ROADS AUSTRALIA FELLOWSHIP 2022 – GROUP PROJECT ASSIGNMENT

PROJECT GROUP 4: SUSTAINABLE MELBOURNE

ZERO EMISSION HEAVY VEHICLES AND PLANT IN THE TRANSPORT CONSTRUCTION SECTOR

DECEMBER 2022

Executive Summary

Described as a global emergency, climate change is the shift in global or regional climate patterns because of human activities, primarily burning fossil fuels like coal, oil and gas[1]. The transport sector is a significant contributor to climate change via the generation of carbon emissions through transportation (petrol and diesel) as well as the construction, operation and decommissioning of transport infrastructure. Across Australia, it is estimated that infrastructure contributes around 70 per cent of national emissions, with about 15 per cent (or approximately 87 million tonnes of CO_2 per year) directly contributed through the delivery and operations of that infrastructure.

The momentum in Australia behind taking more action on climate change is increasing, and the public, stakeholders, shareholders, financiers and alike are demanding change.

In recent years, the transport industry has made significant gains in reducing embodied carbon emissions via recycling as well as reuse and reduction of materials. The gains continue, and the industry changes to reduce the carbon footprint are fast-paced and continually changing. As recently as October 2022, engineers from UNSW Sydney announced that they have successfully developed a dual-fuel system whereby existing diesel engines can operate using 90 per cent hydrogen as fuel, reducing CO_2 emissions by more than 85 per cent in the process[2].

The 2022 Roads Australia Fellows have been tasked with exploring how transport infrastructure sectors are evolving to meet climate change challenges. A broad but very relevant subject, this research project focuses on the transition towards zero-emission heavy vehicles and plant in the transport construction sector. It considers some of the challenges facing the transition and opportunities for overcoming them as well as international advances in this space.

Informally known as 'the greenest freeway', the Mordialloc Freeway project implemented innovative approaches to sustainability whilst achieving the quality requirements and has received the Infrastructure Sustainability Council award for Excellence in Environmental Outcomes (2022). However, much of the construction phase plant and equipment utilised conventional fossil fuels to complete the build, meaning there are untapped opportunities, current and in future, to further reduce carbon emissions through the build period of transport projects.

Using the Mordialloc Freeway project as a baseline, this research project, prepared by the Sustainable Melbourne team, presents the current and future opportunities, locally and abroad, for the construction industry and by extension, the mining, agriculture, and forestry industries to implement zero emission plant as well as the barriers and what changes are needed to effect positive change.

To effect positive change, our top 3 recommendations specific to zero emission heavy vehicles are as follow:

- Advocate for government reforms including the implementation of a national emission standard and targets, with consideration given to a zoned and / or phased approach, and a view to incrementally eliminate non-road diesel engines.
- Advocate for financial incentives with substantial reward to those who lead the industry transition away from reliance on fossil fuels.
- Support technological development in both electric and hydrogen fuel vehicles and engage with industry to strategies on ways to transition this technology into the industry.

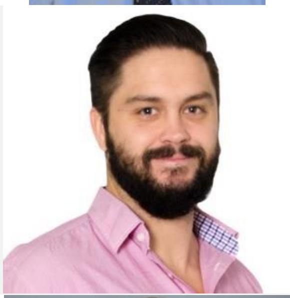
Cover page images, from top left. (Credit: EQ International; power-technology.com; Mordialloc Freeway Project, Victoria's Big Build ; JCB News; Adobe Stock Images)

The Sustainable Melbourne team

Nick Eddy – Senior Project Manager – BildGroup
Nick has 18 years of construction industry experience working with civil contractors in Australia and the United Kingdom. Nick has delivered a wide variety of projects including level crossing removal, freeway interchange, train station, road duplications, and marina works. His current role is leading the delivery of the Princes Highway Duplication – Flynn Section.

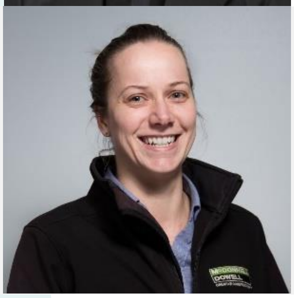
Liz Tinlin – BGL Structures, Bridges & Materials – GHD
Liz has over 18 years of experience in bridge design and design management through the successful delivery of bridge and transport infrastructure projects in WA, NSW and Victoria. Her current role is Manager of the Victorian Structures, Bridges and Materials team, and she is also GHD's APAC Service Line Leader for Bridges.

Glen Chrzanowski – Principal Civil Engineer / Team Leader – SMEC
Glen has 16 years of experience in transport engineering and has worked on major infrastructure road and rail projects including his current role as Road Design Lead for the North-East Link project. His role at SMEC is as the team leader – Engineering and Design for the roads and highways team.



Jason Miles – Senior Associate Engineer – SMEC
Jason is a Civil Structural engineer that has transitioned into Design Management. He has thrived in major transport infrastructure projects across Australia and New Zealand. The majority of his career has been on alliance projects where there has been a focus on high performing team culture. He has recently started on the North East Link project in the SMEC Design Management team.

Jane Ada – Technical Director – AECOM
As a leader, mentor and professional engineer, Jane has a successful track record of delivering detailed designs for transport projects across the eastern states. One to enjoy the outdoors and care for the environment, Jane is interested in leaving a positive legacy in engineering and the transport sector.



Rosemary Rice – Construction Manager – McConnell Dowell
Forging the way, with over 14 years of experience in the transport construction sector, Rosemary has successfully led teams and delivered projects safely, on budget and to program. Rosie is passionate about mental health and well-being in the transport sector, as well as sustainability and innovation in the project delivery space.

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Mordialloc Freeway Project June 2020 Piling for the 400-metre twin bridges (Credit: Victoria's Big Build)

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Glossary

AEMO	Australian Energy Market Operator
BEV	Battery electric vehicle
CCE	Civil Contractors Federation
CCS	Carbon capture and storing
CO	Carbon Monoxide
DOC	Diesel oxