even if all on farm diesel usage stopped tomorrow, it would only reduce agricultural GHG emissions by 8%. To meet Australia's international emissions reduction commitments, agriculture needs to achieve significant GHG reductions in other areas.

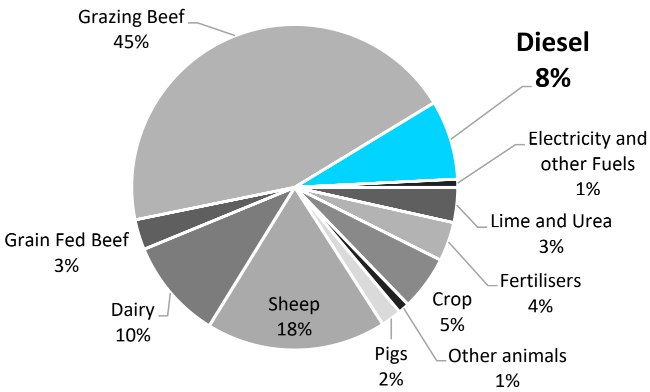


Figure 4 Diesel contribution to Agriculture's total GHG emissions

This does not mean that reducing diesel usage is futile from a climate perspective. 80% of the energy used in the agricultural sector is in the form of diesel. For a single fuel such as diesel there is a direct correlation between the volume of fuel used and mass of greenhouse gas emissions emitted. With the agricultural sector annually burning its way through 2,430 ML of diesel (ABS, 2020) and each litre producing 2.7kg CO2-e (DISER, 2020), there is plenty of scope for reduction. Reducing agriculture's carbon emissions will be an important part of meeting Australia's international commitments to reduce emissions. It also creates new business and revenue opportunities in sequestration, and many farmers are keen to become part of this market.

3.4 Community

Reduced energy consumption and diesel dependence in agriculture has the potential to not only improve Australia's strategic situation but also the agriculture industry's competitiveness. A stronger, more profitable agricultural sector, less exposed to risk and enjoying lower energy costs and greater margins will help both farmers and regional communities.

4 Options for reducing reliance on diesel

There are many options for reducing on-farm diesel use, from simply running existing equipment in a more efficient manner, through modifications and the gradual upgrade of equipment as it reaches its end of life, to installation of an alternative fuel manufacturing plant and replacing all equipment to suit.

A considered approach is needed to prioritise activities to transition from high diesel use to a low carbon intensity operation. One such example is a transition hierarchy to guide the order of actions or somehow weight the more important/effective actions.

4.1 The transition hierarchy

When looking at options for reducing diesel dependency, it is all too easy to ignore the potential of existing cheap or free methods for improvement and jump to attractive but expensive changes (the allure of "shiny new things"). Using a transition hierarchy is a strategy to resist this temptation and ensure all avenues are appropriately considered. Figure 5 shows the hierarchy as applied to agriculture.

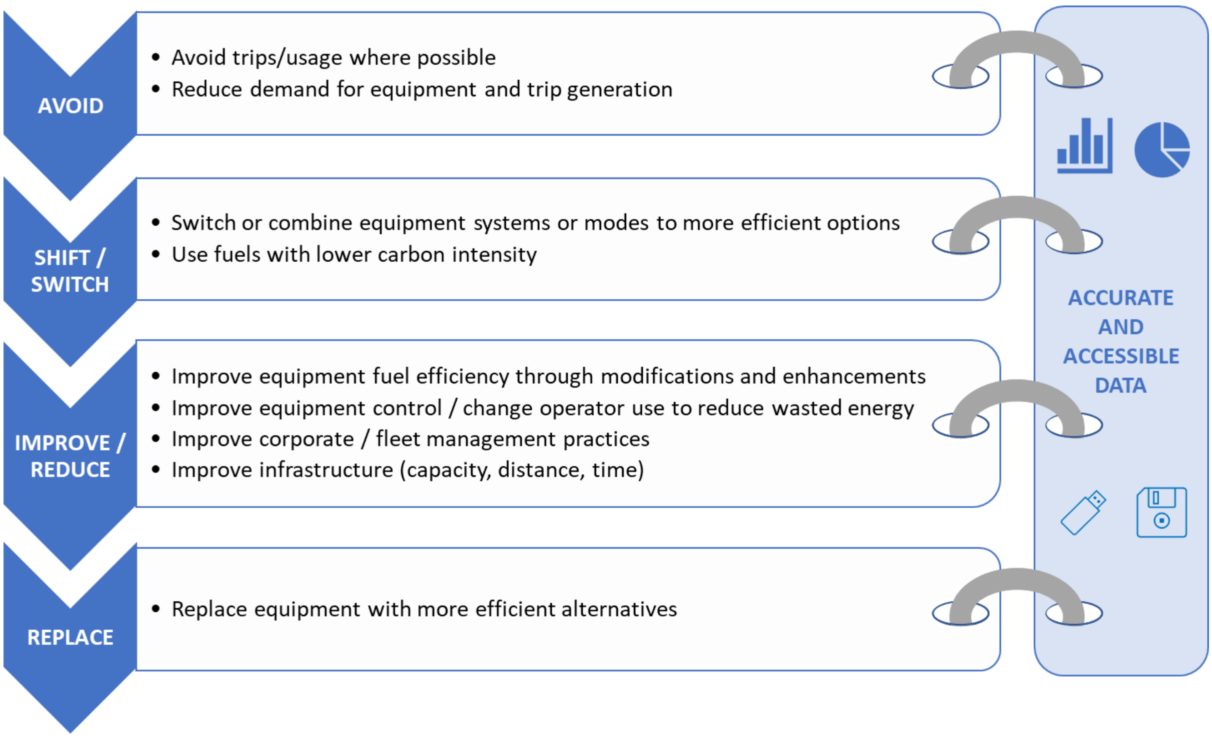


Figure 5 MOV3MENT's energy transition hierarchy

For example, where a truck carrying out a daily inspection could be replaced with a high capital battery electric truck (Replace), consideration should be first be given to whether:

- the trip is necessary that often, or at all (Avoid),
- a smaller vehicle could be used (Shift), or
- modifications to the existing vehicle (such as to accept B100 fuel) would give a more appropriate end result (Improve).

Replacement is the last option after all other steps have been considered. The options for reducing diesel dependence below have been laid out in this order.

4.1.1 The importance of accurate, reliable data

Underpinning all steps of the transition hierarchy is reliable and accurate data. It is impossible to be certain about what the cost of any energy option will be without understanding the amount of energy currently being consumed. In many cases, whether a change from diesel to another energy type can be cost-effective depends on parameters such as how much energy is being used, by which machines or operations.

Measurement is the first step in understanding scale. Installing relatively inexpensive fuel meters on diesel tanks enables farmers to keep an accurate record of fuel use in different equipment. Diesel consumption records are then possible for each machine. Without monitoring, farmers only have ballpark numbers when it comes to the fuel used and would be unable to detect even major variations in fuel consumption indicative of maintenance issues, component failures or poor operation. The cotton industry reflects this with the statement that the very first thing cotton farmers should do is test and monitor the efficiency of their pumps, as significant efficiency gains are delivered through optimized pump performance (CottonInfo, 2018).

At the simplest level, monitoring diesel (or other energy) consumption of individual machines can target day to day reactive maintenance (Shorten, 2014). Recording the production rate or output (e.g. water pressure of irrigation systems, tonnes of seed harvested) is also useful. Leak checking and simple maintenance of irrigation systems can save energy and money (DELWP, 2018). Irrigation systems are a clear example of energy consumption that can be avoided, a leak is not only a potential wastage of water, but the energy used to move the water is also lost.

By understanding where the bulk of the energy is used, managers have the information to decide where their resources are best applied for energy, diesel or financial savings.

4.1.2 Segmentation

For diesel replacement options in agriculture, it is useful to split the energy consumers into two groups, namely off-grid stationary and mobile machinery.

Off-grid stationary machinery

Stationary machinery includes pumps, off-grid electricity generation and other equipment where the energy is consumed in one location, on a permanent basis, or at least for months at a time (as is the case with some bore pumps). This report is only considering stationary machines that are off grid, as these are the largest concern for extensive agriculture. Grid connected stationary machines, believed to be a minor portion of extensive agriculture's energy use, have already been considered in the A2EP's previous report on intensive agriculture (A2EP, 2019).

With stationary machines the weight of any technology can generally be ignored, and there is the opportunity to generate fuel or energy on the spot, or plumb into a local energy source. For example, pumps can be electrified with a photovoltaic array to generate the energy; if necessary, battery storage or a small diesel generator can be installed to ensure continuous operation. If liquid fuels are used, a semi-permanent or permanent fuel storage can be installed on site.

In the irrigation heavy sub-sectors (wheat, cotton), up to about 50% of diesel may be used in off-grid stationary machines (see section 2).

Mobile machinery

Mobile machinery includes tractors, headers, certain irrigation systems and vehicles, part of whose job is to change location. Unlike stationary machinery, the size and weight of the power system and fuel storage is critical, along with the practicality of transporting the fuel from a centralised depot out to a field where the mobile equipment happens to be working, often multiple times a day.

Irrigation machinery is unusual in that it can fall into either the stationary or mobile categories, depending on the situation.

For most sub-sectors, the vast amount of diesel used is in mobile machines (see section 2).

4.2 Avoid (Reducing equipment usage)

For extensive agriculture, the options for reducing equipment usage may be limited. At the simplest level, it can include consolidated vehicle trips as far as possible, combining pumps where possible, or switching off when the full flow is not required (analogous to turning off the lights when not in the room). However, certain farming practices, such as minimum or no-till farming, can reduce the number of times a tractor has to visit the field or how hard it works.

Tillage aside, reduction in on-field diesel use by avoiding use is in many cases going to have the additional advantage of reducing soil compaction.

4.2.1 Reduced tillage farming

Minimum tillage (where tines and discs are used to cultivate) and no-till farming, which allows crops to grow without disturbing the soil, are both practices that were introduced primarily to improve soil health. The benefits are reduced soil erosion; higher soil moisture and organic levels; and in some cases, greater overall yields (Giles, 2013), (Khaledian, 2013). This practice is already well established in Australia: In 2016/17, around 79% of cropland and 70% of pastureland receiving no tillage except at sowing (ABS, 2018). Australia's place as the most efficient farmers in the world is supported by multiple consultees on this project indicating that no-till farming, although not possible in all situations, is already close to saturation point in Australia.

As Figure 6 shows, tillage (ploughing) is one of the highest energy users per hectare, so any reduction can have a significant impact on overall diesel usage. Industry consultation confirmed that even though no-till farming is expected to lead to an increase in spraying, the net diesel used by a farm will be lower. In one study, no-till farming halved diesel usage (81 L/ha to 42 L/ha) (Khaledian, 2013). Similar results have been recorded in NSW and QLD grain farms, as seen in Table 2 (Chen, 2015).

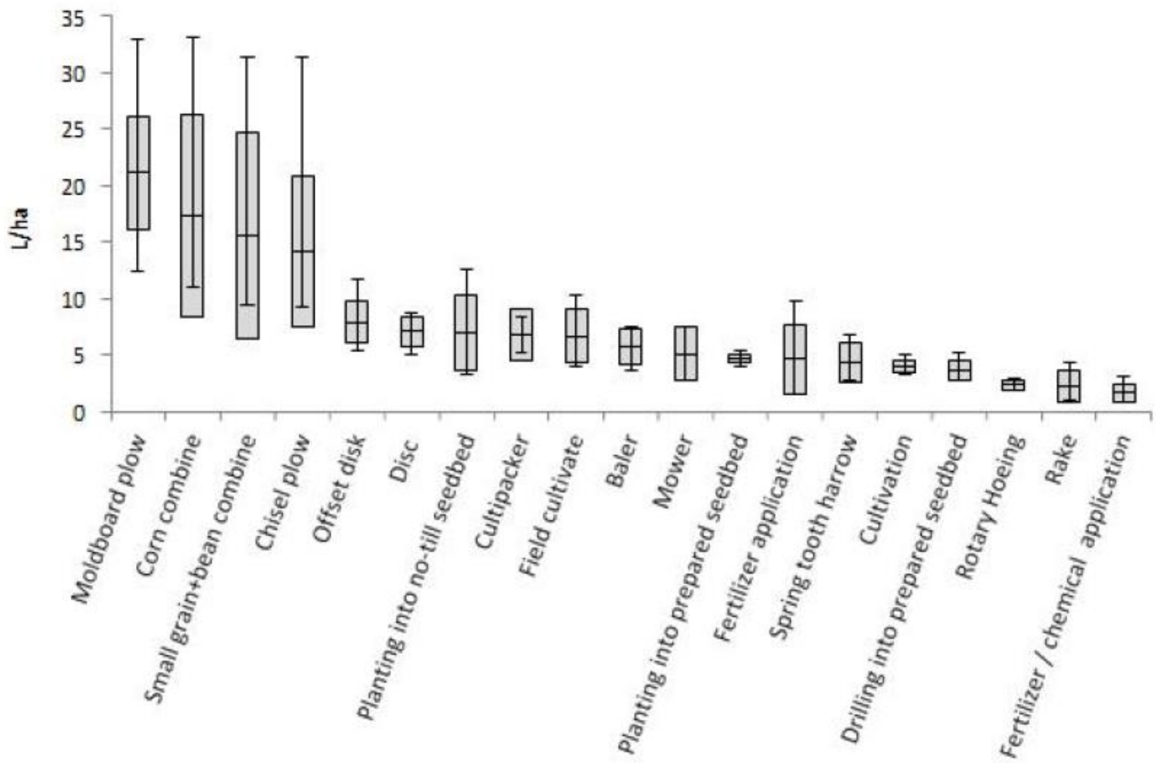


Figure 6 Diesel use for combines and tractors with implements (Hoy, 2014)

Table 2 Diesel consumption in grain farming (excluding irrigation) (Chen, 2015)

Farming operation	Fuel consumption (L/ha) for dry land (conventional tillage)			Fuel consumption (L/ha) for dry land (zero tillage)			Fuel consumption (L/ha) for irrigated land		
	Wheat	Barley	Sorghum	Wheat	Barley	Sorghum	Wheat	Barley	Sorghum
Primary tillage	18	18	0	0	0	0	0	18	18
Secondary tillage	24	16	8	0	0	0	0	0	0
Fertiliser application	5	0	0	5	0	5	5	5	0
Boom spraying	2.3	4.5	2.3	13.5	13.5	6.8	11.3	4.5	0
Planting	5	5	5	5	5	5	5	5	5
Aerial spray	3	0	0	3	3	0	3	0	6
Harvest	6.6	8.1	8	6.6	8.1	8	12.9	12.9	11.5
Total diesel (L/ha)	63.9	51.6	23.4	33.1	29.6	24.8	37.2	45.5	40.5

No-till can certainly be a common sense move financially. No-till farmers in Northern NSW averaged gross margins close to $100 per ha higher than their conventional till counterparts (Scott, 2020). It is reasonable to assume that the cost savings from this technique are one of the drivers for its high adoption. Industry consultation indicated that, in Australia, no-till farming has probably already been adopted in most of the situations where it is possible.

4.3 Shift/Switch (Changing modes or using biofuels)

For extensive agriculture, there are two options considered under shift/switch. The first is mode shift, carefully considering the final outcome required of the job in hand, then working out if a less energy intensive piece of equipment could do the job as well. The second option is switching to biodiesel, which can be dropped in as a direct replacement for current diesel use.

Bioethanol, another potential drop-in renewable fuel, is outside the scope of this report as it is a petrol replacement, not diesel. Biogas, Hydrogen and other fuels are considered later in section 4.5 (Replace) as current diesel engines cannot run on them. In most, if not all cases, the machinery will have to be replaced in order to take advantage of these alternative fuels.

4.3.1 Mode shift

On a very practical level, for any particular job, after deciding the job is necessary (Avoid), the first decision should be whether the most suitable equipment is being used. For example, a small truck or ute may be routinely used for transport around the farm. If the large carrying capacity of these vehicles is not needed, the same job could be done with a smaller vehicle, road car or ATV that is already to hand. Similarly, jobs such as spraying, spreading, rock-picking can sometimes be done with smaller, lighter weight vehicles such as ATVs (Svejkovsky, 2007).

Most of the current mode shift options fall under the catch-all of precision agriculture, using new information technology systems to reduce or replace manual and/or machine work. In most cases, however, practical implementation of new precision agriculture practices generally requires purchasing new machinery, or even investing in additional systems (such as drones). For this reason, precision agriculture is covered in Section 4.5 (Replace).

4.3.2 Biodiesel

Conventional biodiesel is the only fuel currently available at scale that could be a replacement for a portion of petroleum diesel use. Sometimes referred to as FAME (Fatty Acid Methyl Ester), it is produced by transesterification of vegetable oils and waste fats.

Any diesel engine can potentially run on biodiesel blended with petroleum diesel. The Australian diesel fuel standard already allows up to 5% biodiesel in pump fuel (Federal Register of Legislation, 2019). High concentrations of biodiesel can cause issues with current infrastructure and engines due to its higher oxygen and moisture levels, along with sedimentation and cold flow problems (CEFC and ARENA, 2019). But some road fleets are known to have used up to 50% blends of biodiesel (e.g. City of Sydney).

An important benefit of biodiesel use is reduced carbon emissions, but these vary greatly with the type of feedstock, the on-farm practices, production process and energy source, and the distribution network. In some cases, the carbon impact can be worse than regular diesel, but in others the benefit can be as high as an 83% reduction in greenhouse gas emissions (Somerville, 2019).

New Holland and Kubota are stand-out OEMs, who warrant some of their agricultural engines for biodiesel usage (possibly with increased servicing). The vast majority of biodiesel worldwide is conventional, as is all of Australia's current commercial scale production.

In addition to large scale biodiesel refining, smaller scaled units are available. A farm-sized biodiesel production unit starts from about $20,000 (Heard, 2020).

If biodiesel is manufactured from dedicated oil crops (such as canola) the value as a fuel must be balanced against the value as a food crop. In a recent example, canola was worth 20% more as a food than being processed into a fuel (Luo, 2020). On-farm biodiesel manufacture creates "waste" products that could be used for heating and fodder, which will help to offset costs (Wapstra, 2020).

Currently Australia has capacity to manufacture 100 ML per year (CEFC and ARENA, 2019), which is approximately four percent of the amount of fuel oil consumed by Australian agriculture. Even then, the largest Australian refinery, Barnawartha, exported over half its fuel last year and this proportion is expected to increase. Europe and the US are its largest market, chiefly due to their mandating of renewable fuels (Somerville, 2020). 90% of the canola grown in Australia is exported for European biodiesel production (Editor, 2017).

If the cost and availability hurdles can be overcome, biodiesel is likely to be the least resistance option for Australian farming to adopt in the near term. One factor that may affect industry viability is changes to fuel excise. Biofuels are taxed lower than other fuels, but the level of support is scheduled to decline over the next 10 years as excise has been linked to the CPI since October 2018. Excise rates will increase from 0.041c/ L up to half the rate of standard diesel excise by 2030 (USDA, 2018).

When farming industry representatives were consulted for this project, two common themes arose around biodiesel. The first was optimism, that biodiesel will have a significant place in the future of fuel supply. The second was concern about negative effects of biofuels on equipment.

The optimism mainly seems to stem from the potential opportunity for farms to create value from additional crops, or existing waste, by either selling feedstocks for biofuel production, or producing their own fuel for their own consumption. Producing their own fuel has the potential to alleviate some energy security concerns that were stated – industry consultation reinforced that some farms are creating their own fuel reserves to guard against supply issues at critical times, such as during harvest. In the current market however, it seems that relative costs make biodiesel uneconomic. Manufacture is energy intensive and expensive, and in some cases at least, feedstocks can have a higher value being sold into other industries.

The concern about biodiesel usage is based on recent experience, where some operators have suffered higher maintenance costs from trialling biofuels. According to one industry consultee, poor quality of the biodiesel used contributed to these issues. The general concern in the farming community is neatly expressed by one quote "if you use biodiesel, you can find another mechanic" – this is especially powerful in the light of the fact that local access to local maintenance is a primary concern for farmers, and they are likely to turn to this same network of dealers and mechanics for any fuel consumption and efficiency advice. It also possible that biodiesel's detergent properties – cleaning fuel tanks of vehicles that have previously run on conventional diesel, and depositing this dirt in filters, may be a cause of this apparent concern (Wapstra, 2020).

4.3.3 Renewable diesel

Renewable diesel (similar to "green" and "Fischer–Tropsch diesel") is an advanced biodiesel that is synthetically refined to a point where it is a true "drop-in" fuel – it meets the fuel quality standard and therefore can be used as a direct replacement for petroleum diesel without the need to blend. It is compatible with existing infrastructure and vehicles.

Renewable diesel can have a wider variety of feedstocks than conventional biodiesel, including non-food biomass and feedstock such as straw, cotton trash and urban waste streams. It can also use purpose-grown crops such as grass, woody biomass or algae (CEFC and ARENA, 2019).

Although there is no production of renewable diesel at a commercial scale in Australia, there has been some testing. For example, the Australian Renewable Energy Agency (ARENA) has supported research, development and demonstration projects on advanced biofuels, including renewable diesel. Most recently, in 2019, ARENA funded a project led by Southern Oil Refining to build a demonstration scale production facility of crude oil from waste by-products that can then be refined into renewable diesel in an existing facility located in Gladstone, Queensland, with a capacity of 200 million litres (IEA, 2019; ARENA, 2019).

Also in 2019, Licella (owner of one of the largest pilot scale plants in the world, located in NSW, with a pilot capacity of 10,000 tonnes of feedstock slurry per year) announced the construction of a commercial scale plant and a collaboration with Neste (the world's top provider of renewable diesel which opened its office in Melbourne) to potentially develop a renewable drop-in fuel (IEA, 2019; Licella, 2019; Bioenergy Australia , 2020; Neste, 2019).

4.4 Improve/Reduce (Improving fuel efficiency)

For extensive agriculture, there are a huge variety of options for improving equipment and practices to increase fuel efficiency and reduce equipment usage. A lot of these will be second nature to farmers, such as increasing the size of seed hoppers reducing the number of trips for refilling (Svejkovsky, 2007).

However, the fuel consumption of most farming processes is variable and often obscure. This is where Australian governments and industry associations have done an admirable job of getting energy efficiency information freely available online.

4.4.1 Online resources available for guidance

A good first stopping point for energy consumption advice is the federal business agriculture webpage, that lists multiple valuable Australian sources (Australian government, 2020). AgInnovators, a joint project of the NSW Farmers Association and the Federal Government, has many detailed information sheets aiming to help farmers reduce their energy use, covering irrigation, vehicle and shed efficiency. Taking tractors as an example, there is information about staff training, ballasting, tyre pressure optimisation and planning field operations (NSW Farmers, 2013).

It is not clear how well known this online information is, and how widely it is already being used to improve energy efficiency. Consultations in this project have indicated that online information is not the best method of communication for this audience. In the conservative industry of agriculture, farmers largely learn face to face from trusted persons, “by looking over the fence” at successful farms and agricultural shows (K. Stark, 2019).

To look forward at technologies that are not yet available in Australia, but may be elsewhere, it is useful to look at European and US sources. A report from the US Department of energy looks specifically at reducing diesel usage in tractors (Hoy, 2014). The European Efficient20 project also has a lot of information on the effectiveness of actions to reduce fuel consumption (AILE, 2013) (Debroize, 2013), (Giles, 2013). Figure 7 is an example showing that 8-26% fuel can be saved by through better implement settings alone.

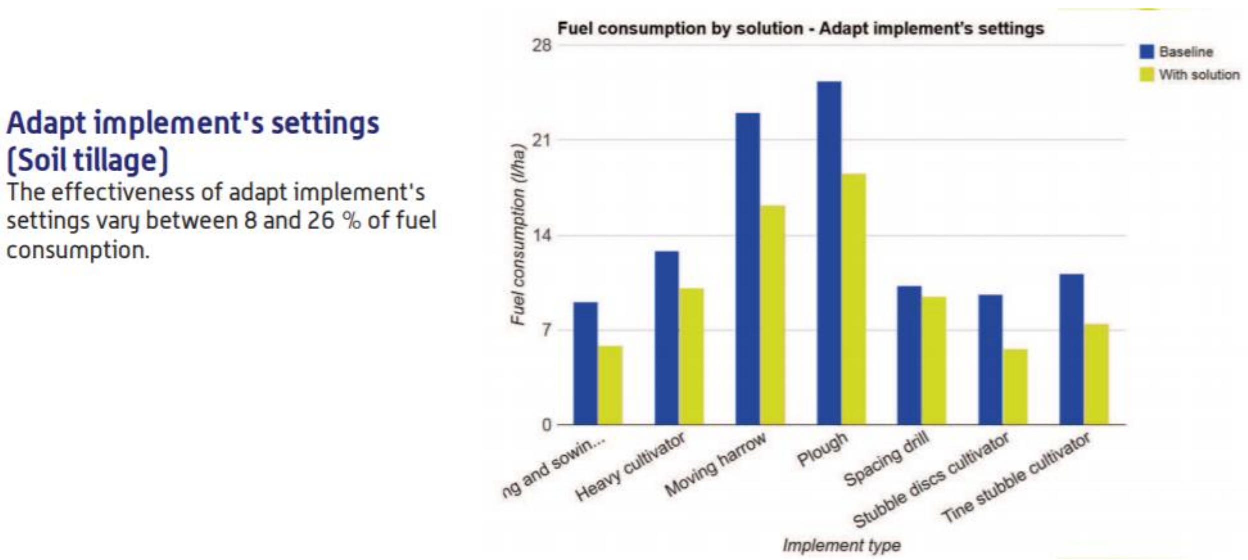


Figure 7 Tillage fuel usage (Debroize, 2013)

Irrigation system design

Irrigation systems have the two, sometimes opposing, environmental (and cost) goals of reducing water usage and energy inputs. The two most popular types of irrigation for grain growing – surface irrigation and pressurised irrigation – have an energy efficiency/water efficiency trade-off (Chen, 2015). The best choice will vary from one farm to another. Several studies have also showed fuel savings of up to 40% through improvements in irrigation equipment and water management. Often, irrigators are not even aware of the inefficiencies in their own systems (Chen, 2015).

4.4.2 Farming Practices

There are many farming practices that have a benefit of reduced diesel consumption. In some cases, such as automatic path planning, the primary aim is to reduce fuel consumption. There are other practices however, whose primary aim is to improve yield, quality, water or fertiliser/pesticide use, but have reduced fuel usage as a significant side effect. Reduced tillage farming has already been discussed under “Avoid” (Section 4.2). Controlled traffic farming and aspects of precision agriculture are examples here that are likely to require investment in machine upgrades.

Precision Agriculture

Precision agriculture, which is the application of rapidly developing information technology to the agriculture sector, is often touted as reducing inputs, improving yields and minimising environmental impacts. Precision agriculture technologies include:

- GPS (Global Positioning Systems)
- Automatic steering
- Aerial and satellite imagery
- Yield monitoring
- SSNM (Site Specific Nutrient Mapping)
- Contour mapping
- NDVI (Normalised difference vegetation index) mapping,
- Automatic boom systems

Many of these do not provide benefits in themselves but are enablers for improved practices. For example, GPS alone provides no benefits, but it can be used to reduce overlap and is necessary to relate current vehicle positions to the detailed maps that allow selective spray applications. The benefit of GPS and autosteer alone have been shown to reduce fuel consumption by 12-15% (Hoy, 2014). In one case, purchase of a self-propelled sprayer in NSW reduced fuel requirements by 50% (CEFC, 2019). Variable rate irrigation and variable depth tillage have been shown to give efficiency benefits from 8% to 50% (Hoy, 2014).

Given the broad nature of technologies and techniques that fit under precision agriculture, it is hard to gauge the current level of usage in Australia. Consultee opinions in this project varies widely from “some farmers starting” to “most of the large gains have already been realised”. However, recent research reported precision agriculture to still be in an immature state, indicating efficiency benefits to come as the many barriers, including of data ownership and remote connectivity, are overcome.

Controlled Traffic Farming (CTF)

CTF uses one set of permanent tracks for all field operations, often in conjunction with a wider (three meter) track on all farm vehicles. Already in use in Australia, in 2005 an estimated 1 million hectares were farmed under CTF. Largely enabled by GPS and autosteer systems, CTF has the double benefit of reducing soil compaction in the tilled areas (reducing pulling force by 18-37%) and reducing the rolling resistance of the heavily compacted tyre tracks. It can improve fuel efficiency by up to 45% or 70% (Giles, 2013), (Hoy, 2014).

Operator techniques

Most powered equipment has an operating range or technique in which it operates most efficiently. However, this may not be obvious, intuitive, or even the same as “the way it’s always been done”. A phenomenon not peculiar to farming, equipment might just be operated in a way that simply gets the job done, with little thought to fuel efficiency. This is particularly the case when:

- time is short or stress is high (e.g. harvest)
- operators have little specific knowledge about the equipment (e.g. itinerant workers)
- equipment does not have specific operating instructions (e.g. purchased at auction)
- or newer equipment requires different techniques and knowledge than previous experience with other makes, models or features (as technology and capability changes over time).

While there are a range of information sources to help broadly understand the techniques, they do vary by machine or application. For example, "Shift-up-throttle-back" operation is a driver technique that typically results in 15 to 30% reduction in fuel consumption (Hoy, 2014).

4.5 Replace (Replacing machinery)

As the opportunities to avoid, shift, switch, and improve are progressively adopted, the remaining option is replacement. New machinery and equipment are often more energy efficient than the models they replace, and often come with new technology that can enable further efficiency improvements (i.e. precision agriculture) as well as a wider choice of fuels that could be used.

In practice, on farms with low margins it is most likely that this option will only occur at the end of life of any piece of machinery (on that farm). Importantly, technology improvements tied to new equipment will only really be considered by farms that already purchase new equipment, whereas many farms tend to favour used equipment for non-critical applications to reduce capital costs.

Other machinery (such as smaller diesel engines used in pumps) may have a shorter service life, giving any replacement technology the chance of a faster impact.

4.5.1 Stationary off-grid machinery

There are many solutions to reduce diesel use when it comes to replacing existing stationary machinery. These include both newer diesel machinery and switching fuels to another (non-diesel) energy type. Drop-in fuels were already considered as part of section 4.3, because they do not require a change in equipment. However, this section considers fuel/energy types that require a different or adapted piece of machinery, possibly different means of energy storage, as well as the new fuel.

Along with the switch to a new fuel and any associated storage and machinery, the source of energy also becomes important. For example, with electrically powered machinery there are many options for sourcing power, and each has pros and cons.

Technology improvements also mean that stationary machinery can also now be monitored or even controlled remotely, which reduces diesel used in transport just to visit remote sites.

All diesel reduction solutions vary in terms of technology cost, payback times and continuity of operation.

Modern diesel

The simplest option is buying a new diesel machine. Technological advances such as combustion chamber optimisation and advanced fuel injectors mean that a new stationary off-grid machine is likely to be more efficient than its predecessor (Generator Source, n.d.). This comes with the advantage of leaving existing diesel infrastructure in place. Purchasing newer generation diesel off-grid equipment may also seem like the most cost-effective option: purchase price is only around 1-2% of its total lifetime operating cost (Precision Agriculture, 2020).

Given that farmers' main energy priorities are cost and reliability (PWC, 2019), it is unsurprising that diesel remains very appealing. In cases like irrigation or pumping where both diesel and electric pumps are well established, farmers have been seen to transition from electricity to higher emissions diesel due to increasing electricity supply cost (Barbour, 2017). Recent COVID-related decreases in diesel price will likely have a similar effect (Hayes, 2020).

Electrification

The biggest advances in equipment energy efficiency are being achieved with some degree of electric assistance. From diesel-electric hybrids, through battery electric solutions, to hydrogen fuel cells – all rely on some degree of electrification using electric motors to replace or support diesel engines. The main reason is that combustion engines are not particularly efficient, wasting between a half and two thirds of the fuel energy by converting it to heat. Electric motors on the other hand convert more than 90% of the electrical energy supplied into motion.

Fully electric stationary machinery is an option when electricity is available. Electric machines such as pumps are generally robust and efficient. The working life of a diesel pump is typically 7000-15000 hours but for an electric pump it is "almost infinite" (Chen, 2015). Maintenance costs for a diesel pump are almost double that of an electric pump. Furthermore, diesel pumps are more labour intensive and harder to activate/operate remotely (Chen, 2015). Electric machinery is also quieter and more user-friendly (Shorten, 2014). In the past these advantages, and electric machinery's lower average running costs (NSWF, 2013), have been outweighed by the cost of hooking remotely located machinery to the grid. In recent years, the steady increase in power prices has also acted as a disincentive, extending the payback period. The overall cost for electrical drives in some applications is still slightly more than diesel, as shown in Table 3 – mainly due to low diesel prices (excise free) and high peak electricity costs.[1]

Table 3 Cost of mechanical energy (Luo, 2020)

Fuel	Cost of mechanical energy delivered
Diesel	0.217 $/kWh
Electricity	0.294 $/kWh

Farmers already know about and use electric equipment and machines powered from the electricity grid if that is available on-farm. The main difference now is the variety of off-grid options emerging. Low-cost renewable generation and battery storage (where applicable) are needed to make off-grid stationary electric machines a more attractive proposition (Luo, 2020). These off-grid options include solar PV, hybrids, wind and solar thermal.

[1] While the cost of generating electricity from diesel is $300-400/MWh, wholesale electricity prices are volatile and can peak at up to $14000/MWh (A2EP, 2019).

- Solar PV. Solar is reliable and affordable. There are no network outages or fuel tanks to worry about. Systems also vary in size and degree of portability: even those of industrial size suitable for grid connection can be engineered for moving between sites (Luo, 2020), (ARENA, 2018). This may be a solution for farmers requiring electricity on leased land, or relatively temporary locations such as water sources.
  In terms of costs, rooftop solar is approximately $120 per MWh (PWC, 2019). This is roughly half the cost of a diesel generator. The relentless reduction in price has created a compelling case with relatively short payback periods, especially in combination with other technologies such as smart irrigation pumps and energy management (Australian Farm Institute, 2018).

  If intermittency of power is acceptable then solar PV on its own is a valid option. In one example diesel pumps were run continuously for three months to fill a dam pre-planting. A solar PV system now does this job, even if it takes nine months to fill the dam during daylight hours (K. Stark, 2019). There is some resistance from farmers to giving over arable land to PV systems, but there is at least one company growing crops underneath solar panels (K. Stark, 2019).

- Solar-diesel hybrid. Many situations demand continuous power. Solar is now being combined with diesel generation to supply continuous power in off-grid areas – from small single-pump projects to large irrigation systems such as the 500kW solar/diesel system at the Waverleigh Cotton farm in North West NSW. Diesel was the farm's greatest operating expense, but diesel consumption has been reduced 55% and the large project has an ROI of under 5 years with a low interest loan from NSW Rural Assistance Authority (Australian Farm Institute, 2018), (K. Stark, 2019). The majority of consultees for this study, both farmers and representatives from industry bodies such as NSW Farmers Federation, believe off-grid solar and hybrid solar pumping will continue its present growth.

- Wind and solar thermal. With energy costs of around $50/MWh, wind can be useful for pumping operations off-grid in wind-prone areas if there are suitable sites and if the risk of intermittency and variability are acceptable. Like solar, wind can power electric pumps unaided and in many situations this may be sufficient. However, wind is far more variable than solar and site selection is critical. A small-scale wind turbine also costs far more than a basic solar system, it is more comparable to the cost of a solar system with battery backup (Selectra, 2021).

  Solar thermal, which captures energy from a large focused solar array (and stores it in the form of heat) can generate power around the clock. Despite low running costs, build cost is high for a small private farm, so may be better suited to large scale projects than individual farms (PWC, 2019).

- Electricity storage. The arrival of more affordable energy storage combined with renewable power generation should reduce future diesel consumption due to its ability to deliver reliable lower cost continuous power. There are several technologies competing around the $200/MWh price point. This includes gravity storage/pumped hydro, which is cheap but not viable is some areas due to the topographic requirements and other factors. Some small-scale systems made through excavation are possible but must be carefully planned and implemented (West, 2018).

The storage technology which has been enjoying both strong growth and a steep drop in price over recent years is the lithium-ion based battery. According to BloombergNEF, pack prices fell 87% from 2010 to 2019 (See Figure 9) with the volume weighted average hitting $US 156/kWh (Field, 2020). The introduction of new chemistries, new manufacturing techniques and simplified pack designs will keep prices falling (Field, 2020).

Increasingly affordable battery storage and solar power generation will mean shorter payback times for investments. However, the overall costs will still be high. Excellent information about ROI and suitability is available to assist farmers via sources such the NSW Farmers Renewable Energy Landholder Guide, and national level programs such as the Business Energy Advice and the Energy Efficient Communities programs.

Alternative fuels

Biogas, hydrogen fuel cells, biomethane and CNG are all potential energy sources for stationary machinery. However, they require wholesale replacement (or significant adaptation) of existing diesel equipment. These are individually discussed in section 4.5.3.

Remote monitoring

Historically, farms use mobile machines such as utes and aircraft to transport personnel out to remote locations for regular checks on infrastructure such as cattle watering points, dams, soil moisture levels, and fence condition. The advent of higher performance and decreased cost sensors, communication systems and drones mean that dedicated sensors and cameras can communicate this information back to base, vastly reducing the frequency with which personnel must be directly moved.

Drones used for monitoring can be considered as "stationary equipment" here as they generally return to a fixed base for recharging/refuelling. Farmbot, for example, claim their systems can provide up to 90% reduction in manual inspections (FARMBOT, 2020). Similarly, Sunbirds claim that bore-runs were reduced by over 90% (Sunbirds Aero, 2020) with use of their long-distance drones. With drone vision equivalent to manned aircraft at a fraction of the cost, other checks on fence lines and livestock can be carried out with the same equipment.

4.5.2 Mobile machinery

Unlike stationary off-grid machinery, where electricity or LPG are starting to be used as energy sources, nearly all mobile farm machinery in Australia is currently diesel powered. According to Future Farming there are four options to reducing diesel dependence in vehicles, in order of likely adoption: electric hybridisation, methane, full electrification and hydrogen (Future Farming, 2018). Fuel is a large part of total cost of ownership, quoted as 35% of the total cost for a tractor, and 10-15% for a combine harvester.

Modern diesel

Agricultural machinery tends to have a long service life. With no requirement to retire old equipment, and few of the environmental and safety requirements of road-registered vehicles, there are inevitably many mobile farm machines such as tractors still operating that are decades old (J Miller, 2006).

Over time, there has been a general improvement in the efficiency and productivity of conventional diesel mobile machines. A 2012 tractor could be expected to do 20% more work than a 1962 model for the same amount of diesel (Figure 8). Modern tractors with an increased number of drive gears expand the potential for efficient operation (but may also increase driver demands). Auto shift or CVT transmissions are available to further reduce the driver skill necessary to achieve some, if not all, of these gains (John Deere Australia, 2020).

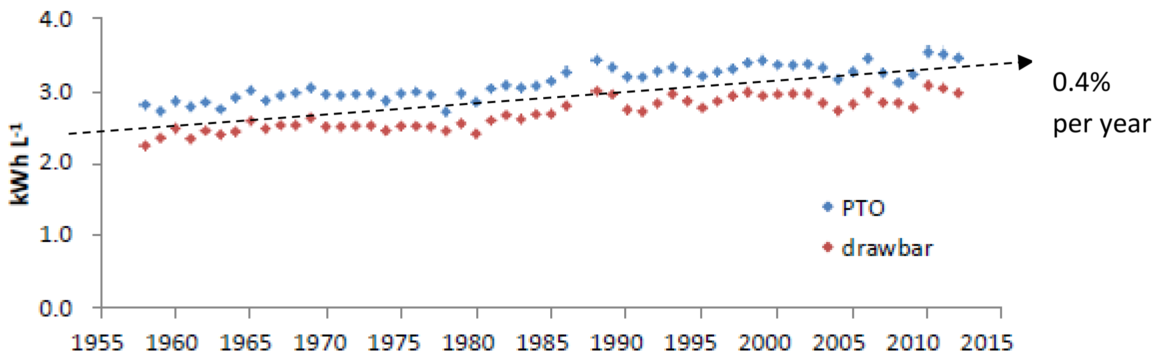


Figure 8 Increasing efficiency of tractors (Hoy, 2014)

Many conventional tractors have systems capable of producing very high outputs through their hydraulic, drawbar or PTO – requiring significant cooling. Yet significant time can also be spent at idle or very low loads, where oversized cooling systems become parasitic losses. Modern tractors are using refinements such as variable speed fans, electrically driven coolant pumps, intelligent oil pressure control and selectively reducing idle speed to reduce these parasitic losses. Other systems such as waste heat recovery from the exhaust are emerging, in prototype form at least (Hoy, 2014).

Modern tractor implements, employing electronic control systems, can also lower energy demands. For example, the John Deere 9 series premium balers can sense the volume of hay entering the baler and directly request speed and PTO parameters from the tractor. Hydraulic pressure is only requested when each bale is tied and ready to be ejected (John Deere, 2020). Apart from reducing demand on the operator, it also significantly reduces diesel use as a co-benefit.

All mobile machines, not just tractors, are benefiting from similar developments, leading to a reduction in diesel use for the same work. The scale of this benefit is hard to judge, but promising as these new technologies sound, their introduction is probably needed to continue the historical trend of 0.4% improvement per year.

However, it is worth restating the purchase of new machinery is often restricted to the most critical function or activity, which varies by farm type, location, and scale of enterprise. Often, used or second-hand equipment is purchased rather than new.

Electrification

Considering the higher efficiency of electric motors over diesel engines, and the inherently better torque and power characteristics at low speed, electric machinery seems a promising solution for extensive farming. However, batteries cannot yet store the same amount of energy as a similarly sized diesel machine. For example, conventional tractors can work for 10-12 hours without needing to refuel, and when they do the refuel, it can be brought to them in a tank to minimise downtime. Yet current electric tractors seem limited to about 130kWh, allowing only about 4 hours operation before recharging (Ham, 2020), (Jetcharge, 2020).

Given the shorter operating time, it would be necessary to have the equivalent of 3-4 Tesla chargers in the field, to allow 20 minutes of fast charging before continuing operation (Ham, 2020). This is obviously not a practical solution for most broadacre farms. Although battery swapping might be possible, capital investment required for a second very large battery makes this option unlikely (Ham, 2020), and there are few commercial developers of battery swap solutions.

The few electric tractors on the market currently are smaller sized and aimed at urban usage and lighter duties, such as council fleets or vineyards, where the energy requirements are not as high and reduced noise and lack of emissions are distinct advantages (Fendt, 2017), (Kubota, 2020), (Campbell, 2020).

Many of the objections and disadvantages of early battery-electric machines – robustness, safety, interfaces (Hoy, 2014) – had comparable concerns in the road vehicle sector, which have since been shown to be less significant or amenable to solution. Price and mass remain barriers, but BloombergNEF has shown that battery costs are now less than a quarter of what they were in 2012, whilst their energy density (Wh/kg) has almost doubled (Figure 9 and Figure 10). Despite these steep falls in battery prices, capital investment for battery electric machinery may still be 30% more than for conventional diesel today (Campbell, 2020). Most of this cost is in the battery itself.

Given high energy demands and long work shifts, the time that battery electric machines can operate between charges remains a major obstacle. Battery research and manufacturing are scaling up worldwide to support battery electric road vehicle sales, driving improvements in battery cost and energy density that agricultural machines will benefit from. Unfortunately, even at current rates of progress, it would still be 2040 before battery electric tractors would be able to match today's diesel with a 12-hour shift. Clearly, further technology breakthroughs or modified operating/charging practices will be required to see a broadscale shift.

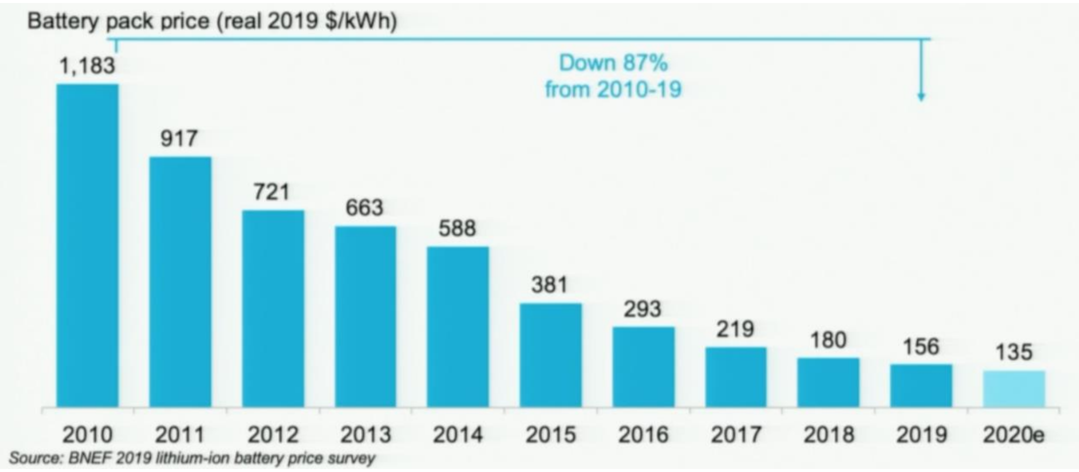


Figure 9 Vehicle battery prices (USD) 2010-2020 (Field, 2020)

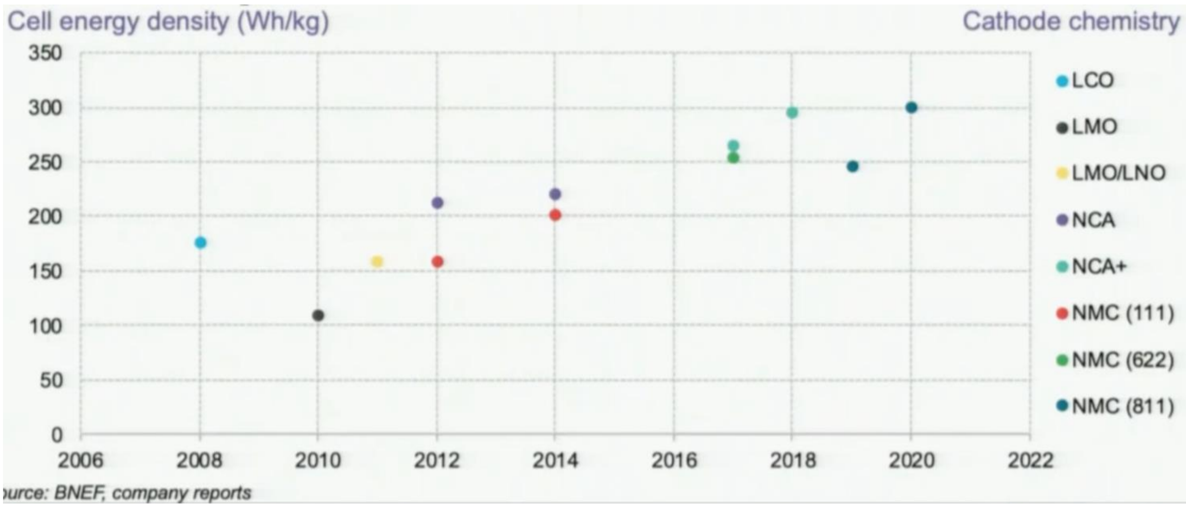


Figure 10 Battery energy density 2008-2020 (Field, 2020)

Diesel-electric hybrids

Diesel-electric hybrids retain many advantages that electric motors provide, whilst minimising the disadvantages of large expensive batteries. However, they also add complexity of two powertrains.

In agricultural machines, the major benefit of hybridisation is the ability to optimise the power source to the speed and load of the demand. In the simplest form, an electric motor can run at the desired speed for the PTO, freeing the diesel engine to run at the most efficient speed for driving the wheels. In America at least, this is already available on some tractors (Hoy, 2014). Hybrid benefits will likely include a reduction in engine idling, enhanced manoeuvring, and zero engine noise at low speeds.

As in road vehicles, it can be expected that the size of batteries and the work that the electric system does will gradually increase. Series hybrid machines, where electric motors carry out all the mechanical work, leaving an optimised diesel engine to charge a relatively small battery, could be the ultimate application of electric motor efficiency whilst retaining diesel's energy density and refuelling ease. This leads to a definite hierarchy of electrification, starting with low cost and low benefit, ramping up to higher cost but potentially higher benefits:

- Electrified accessories (Implements, PTO, aircon, power steering)
- Powertrain hybrid (diesel engine does the bulk of the work and electric motor assists driving the wheels under certain conditions) – this would be in conjunction with electrified accessories.
- Range extenders or series hybrids (BEVs with a diesel generator / range extender engine on board to charge the batteries when necessary).
- Battery electric vehicles (All the energy for a full shift is stored in an on-board battery)

H2 Trac are developing two options to extend the range of their prototype 35kWh electric tractor, with either a diesel engine or a hydrogen fuel cell (Ham, 2020). Methane or biogas fuelled range extenders would also be possible. H2 Trac anticipate more than 500,000 units are necessary to bring the price of hydrogen fuel cells to be competitive with diesel engines in this range extender application. The vehicle has sufficient space to store enough hydrogen for 6-8 hours operation, taking 10 minutes to refuel.

Several hybrid tractors have been offered in the past, using electric motors to help power the drive wheels (Hoy, 2014), (Future Farming, 2018). John Deere currently offers small diesel-electric hybrid tractors in Australia and believes diesel electric hybrid drivelines, already used in one of their large loaders, will be introduced to agricultural machines (Karsten, 2019).

Looking at how hybrid powertrains have affected the road vehicle market, it is fair to assume that this developing technology should rapidly improve the efficiency of diesel-electric hybrid farm equipment, over and above the historical trend (Figure 8).

Implements

Tractor implements often derive their power from the tractor engine, through a power take-off (PTO) arrangement that is either mechanical, hydraulic, or electric. Manufacturers such as Fliegl Agrartechnik, Kinze, Amazone, and John Deere have developed implements that take advantage of the efficiency that electric motors can provide (an example is shown in Figure 11) (Hoy, 2014). The main benefit seems to be that multiple motors and/or pumps can be sized to carry out each function with the maximum efficiency, rather than relying on one oversized power input. Distributing energy in the form of electrical energy also has much lower losses than using hydraulic pressure. Even partial electrification can bring efficiency advantages over solely diesel or PTO driven implements (Hoy, 2014).

Electric implements can require a large amount of electrical energy from the tractor, creating a perceived chicken & egg barrier to electrification with little point in an electric tractor without electric implements, or vice-versa electric implements without electric tractors (Future Farming, 2018).

Lack of available electrically driven implements, and standardisation of electrical equipment interfaces to the vehicle, are two reasons stated for John Deere's hybrid tractors' lack of commercial success (Hoy, 2014). The Agriculture Industry Electronics Foundation representing multiple agricultural equipment manufacturers, has been working on a standard for implement to high power electrical connections and communication (AEF, 2015). This should go some way to ease this particular barrier in the near future.

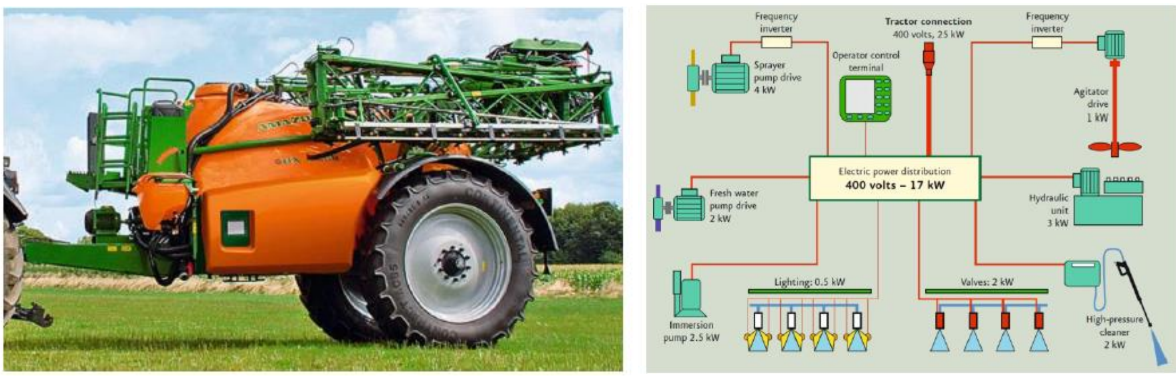


Figure 11 An electrically driven implement (Hoy, 2014)

Alternative fuels

Hydrogen fuel cells, biomethane and CNG are potential energy sources for mobile machinery. These are individually discussed in section 4.5.3.

Agricultural Robots and Autonomous Tractors

Agricultural robots and autonomous tractors are likely to become more prominent in the future. The line between robots and precision agriculture is blurry, but autonomous systems being developed in Australia tend to be smaller individual units. These either work longer hours or in groups to get the job completed. Although smaller units could have lower energy consumption, net energy use is expected to be similar or possibly higher (Luo, 2020). Energy savings from robots and autonomous vehicles are likely to stem from other precision farming factors discussed in Section 4.4.2, rather than autonomy itself.

4.5.3 Alternative fuels

Biogas

Biogas is a mix of methane and other gasses, generated from anerobic digestion of food, crop waste and manure. It relies on large volumes of feedstock so is mostly seen alongside intensive operations with large waste streams (piggeries, dairies) or landfill sites. Biogas is carbon neutral and can be regarded as a 'green' fuel if used to displace fossil fuels. Additionally, the global warming potential of methane is more than 20 times higher than carbon dioxide, so capturing biogas that might otherwise vent into the atmosphere is also seen as a strongly beneficial emissions reduction (University of Florida, 2019). In addition to producing fuel, side benefits of the biogas operation include fertiliser production, GHG and odour reduction.

However, modern combustion engines require high quality, refined fuels and low levels of contamination to ensure their fuel injection systems and pollution control equipment (where fitted) is not fouled. Unrefined Biogas, as a relatively crude fuel, is not often used for mobile or stationary off-grid machinery due to these and other issues. However, it can provide on-site electricity and for heating or cooling water (Luo, 2020). If further processed into renewable natural gas (RNG) or biomethane, it can be used to power any machine that runs on natural gas.

Global biogas production is driven by Germany, the UK, US and China. The reasons for these countries' adoption of biogas vary from addressing landfill issues, supporting renewable energy or the agriculture sector. The common theme across those countries is that appropriate policy mechanisms were put in place before widespread growth was possible (E Carlu, 2019).

According to ENEA consulting, the total biogas production potential in Australia is 371 PJ. If fully realised, this would represent four times the total energy consumed by Australian agriculture. Specialists like EVOET provide electricity and heat generators from biogas and hydrogen in the 20-4000 kW range (EVOET, 2020). Yet, despite more than 240 sites in Australia where anerobic digestion takes place (McCabe, 2018), the options for biogas consumption are currently limited. Barriers include policy conditions, limited industry experience, and the upfront cost which limits the number of viable projects (E Carlu, 2019).

Biomethane/RNG

RNG is the higher-grade, refined form of biogas that is effectively interchangeable with natural gas (methane) derived from fossil sources. It can be stored as either compressed CNG or liquified LNG. It is currently produced in limited quantities in Australia, such as the Biohub in Bundaberg.

Machinery designed to run on natural gas can run RNG. The first production tractor that can be powered solely by RNG was launched last year by New Holland for the European market (New Holland, 2020).

As discussed below for CNG, at present there are very few distribution and storage options for any compressed natural gas product in Australia. There is, however, a major RNG project in Sydney commencing 2022 where initially 95 TJ of RNG will be injected into the Sydney gas network. The source of the RNG is waste from Sydney's sewage treatment plants. If successful, the project will be expanded further (Sherrard, 2020).

As with biogas, RNG can produce up to 80% overall GHG savings compared with diesel (Energetics, 2019). Like other forms of methane, the saving is highly sensitive to fugitive emissions rather than the combustion of the gas. Methane leakage is therefore an important consideration if demand increases and production is scaled, to ensure overall greenhouse gases do not increase (Grubert, 2020).

Fossil fuel gasses (LNG/CNG & LPG)

Liquefied Natural Gas (LNG) and Compressed Natural Gas (CNG) are both natural gas (mostly methane), stored in different states. Methane has conventionally been sourced as fossil fuel; however, as discussed above biomethane/RNG can be sourced from organic matter and landfill sites, with subsequent improvements in its environmental credentials. Here it is discussed as fossil fuel.

- LNG Australia is the world's largest exporter of LNG (Climate Council, 2020), so domestic supplies are in theory abundant. However, most of the production of LNG has been for export markets, where the liquefication increases the energy density for economic transport. Adoption as a vehicle or equipment fuel has been limited by cost and the need for domestic production, distribution and storage infrastructure. All steps require cryogenic handling and storage (at -160°C or lower), which increases costs and complexity, reduces "shelf life", and creates fugitive emissions.
- CNG has made significant inroads into the transport sector in some parts of Asia, Latin America and, to a lesser extent, parts of Europe. Total vehicle numbers are around 20 million (ESAA, 2014). In Australia over 4000 city buses run on CNG with a slightly smaller number of non-bus vehicles (GEA, 2016). Its major drawbacks are fuel density and availability (distribution and storage network). CNG has only 25% the volumetric energy density of diesel (Envocare, 2013). This means either the on-vehicle fuel tanks have to be much larger than for diesel to hold the same amount of stored energy, or vehicles running on CNG have a limited driving range before refuelling is required. A 2016 assessment for road transport found only 5 public CNG refuelling stations, noting "…The general lack of Natural Gas Vehicle (NGV) refuelling and storage infrastructure will continue to hamper the development of a wider NGV market" (ESAA, 2014).

While the industry claims there are significant emissions benefits using CNG over diesel, including lower CO2, NOx, particulate emissions, and SOx (Gas Energy Australia, 2020), recent independent studies using the latest evidence have found that fossil gas used in transport has no meaningful climate benefits, if methane leakage and upstream effects are included. (T&E, 2018). Well-to-Wheel studies show the current diesel emission control laws in Europe negate much of the cleaner burning advantages of gas while the amount of methane leakage throughout the supply chain is high, averaging 2.2% but ranging from 0.2% to 10% (T&E, 2018).

Unlike CNG and LNG, Liquified Petroleum Gas (LPG) is a mixture of butane and propane and is a by-product of crude oil refinement. Of the gaseous fuels, LPG has the greatest number of cars on the road worldwide at around 27 million (WLPGA, 2019). In Australia, LPG has been widely available for decades in urban areas, mostly as a taxi fuel. There are almost 400,000 LPG fuelled vehicles in Australia and around 3000 LPG dispensers (GEA, 2016). This makes LPG the most widely available gas product in Australia by far. But LPG vehicles have experienced no growth in Australia in the last decade, due to rising gas prices, changing tax structures and improvements in petrol/diesel vehicle efficiency, including hybrids (ESAA, 2014). The industry touts the clean nature of LPG, but its own data clearly shows it is the 'least clean' gas alternative to diesel (GEA, 2016).

For pure LPG stationary power generation, a quick review of available products reveals the small number of gas models are massively outnumbered by diesels. Despite being quieter and possessing other positive attributes, uptake appears low. Possible factors could be shorter gaps between refuels and simple lack of awareness of non-diesel options (Generator Power, 2015).

When it comes to stationary generators, LPG injector kits have been used in diesel equipment to save some farmers hundreds of thousands of dollars by reducing diesel consumption (NSW Farmers, 2020). With planned increases in gas excise, the future financial viability of this approach becomes harder.

Hydrogen

Hydrogen can be used to produce power in two ways: combusted in the same way as current diesel and gas fuels; or processed through a fuel cell to produce electricity which then powers electric motors and batteries in the same way as an electric powertrain. Combustion is no longer being promoted as a viable pathway. Therefore, hydrogen fuel cell machines are effectively electric vehicles with a different energy storage system (hydrogen instead of batteries) – not an alternative to electric machines. It can be helpful to think of hydrogen machines as hydrogen/electric hybrids, or an electric machine with a hydrogen fuelled range extender[2] enabling the use of a smaller battery.

Hydrogen is still in its infancy, but it could be used to power both stationary and mobile machinery. Electrolysers to produce hydrogen and fuel cells to use hydrogen are commercially available and could be connected to any grid or off-grid electricity supply to manufacture hydrogen on-farm; but they do not appear to be marketed towards agricultural use (Toshiba, 2020). There are working hydrogen compatible vehicles already at prototype stage, as discussed in section 4.5.2.

More than 95% of the hydrogen created today is made from steam reforming fossil fuel gas (Rapier, 2020), but the great promise of hydrogen is its potential to be produced with zero carbon emissions. Fuel cells produce only water vapour emissions (Shiva Kumar, 2019). And while using renewable energy to power electrolysers to produce hydrogen is far less efficient than simply putting that electricity in batteries, hydrogen has the potential to overcome the energy density (range) and relatively slow charging limitation of batteries.

[2] Historically research did go in to fuelling engines directly with hydrogen, but this was found to be very inefficient compared to fuel cell electric machines (US DoE, n.d.).

Like all gaseous fuels, hydrogen has a higher gravimetric energy density (MJ/kg) than diesel, but a much lower volumetric energy density (MJ/L). Gasses can be compressed or even liquified to decrease their volume, but even after compression in expensive heavy tanks they require more volume than diesel for storage. High pressure gasses have their own issues in terms of leakage and flammability. Hydrogen is far more prone to leakage due to its very small molecular diameter, and any leakage has a greater risk of ignition than common fuels due its very wide flammability range and other factors (IEA, 2020). Researchers are looking not just at high pressure cylinder storage but also liquefaction and chemical storage in the form of ammonia (CEFC and ARENA, 2019).

There is still considerable work required in many areas before hydrogen is able to compete with other fuels – particularly in the area of costs. Common estimates suggest prices to require widespread deployment will not be achieved until the 2030s (Hulst, 2019). Scale of production will help push costs down, with a significant increase in electrolysis capacity in the next 10 years expected to reduce costs by roughly 70% (Hulst, 2019). Falling prices of renewable power generation should also help reduce the cost of hydrogen. The price of producing green hydrogen in electrolysers is predicted to be $4 to $6.50 per kg by 2030 (Gilbert, 2020). On an energy basis, this equates to $1.20 - $1.94 per litre of diesel. The price premium of the vehicle also needs to be added to this cost.

Other barriers to hydrogen apart from the cost of production include changes required in distribution and refuelling. There are fewer than 500 Hydrogen refuelling stations in the world (IEA, 2020); the only one in Australia is exclusively for Hyundai's internal use, but three more are planned (Dowling, 2021). The end use infrastructure required to allow widespread hydrogen adoption simply does not exist yet. For hydrogen to be cost-effective on-farm, it may therefore have to be produced there. These requirements are explored in greater depth in section 5.

Unlike other alternative fuels, hydrogen seems to have captured the imagination and support of government at all levels, having been identified as a strategically important future fuel with support from both ARENA and the CEFC to the tune of hundreds of millions of dollars (QFF, 2020).

Dimethyl ether

Dimethyl ether (DME) is another refined gas-derived diesel alternative that is formed from natural gas and several other sources. DME can be blended to run with LPG, diesel, biodiesel, or run on its own (Makos, 2019).

Only light compression is required at normal temperatures to store DME as a liquid. Diesel engines can run DME with little modification and DME preserves the efficiency of compression ignition (diesel) engines. This an advantage as with spark ignition engines (petrol, CNG, LNG, LPG) are approximately 30% less efficient than compression ignition (diesel) engines. (Kauffman, 2014).

DME can be made via a variety of methods: not only from fossil natural gas, but also RNG, from methanol and from other sources such as landfills and animal waste. Its energy density is higher than CNG, so it can go further between refuels, but it is still only half that of diesel – so tanks need to be twice the size of the equivalent diesel tank for the same energy (US DoE, n.d.).

Like the other alternative fuels, infrastructure and distribution networks are a weakness, even more so with DME than the other alternative fuels as there is no large-scale production in the US or Australia. News broke in November 2020 of a Tasmanian government backed feasibility study into a hydrogen plant that would also make DME from methanol (Lewis, 2020).

Regarding long term viability, there are concerns that the market for methanol (a DME precursor) may be more attractive than making a DME diesel alternative. Price competitiveness is still an unknown factor in the Australian market (Kauffman, 2014).

4.6 Gaps

An understanding of fuel consumption is a necessary first step before a business can start to understand the total cost, or payback periods for any particular technology.

There is no Australian or international system for independent evaluation of whole machine fuel consumption. The Tractor and Machinery Association use “Nebraska testing” as a benchmark, which includes PTO and drawbar (pulling) performance at a variety of speeds, but the reports are geared to an engineering appraisal and not easy to compare (University of Nebraska - Lincoln, 2021).

5 What makes a good alternative to diesel?

The use of diesel as the primary energy source is ingrained in extensive agriculture. Alternative energy sources must equal or better diesel in many ways for the industry to see them as viable options and to spur investment. Seven critical factors were identified that make an energy source desirable to either farmers and/or government. Each of the alternatives considered in previous sections was evaluated against these criteria (against a baseline diesel), for both stationary off-grid and mobile machinery. In approximate order of importance, these criteria are:

- Cost
- Availability
- Practicality
- Technology Readiness Level (TRL)
- Carbon intensity
- Energy Security

Other studies had previously found cost and reliability to be critically important energy characteristics to farmers (PWC, 2019). However, reliability is a subjective criterion, and there is insufficient in-service information about the nascent fuel and technology alternatives to fairly include this criterion. Putting aside the ability of equipment to operate without breaking down, three of the above criteria (TRL, availability, practicality) could be reasonably assumed to substitute for other aspects of reliability.

Energy security and carbon intensity is arguably of most importance to government, although industry consultation did indicate energy security was important to some farmers, who stockpile diesel to ensure it is available at critical times (such as harvest). The other attributes are essentially barriers to adoption.

Cost

Farming is, in many instances, a low margin industry. Industry consultation for this project confirmed the view in the literature that cost is one of the most, if not the most, significant barriers to farmers moving away from diesel (Hoy, 2014), (PWC, 2019).

Cost in this analysis encompasses the ongoing total cost of ownership with a diesel replacement energy, including depreciation, maintenance and labour, but excluding any costs that are only involved with the changeover from diesel to the new energy source. It includes:

- Machinery cost and expected life
- Machinery maintenance costs
- Refuelling activities (especially for stationary off-grid machinery)

Availability

In this case, availability refers to the Australian (or even regional/local) availability of the energy source and associated equipment:

- When will machines be available to buy in Australia?

- Is there already, or potential to quickly develop, fuel supply from an existing refinery, electricity grid, etc?
- Could it reasonably be scaled in Australia to replace a significant amount of diesel?

The availability now, and projected availability over the next decade, were based on research and parallel developments in related sectors (e.g., road transport).

Practicality

Practicality encompasses the ease with which a new diesel replacement technology can be integrated into farming businesses. It includes:

- Portability of stored energy (fuel tanks, batteries)
- Changes of behaviour required to adopt the new energy source and machinery
- The ease of transitioning an existing diesel-based farm to the new energy.

Technology Readiness Level (TRL)

TRL is an established international system for estimating the maturity of different technologies against a consistent measure. The TRL refers to worldwide development, not necessarily availability in Australia. For example, biodiesel and renewable diesel have a TRL of 9, as they are commercially available in the USA, but are not widely available in Australia (EVs). For that reason, "availability" was added to the analysis as noted above.

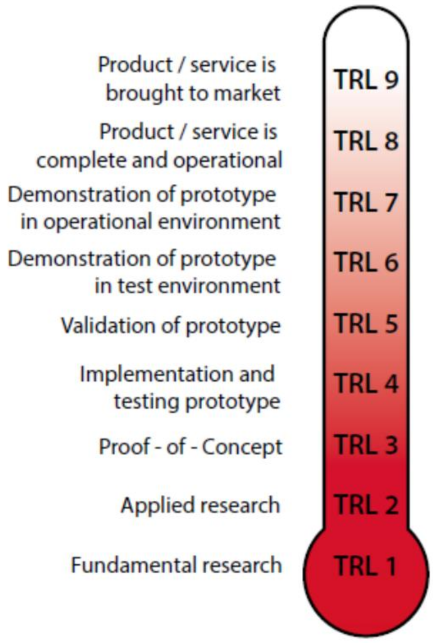


Figure 12 Technology Readiness Levels (M Doussineau, 2018)

Carbon intensity

Carbon intensity refers to the greenhouse gas emissions associated with one unit of the fuel at end use, including fuel manufacture, exhaust emissions and any fugitive emissions. In reality, carbon intensity of a new fuel or technology may be low down the list of a small farmer's priorities, but it is important to government and society more broadly.

A significant reduction in carbon emissions was considered an essential criterion in the assessment because it is one of the main reasons to switch away from diesel, and a founding assumption of this study (meeting a net zero target). It is also unlikely that a new alternative fuel will attract the required investment and support if it does not produce a significant reduction in carbon emissions.

Energy security

Energy security has a national scale as well as a farm scale. At a national scale, it is primarily seen as the government's job to limit any disruptions in the energy supply chain. However, farmers are often self-sufficient in many ways and this could expand to their energy needs in future, if energy is produced on-site or at neighbouring sites (e.g. microgrids, energy hubs). On-farm production of energy can also increase resilience from oil price volatility.

6 Evaluation of alternative energy sources

Meaningful consideration of alternative fuels must be conducted using a segmented analysis, because different types of equipment and uses have different energy requirements that suit some fuels more than others. In this case, the first level of segmentation was for stationary and mobile equipment.

6.1 Stationary off-grid machinery

The six most promising alternative energy sources for stationary off-grid machinery were selected and compared to diesel for the six criteria in section 5. They were scored for the current situation, as well as a foreseeable medium-term outlook (2-5 years) and long-term prospects (5-10 years). The future scenarios assume a policy environment conducive to these energy sources. Figure 13 shows the results.

Figure 13 Evaluation of diesel alternatives for stationary off-grid machinery

"Stationary off-grid machinery" covers diverse use cases, and there will be individual situations that will be different from a nominal average. For example, the figure shows that PV diesel electric hybrid systems are already as good as, if not better than diesel systems (apart from their availability). Many systems are expected to move across to this technology, but time critical systems (such as pumping very high volumes on allotted days only) are likely to stay diesel, and systems where intermittency is not a problem are likely to switch to the cheaper PV/Wind electric systems, avoiding the expense of a diesel or battery backup.

6.2 Mobile machinery

As with stationary off-grid machinery, Figure 14 shows the results of evaluating the six most promising alternative energy sources for mobile machinery against the same six attributes. As before, the future scenarios assume a policy environment conducive to these energy sources.

The results for mobile are very different to stationary machinery, mainly due to the need for a mobile machine to load large amounts of energy in a relatively short time, and to carry this energy in a relatively light and compact form – two things for which diesel is excellent.

Mobile machinery covers a diverse swathe of vehicles from one and two person ATVs, utes and trucks, to tractors, sprayers and headers. Figure 14 indicates that even in 2030, battery electric machines and fuel cell hydrogen equipment will not be widely available to replace the bulk of diesel used. This is largely due to the weight penalty associated with heavy batteries, and the volumetric penalty of hydrogen storage versus diesel (around 7:1). Although electric ATVs and rigid trucks are already available in Australia today (EMC, 2020), (SEA, 2021), these are smaller support vehicles with a correspondingly small contribution to total diesel use. Larger, specialised machines that consume hundreds of litres of diesel in a single shift (tractors, sprayers, headers) are unlikely to be widely available within that timeframe.

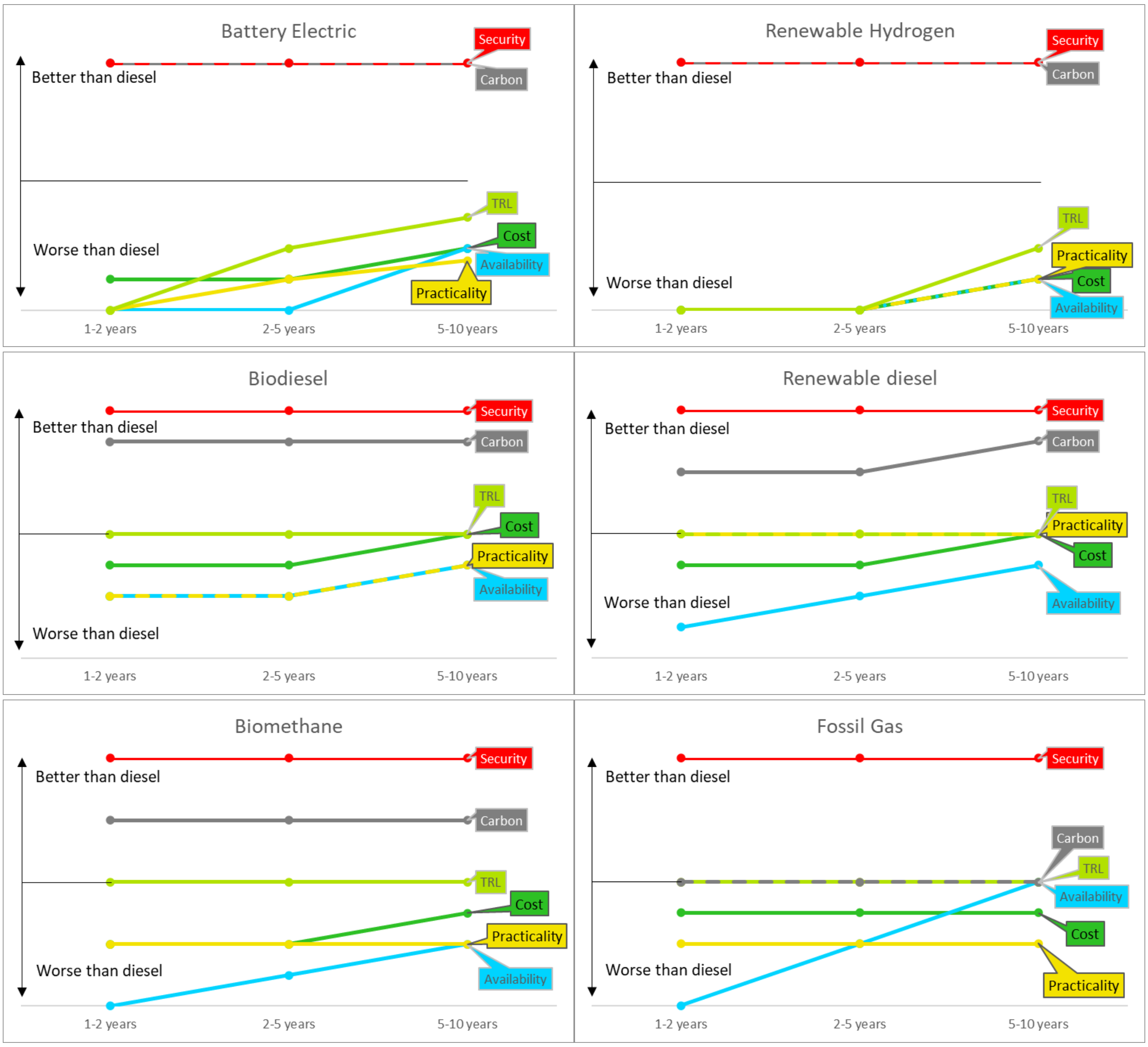


Figure 14 Evaluation of diesel alternatives for mobile machinery

6.3 Summary

Combining these prospects for each fuel provides a summary indicative score for each fuel, indicating which are more competitive than others overall. Figure 14 and Figure 15 show this result for the three time periods and from the farmers perspective. Farmers are most concerned with cost and reliability, so the prospects for a less flexible, more expensive or inconvenient energy source is unlikely to be traded simply to achieve a GHG gain (i.e. carbon and energy security are less important). The graphs therefore represent what farms are likely to invest in, unless significant policies or incentives/disincentives are provided to shift behaviours.

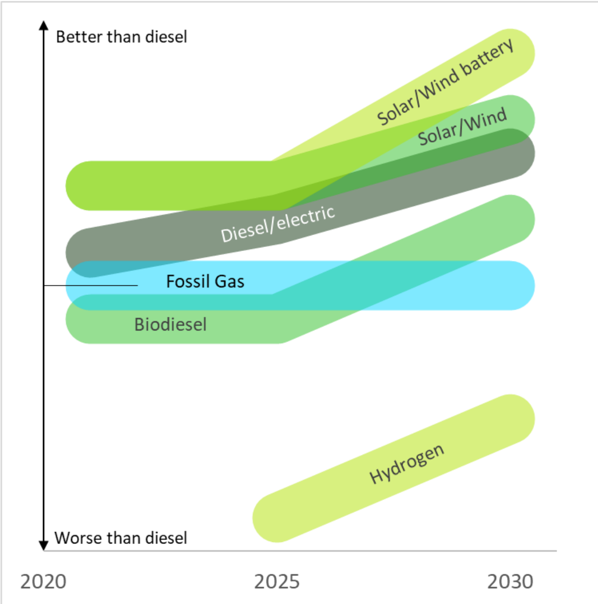


Figure 15 Overall relative score of diesel alternatives for stationary off-grid equipment

The result for stationary machinery is clear: with sufficient education and resources, farms will tend towards a continuing electrification of stationary equipment, replacing diesel with electricity generated on-site from solar or wind energy. This is clearly in line with the policy priority of decarbonisation. Assuming no large reductions in diesel price occur, little needs to be done, except take the opportunity to support and accelerate this change.

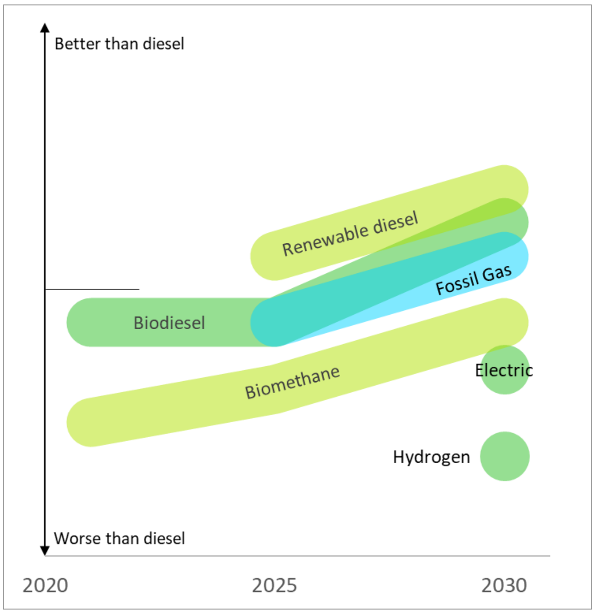


Figure 16 Overall relative score of diesel alternatives for mobile machinery

The result for mobile machinery is equally clear. In the time horizon considered, there is no real reason or benefit for farms to switch from conventional diesel until 2025 at least. Even then, the incentive to use renewable or biodiesel is very small (mostly on energy security grounds). Driven by price, there is also a risk that farms may move to fossil gas, providing little or no GHG benefit over diesel.

For large and high consumption agricultural machines, battery electric, hydrogen, fossil gas and even biomethane will not meaningfully assist extensive agriculture in reducing its energy emissions in the short-to-medium term and may not do so before 2030 either.

6.4 Insights

These fuel assessments, coupled with the information provided via targeted consultations, highlighted several insights about the prospects for low-carbon diesel alternatives in agriculture.

- Natural gas from fossil fuels provides little to no GHG benefits, either now or in the future. Its main benefit over diesel relates to energy security, with Australia being a major producer and exporter.
- The future of extensive farming will be increasingly electrified, though not necessarily fully electric.
    - Electric motors are more reliable, flexible and energy efficient than diesel engines.
    - Most agricultural machinery is not simply an engine driving the wheels. Engine power is redirected through a mixture of hydraulic and mechanical means to power many functions from raising/lowering a plough, powering a slasher, and cutting, threshing and unloading in a combine harvester. Electrification o some of these functions means they can operate independently at their optimum speed, and only when required.
    - Hydrogen fuelled machinery is simply electric machinery with an onboard electricity generator (the fuel cell) that is fuelled with hydrogen.
    - Even if biogas or LPG were to become suddenly cheaper and seen as favourable under a gas-focussed policy, a gas-electric hybrid will be more efficient in mobile machinery than a gas fuelled engine alone.
- For the larger mobile machinery, battery electric technology is immature and won't contribute significantly in the next 10 years. There is likely to be some uptake in the smaller (road going) vehicles, which have a vital support role on-farm. Battery electric ATVs, cars and even trucks are already commercially available, and the choice and number will only increase. It is expected that by 2030 the ubiquitous farm ute and motorcycles will be available as fully electric. Given that these vehicles can slow charge overnight with existing farm infrastructure, the main limitation is likely to be access to a trusted local dealer/maintenance support network.
- Hydrogen is still an immature technology. Although it shows some promise, in the 10-year timeline considered, it cannot take over a significant portion of work currently done by diesel. Questions also remain over its practicality, due to a significant volumetric payload penalty compared with diesel. And the lower round-trip efficiency required to produce it through electrolysis means that two to three times as much renewable energy will be required than if the electricity was just used directly.
- For stationary off-grid situations, electrification via PV solar or wind, with diesel or battery backup where necessary, is already an option in some situations. By 2030 these systems will be cheaper and more available, allowing them to take an increasing share of the work from diesel.

- Unglamorous though it is when compared to battery electric and hydrogen fuel cell vehicles, efficiency could be the key to enabling a significant emissions reduction in the short to medium term. Though not often recognised as such, energy efficiency is also a key enabler of all the other alternative energy sources. The more efficient the equipment or system, the less energy it uses, and so less energy needs to be supplied from renewable sources that need to be built. It also means the equipment needs to carry less fuel and suffers a smaller mass/volume payload penalty – a weakness common to all the non-ICE future fuels.
- Given the immature nature of other low carbon fuels and the slow turnover of the fleet, in this short 10 year timeline to 2030 the only way to significantly reduce GHG emissions is by rapidly ramping up biodiesel and/or renewable diesel usage.
    - Current Australian biodiesel production is very low at around 100 ML per year (CEFC and ARENA, 2019), which equates to only 4% of agriculture's consumption. There is little to no commercial scale renewable diesel production.
    - Biofuels can be made in large refineries and shipped to the user (current diesel model), or produced on farm from local feedstocks, at prices roughly competitive with diesel.
    - Biodiesel usage is currently limited to specific blending ratios with regular diesel, but can be used up to 5% (B5) without specific labelling. Renewable diesel can, in theory, be dropped in to replace diesel entirely, without blending.
    - There appears to be an appetite for farmers to participate in the supply chain of biodiesel and renewable diesel production, given the alignment with their agriculture production and waste streams.
- Industry consultation showed that biodiesel has a negative image due to past issues with fuel quality, which may be hard to shift. An additional challenge is that there are currently few machines warranted for its use with biodiesel beyond a 20% blend.

7 Pathways to zero

7.1 The bigger picture for agriculture

As discussed in Section 3, diesel usage causes only 8% of Australian agriculture's greenhouse emissions. Figure 17 shows the historical and projected future emissions from Agriculture. This figure excludes diesel, which was an additional 6 Mt CO2-e in 2020. The segments in this figure lie outside the scope of this project, but there is no doubt that the opportunities to reduce or sequester carbon emissions in these areas will be critical in the path to net zero for agriculture. Examples of such opportunities include:

- Soil sequestration, where atmospheric carbon is stored in soil and vegetation
- Establishing permanent plantings of native trees and shrubs on previously cleared land
- Managing stock to allow native forest regrowth
- Reducing beef herd methane emissions through changes in genetics, diet or grazing management
- Reducing NOx emissions from irrigated cotton by changes to fertilizer application

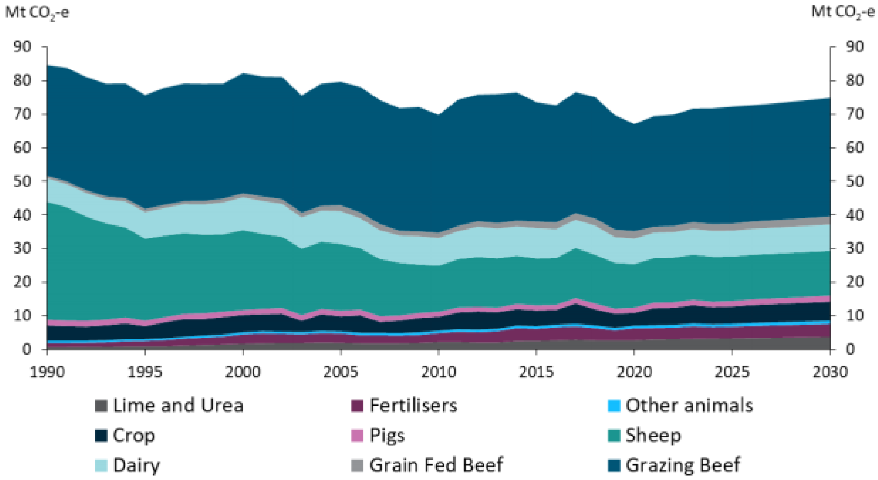


Figure 17 Agriculture's total emissions projection (DISER, 2020)

According to the National Farmers Federation roadmap, the Australian farming industry is already tracking towards carbon neutrality by 2030 (Luo, 2020). So, some of these actions are already underway.

7.2 Potential contribution from efficiency alone

With practical battery electric agricultural vehicles expected in 2025 at the earliest, and hydrogen later than that, the bulk of the energy in 2030 will have to be supplied by diesel, renewable diesel or biodiesel. Even if renewable hydrogen is an affordable option for some agricultural vehicles in 2030, there will still be many diesel-powered vehicles in service due to their long service lives and consequent slow rate of replacement.

Figure 18 shows the potential to reduce diesel demand in agricultural mobile machinery through fuel efficiency measures alone. The BAU line shows the expected 18% increase in agricultural output in 2030. If there were no efficiency gains in this time, the 18% increase in output will mean 2030 diesel usage will be 118% of 2020's diesel usage. The high estimate shows the combined effects of expected efficiency improvements – 2030 diesel usage will still be 110% of 2020. The low estimate shows the best case scenario, where industry adopts most of the available efficiency options as fast as reasonably practical. Given an 18% increase in agricultural output, in the very best case efficiency improvements could only keep 2030 diesel usage at the same level as in 2020.

However, if the Department of Agriculture, Water and Environment's current Ag2030 agenda were to come to fruition, it is likely that growth will be higher, leading to 2030 energy consumption being 40%-55% higher than 2020 (DAWE, 2020).

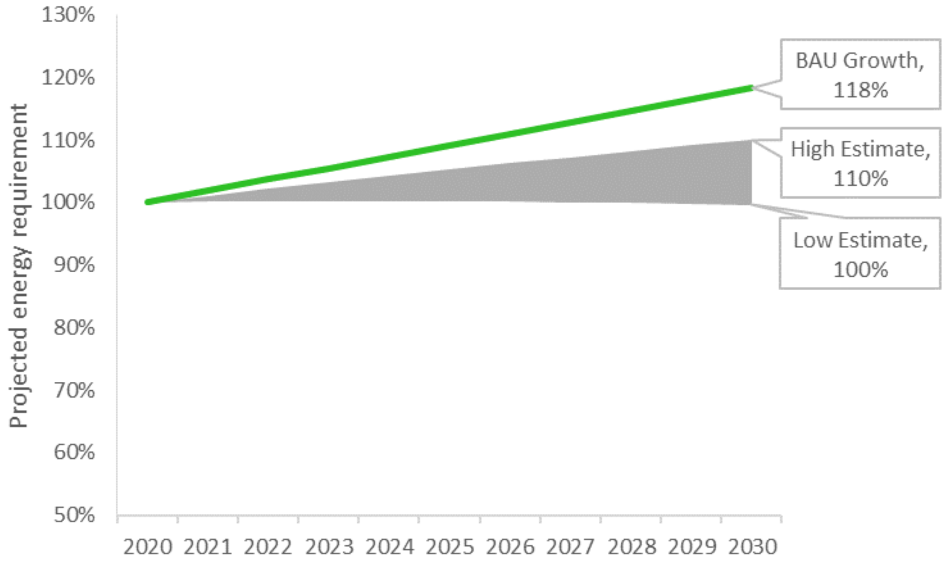


Figure 18 Mobile machinery: Benefits of fuel efficiency alone over BAU

Even though specific changes such as increasing hybridisation could improve a 2030 machine's efficiency by around 20% in aggregate compared with 2020 levels, agricultural machines have long service lives of 20 years or so. No matter what technology advances are made, the 2030 fleet will still be hampered by older equipment built in 2010 or earlier.

The largest net efficiency gains expected by 2030 will be those that can be "bolted-on", such as some aspects of precision agriculture (total 4-8% net fleet impact), and further implementation of operator techniques, which are being assisted by driver aids (2-4%). Given the relatively small number of vehicles that will be in the fleet, hybridisation is expected to contribute less than 2% fuel savings to the fleet by 2030.

Similarly, Figure 19 shows the potential for efficiency and electrification in stationary equipment to reduce diesel consumption levels to between 61% and 92% of 2020 levels. Unlike mobile machinery, electrification of stationary machinery is already occurring and will only accelerate up to 2030, significantly reducing the amount of diesel used.

As above, success with the Ag2030 agenda may negate these improvements, leading to an estimated 85%-129% of 2020 consumption by 2030.

Given that agricultural energy consumption is going to increase over the next 10 years, and most of the diesel is used in mobile machinery, energy efficiency measures will be vital in reducing the emissions intensity of the sector and containing increases in emissions.

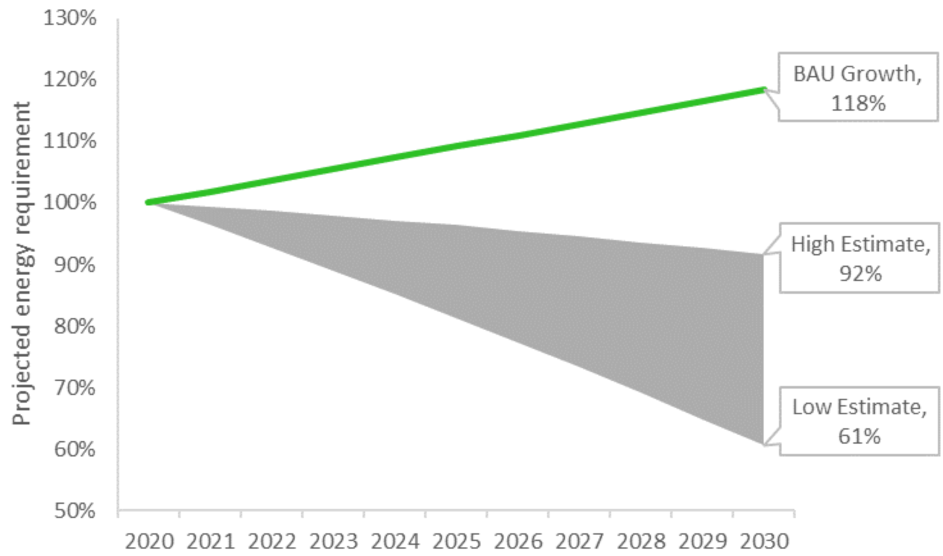


Figure 19 Stationary machinery: Benefits of system efficiency and electrification over BAU

7.3 Barriers to improvement

While cost is a critical factor for transitioning to any new technology, it is particularly important for new fuels because energy is fundamentally linked to farm activity. But this is not the only consideration: electrification, gas fuels, and particularly efficiency are pathways to significantly reduce costs, and despite some of these being cost-effective and reliable already, they are still not widely used. Clearly, other barriers (both financial and non-financial) are constraining energy improvements.

- Choice In extensive agriculture, Australia is first and foremost a technology taker - If the technology isn't ready or sales potential too small, Australia is unlikely to see much model availability or choice.
- Uncertainty Broadacre farming is a low margin, conservative industry. Understandably, farmers want to see proven and reliable real-world results before risking borrowed money on expensive but unproven infrastructure and/or equipment. There is little risk in persisting with diesel, but there are multiple risks with new fuels and equipment.
- After sales support. Fuel stations and distribution networks are often considered when looking at alternative energy sources, but local support for parts and maintenance is often overlooked. Given the cost of equipment downtime – particularly at peak times like harvest – local support for parts and maintenance will trump any fuel or efficiency benefits. A relevant example identified during consultation was the purchase of a less fuel efficient tractor simply because there was no local dealer for the more efficient model that was preferred. A lack of local expertise in maintaining and repairing new technology systems, and competition with existing well established diesel services, can only be overcome with time and significant investment by manufacturers, dealers and other suppliers, and with relevant technical and vocational training.

- Cost is a critical factor. While there are many low-cost efficiency improvements such as behaviour change and improved practices (e.g. driving technique or equipment operation), some potential improvements require significant capital investment. Similarly, grid power for electric equipment can be cheaper than diesel; but where reliable instant power is required, off-grid electrification and storage is still expensive.
- Policy The regulatory and policy environment is often essential in building market confidence and can make or break fuel alternatives. For example, government excise changes increasing excise on gas makes it harder for LPG or biomethane to compete with diesel. At the same time, diesel rebates lower the cost of diesel-powered equipment, making it harder for alternatives to be financially viable (Luo, 2020). Local authorities may also inadvertently discriminate against newer technologies. For example, in parts of WA where pumping is limited to certain days after rainfall, farmers want to pump as much water as possible in the time allowed. This leads to oversize systems with low utilisation, where solar PV has a less attractive ROI. A lack of supporting programs, such as the CARB FARMER program in the US, means that famers have to pay up-front for clean tech infrastructure.
- The long asset life of farm machinery, especially mobile machinery, means any new technology that replaces old equipment – such as battery electric or hydrogen fuel cells – will take a long time to propagate through the national farm fleet in Australia. To illustrate the effect: even if a tractor replacement program halved tractor life by doubling annual new sales, and every new tractor sold was electric, only around half the fleet would be replaced by 2030.
- Critical fuel infrastructure. Often there is a major focus on the end technology and not enough on the energy supply. Reliability and cost of supply is perhaps the most critical factor in any one operation considering a switch to alternative fuels. Diesel is reliably delivered and stored through regional networks all around the country. Any switch to an alternative requires secure production, distribution, storage and a long stable shelf life. The risk of supply interruption would turn many farmers off an alternative.
- Electricity grid quality. Poor quality electricity grid connections remain a barrier for many farms in rural Australia, exacerbated by extreme temperatures putting "a massive strain" on the network (Luo, 2020). This could potentially be alleviated by some on-farm energy storage and smarter controls, evening out the demand on the grid, and reducing or eliminating power demand at peak prices.
- Biofuel feedstocks Biofuels that use crops (rather than waste products) as a feedstock will be needed in higher volumes. There is a delicate balance to be struck to achieve success: Growers must get a high enough return for the crop to be viable, but the fuel must still sell at a price that is competitive with diesel. With lower diesel prices and increased biofuel excise this may not be easy.
- Renewable diesel excise duty. Although conventional biofuels are taxed at lower levels than other fuels, there is no excise relief for renewable diesel, as there is no production at a commercial scale in Australia (IEA, 2019; Bioenergy Australia , 2020).

7.3.1 Stationary off-grid machinery

The most beneficial diesel alternatives for stationary off-grid machinery are already available on the market, and starting to become better known (i.e. on-site generation of electricity through solar PV or wind, with battery or diesel backup if necessary). These have two main barriers:

- Capital costs are high relative to diesel. Currently, diesel still has the lowest up-front cost. A 10kW diesel generator can be bought for $8000 (Blue Diamond Machinery, 2020); while a photovoltaic replacement is likely to cost over $10,000 (Solar Choice, 2020). If batteries are required for continuous supply, an additional $14,000 is likely (solarbattery, 2020). The reduced running costs of the electric system may only compensate for this additional capital if utilisation is high.
- Education/information is a smaller barrier, but until off-grid electric systems are widespread, there are only limited opportunities for "over the fence" discussions to build confidence.

7.3.2 Mobile machinery

Some barriers are expected to be unique to mobile machinery.

- Utilisation. Many mobile agricultural machines sit idle for long periods between seasonal work, compounding the effect of higher capital costs (Future Farming, 2018). This especially affects future hydrogen fuel cell and battery electric machinery which have significantly higher up-front costs.
- Energy density, often expressed as "range", is still a primary barrier to adoption of BEV technology in tractors and larger mobile machines. Diesel models can work 10-12 hours in the field without needing to return to base to refuel (Campbell, 2020). Current technology battery electric tractors would only allow 3-4 hours of operation before recharging is necessary (Ham, 2020).
- Unavailability in Australia. Despite prototypes and demonstration projects overseas, there are few advanced zero emission models available in Australia. So even if farmers want to switch, they can't.
- Capital investment for battery electric tractors may be 30% to 80% more than conventional tractors. However, they may become popular in niche sectors where the energy requirements of the machine are less intense (such as vineyards) (Campbell, 2020).

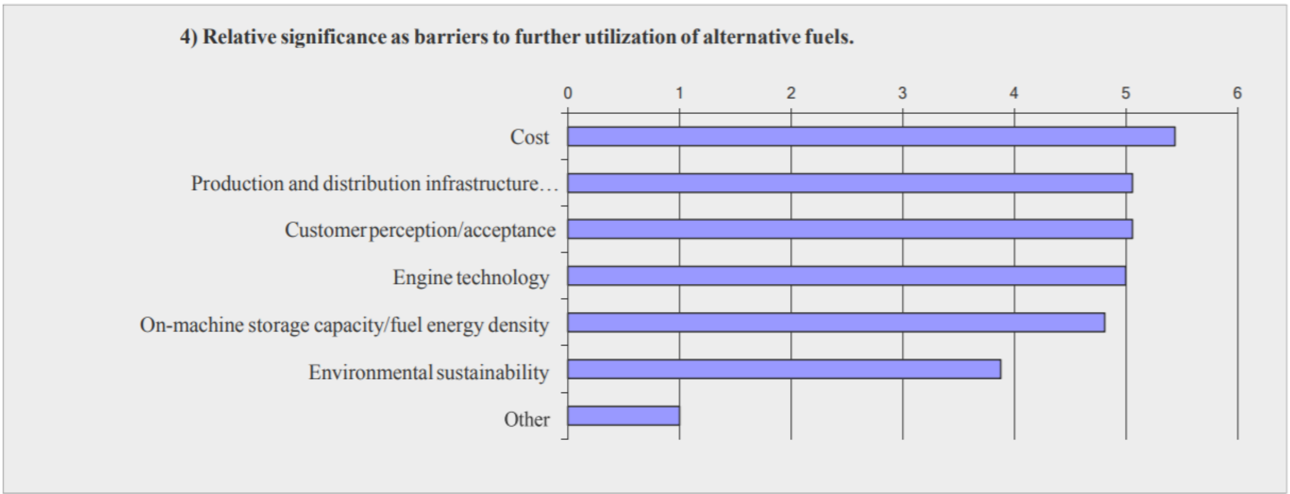


Figure 20 Barriers to alternative fuel adoption (Hoy, 2014)

8 Potential actions for government to 2030

To reduce greenhouse gas emissions to zero, the performance of not only new machinery, but also legacy (ageing) fleet, must be addressed. Without a radical repower program to address all in-service machinery, the widespread use of renewable diesel and/or biodiesel is the only way to achieve this.

The technology and experience of producing biofuels in Australia already exists, having previously taken place at larger scale and more locations than occurs today. It is here that government policy could make a real difference. The 2018 Farm Institute report found the uptake of renewables is dampened partly due to a lack of any comprehensive state or federal government framework that supports the new generation technologies, or any subsidy support in this area (Australian Farm Institute, 2018).

One of the most effective ways to accelerate emission reductions is to support fuel efficiency and energy productivity measures. Not only does higher on-farm energy efficiency reduce emissions per unit of production, but it also reduces the amount of new transition fuels required – both combustion fuels and non-combustion zero emission future alternatives (electric, hydrogen). This makes the overall challenge more achievable, because the number and size of production plants can be much lower.

Energy productivity also brings other major co-benefits. It reduces running costs, in many cases making farms more profitable. It also typically has a better return on investment for the user, compared with large wholesale shifts in fuel type that bring large switching costs. Perhaps most importantly, much of the required knowledge and technology is already available but not widely known or adopted; and many of the potential opportunities require little capital cost and/or have an attractive return on investment.

Although the agriculture sector has been a leader in the shift to renewables, with over $100m spent on solar projects since 2017 (NIC, 2019), the high up-front cost of the clean technology investment is the single biggest barrier for most farmers to reducing energy costs such as diesel and integration of solar energy production with battery storage. There are some existing mechanisms and support measures that go some way toward reducing the investment gap (e.g. ARENA, CEFC, state grants); but in some cases, and particularly for mobile machinery, simply meeting the same price point as diesel may not be enough to overcome the other uncertainties of new technology (reliability and downtime risks, practicality, switching costs for new tanks and pumping equipment of alternative fuels, new tooling and training, etc). This is where targeted government assistance can smooth the transition.

There are longstanding examples of effective government intervention and assistance in the Australian agricultural sector, such as the diesel tax rebate, and assistance for drought declared land. So, directly intervening with farmer assistance would not be a new step. If government was able to reduce some of the transition costs for farmers, it should increase farmer uptake of these newer technologies. Industry consultation did show that some farms were taking advantage of loans for drought assistance to invest in new technology.

The importance of government support to seed and normalise new fuels and technologies to supplant current fuels is best illustrated by an example of what happens in the absence of such support. The adoption of battery electric vehicle technology in Australian cars over the last decade serves as such an example. Ten years ago, although battery technology was mature enough to make viable road cars in several segments, the vehicles had some limitations and buyers baulked at the much higher up-front costs, so adoption rates were very low. Governments at state and federal level provided only minor support measures (e.g. registration discounts) but did not tackle the major barriers of supporting infrastructure or meaningful transition subsidies.

A decade later, electric cars still only comprise 0.6% of Australian new car sales (Figure 21). Yet countries that supported the transition with meaningful subsidies, integrated charging networks, and consumer and fleet information, have managed to achieve much higher levels of adoption in the same timeframe – as shown in the right-side column of the graph.

The lesson is that development of a mature fuels market in agriculture, which is more conservative and price sensitive than the car market, is going to be similarly slow without meaningful and substantial support. This support must include incentives to attract the technology to Australia (manufacturers prioritising this market), supporting users with information and decision tools, and leveraging investment in fuel infrastructure and availability. These were all lacking in the EV market or cars until very recently.

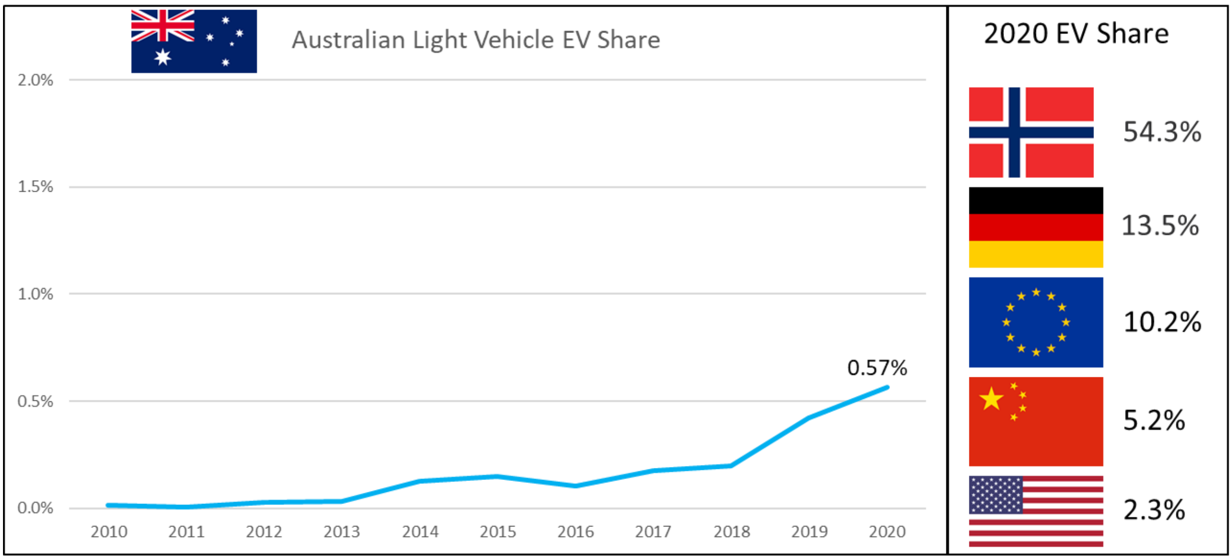


Figure 21 Light electric vehicle market share Australia and select markets (Source: Vfacts, EV Council)

Californian FARMER scheme

The Californian "FARMER" scheme (Funding Agricultural Replacement Measures for Emission Reductions) is a current example of direct government intervention designed to increase uptake of cleaner technologies at the individual farmer level, which could serve as an example for local action.

In 2018 the California Air Resources Board (CARB) approved the use of $US 135 million to reduce emissions from the agricultural sector. The funding allows for harvesting equipment, trucks, agricultural pump engines, tractors, and other equipment used in agricultural operations to be replaced by cleaner more efficient technology that is cheaper to operate.

There are several strict guidelines for the scheme. Eligibility requires all vehicles and equipment to be actively engaged in agricultural operations within California. Project categories include:

- On-road heavy-duty trucks

- Off-road vehicles, such as tractors
- Stationary and portable engine sources, such as agricultural pumps
- Utility Terrain Vehicles (UTV), or small tractors, (eligible for replacement with electric UTV)
- Infrastructure engaged in, or supporting, agricultural operations.

Grants of up to $US 135,000 (80% to 100% of project) assist the purchase of more efficient, or zero emission agricultural vehicles. For eligible infrastructure projects, the maximum percentage of project cost that the scheme covers depends on utilization of renewable power sources and whether some of that power is publicly accessible, but up to 75% of project cost can be subsidised. Projects may be based on clean power generation with battery backup, alternative fuel stations, or improved efficiency pumping (CARB, 2020).

Addressing key barriers in agriculture. Policy and program support measures are most effective when they target the barriers to natural market uptake. Agriculture is a conservative industry. The remote nature of most farms also means that a major barrier to future new energy sources will be familiarity with the technology and local support/backup. Will the farmer be able to carry out simple repairs and maintenance themselves? Will they be able to get spares? Will trusted local (regional) workshops be able to work on it?

By demonstrating and promoting the viability of electric or diesel-electric stationary machinery that is already economically viable in some instances, and diesel-electric hybrid mobile machinery, Australian regions can build experience and confidence working with electrified equipment, making any future transition to battery electric, hydrogen, or gas-powered mobile equipment much easier.

8.1 Short term actions (1-2 years)

- **Improve the level of current baseline information.** Compiling the energy data to support this study highlighted the need for more granular and disaggregated energy data in this sector. In some data sources, agriculture is bundled with forestry and fishing; in other cases, the farm machinery fuel consumption is bundled with other industrial or stationary sources (even though mobile equipment is clearly not stationary equipment). The understanding of diesel consumption in different farm types (e.g. wool and sheep), appears to be equally poor. And a better understanding of the degree to which known fuel saving methods such as CTF and other Precision agriculture technologies are being implemented, also appears to be an information gap based on the feedback in consultations. (CTF: 45% FC benefit (Giles, 2013)).

  Yet a good baseline understanding of energy use segmented by activity is the most critical foundation for any effective action in this area. Government support for more research or assessment of energy use would build a solid foundation for future policies or programs that could effectively target priority sectors or users, reducing the overall cost of emissions reductions.

- **Incentivise farm assessment.** Follow and possibly replicate Business Victoria's Agriculture Energy Investment Plan on-farm assessments. Only very limited case studies have been released so far, such as a vineyard that could save a projected $7,700 p.a., mainly through optimisation of electrical equipment and installation of solar photovoltaics (Agriculture Victoria, 2020).

- **Aggregate, update and centralise information.** Access to trusted information is a key enabler of change. Information sources about energy efficiency measures in particular are currently dispersed and in some cases outdated. This is particularly important in the area of costs, cost effectiveness and RoI. Government could support the centralisation of relevant information and case studies in a dedicated information hub tailored to the agriculture sector. There are many models for this approach, and it is likely that industry associations would eb good partners in either compiling or hosting the final information.
- **Diversify knowledge transfer mechanisms.** Recognising that not all farmers will access information via a website or centralised information hub, education opportunities could be expanded to field days, and the existing farm supply chain (rural stores, equipment suppliers, seed and chemical sellers, contractors, and training organisations). Access to trusted information is a key enabler of change. Ultimately the message must be disseminated through a peer-to-peer network, so the more channels that can be harnessed the more effective the information exchange will be.
- **Leverage opportunities from other industry changes** to incentivise lower diesel consumption. For example, the NSW and Commonwealth Governments are reviewing the potential to manage non-road diesel engine emissions (such as particulate matter and nitrogen oxides, not carbon dioxide) (DEE, 2020). If Australia decides to follow the US, Europe and many other countries by adopting exhaust emissions limits for new non-road diesel engines (including farm equipment), this could be done with concurrent introduction of other initiatives like:
  - Publication of standardised machinery efficiency ratings to guide purchase decisions
  - Alternative fuel financial incentives
  - Machinery efficiency incentives
  - Promoting and combining information events (e.g. field day with an extra demonstration)
- **Benchmarking and defining best practice.** Review the latest developments and best practices used in the EU, UK, US and China. This could be to identify effective policy measures that are accelerating adoption of alternative fuels, or to identify case studies and associated data (e.g. cost, reliability, scaling factors) that could be transferrable to NSW farms.
- **Prepare for a bottom-up approach**, where individual farms can be financially and technically supported in carrying out demonstrations of efficiency or alternative fuels. Ensure these key projects record detailed value-for-money information, and a reliable before/after comparison to effectively demonstrate to “neighbours” whether the technologies being used are indeed reliable and good value. Even then, projects will not be successful if they are seen to happen in a vacuum, or only with specialist, “flown in” support. Projects should ideally rely on local suppliers for the system, parts, repair and maintenance services. Ensuring these projects are spread out geographically will give the maximum opportunity to share the knowledge and support existing suppliers.

8.2 Medium Term (2-5 years)

As noted earlier, the future zero-emission fuels (electric and hydrogen) are, at best, medium to long term opportunities, at least in Australia. Companies like John Deere and AGCO Fendt are working on fully electric agricultural vehicles, with prototype tractors in existence. AGCO Fendt plans to release their first fully electric tractor to market by the end of 2021 (Grooms, 2020), joining Belarus and John Deere who have previously offered electrified tractors[3]. H2 Trac intend to have their diesel-electric hybrid tractor in production in 2021, coming to Australia by 2022. In their opinion, hydrogen would be the next step (Ham, 2020).

Biodiesel produced from dedicated crops might not currently be produced at large scale or economically appealing, but If the value of carbon is priced in, or government incentives provided, then it could be (Luo, 2020). Renewable diesel, while less mature, is a similar or even more attractive drop-in fuel which would not require blending at all, at least in theory.

The idea that farms could be energy self-sufficient, with fuel grown on-site to power equipment, is particularly appealing for some farmers if there is a positive business case (which will hinge on the value of the crop/feedstock in its traditional market versus the fuel market).

In other markets, biofuels are a mature and relatively mainstream choice. Commercial plants of advanced biodiesel, or renewable diesel, have proven successful, for example, in the US, Singapore, Finland and Netherlands (CEFC and ARENA, 2019). This could also be the case in Australia with relatively little effort and cost. The path to market is shorter, quicker, and less complex compared with complete transformation to electric or hydrogen.

Medium term opportunities for the NSW government could be **to support production and adoption of these transition combustion fuels** (biodiesel and renewable diesel). "Support" could be provided in several ways including:

- Demonstrate or prove-out several on-farm demonstrations and promoting the results to help build confidence in the fuels.
- Fund commercial studies that demonstrate or test the business case for both on-farm self-sufficiency or renewable fuels more broadly.
- Educate and disseminate accurate and recent experience with modern biofuels to dispel old myths or misunderstandings.
- Offer production grants or co-investment to support more production facilities.
- Build demand certainty (which strengthens the case for private investment) by committing parts of the NSW government fleet to operate on these fuels (e.g. trucks and utes where an electric option isn't currently available)
- Work with manufacturers and suppliers to expand warranty coverage for users that operate with biodiesel or renewable diesel.

[3] Neither is apparently currently for sale – John Deere quoted lack of customer interest, having sold only 200 hybrids (Future Farming, 2018)

- Work with the Commonwealth to extend excise relief or excise reduction for renewable diesel produced from biomass residues and waste streams used in farming, to make it more cost-competitive with fossil fuels (Bioenergy Australia , 2020).

At the same time, building a clearer understanding about the future market for electric and hydrogen equipment, and products to match that demand, would assist future planning. This could include:

- **Work with OEMs, suppliers and energy experts** to understand and map the likely future market offerings in these fuels. Two factors here are most important. Firstly, how quickly the fuels can reach diesel-parity in terms of on-farm performance (e.g. refuelling time, weight penalty for electric, volume penalty for hydrogen, etc). Secondly, to what extent changes would need to be made to current farming activities to accommodate the future fuels if they cannot be made equivalent to diesel (e.g. number of refuels per day, frequency or repair or parts replacement, constraints on service life or refurbishment in parts like batteries and fuel cells, etc).
- **Support some initial demonstration projects** that are properly designed to quantify the gap between these technologies and diesel – either positive or negative – which could inform both researchers and businesses about where investment should be funnelled to make these options more competitive.
- **Assess the potential for regional clean energy hubs** dedicated to diversifying farm energy supplies. These could provide convenient distribution points for a diverse fuel mix (biogas, biodiesel, renewable diesel, hydrogen and renewable electricity), streamline infrastructure investment and bring energy supplies closer to their point of use. This model means farmers need not be responsible for the whole energy supply chain to begin their transition. But for those that do wish to diversify into biofuel production, it also means they have access to a distribution point to supply other farms.

8.3 Long Term (5-10 years)

Long-term actions should maximise the benefits from the medium-term actions for low-carbon combustion fuels, while simultaneously preparing the market for the zero emissions technologies that will become available as their cost and technology improves (battery electric, hydrogen). For example, the development of a prototype energy hub as suggested above, could be undertaken in partnership with industry and the farming sector, providing that concept has been assessed as commercially viable.

For applications in which electric or hydrogen powered equipment may not be viable in the foreseeable future, the focus could be on developing the national market for clean combustion fuels via incentives for low carbon advanced biofuels. California's Low Carbon Fuel Standard can be used as an example (CEFC and ARENA, 2019).

In applications where electric and hydrogen powered equipment could be viable (and this group will continue to increase as the technology develops), support for manufacturers to bring more models to market could be effective in demonstrating demand certainty. The NSW *EV Infrastructure and Model Availability Program*, as flagged in the Net Zero Strategy, could be a good template to transfer to agricultural equipment manufacturers (depending on its success with road vehicles).

Another role for government could be to help the sector over-achieve on emissions reductions with technologies and activities that have a low cost of abatement, so that those reductions can be monetised and transferred to other more challenging sectors.

A specific advantage in this sector is access to large areas of land that provides multiple options for renewable electricity generation, making up for sectors in which reductions are more difficult or more expensive.

This has the advantage of creating a potential additional revenue stream for farmers, by participating in a market many currently don’t access. Recent media reports suggest that many farmers are keen for agriculture to be brought into a national net zero plan to open up these market opportunities. CSIRO believes that by 2050 the carbon market could provide $40bn to the land sector (Luo, 2020).

The right support and integration could therefore make the agriculture sector a leader and enabler of emission reductions across the economy.

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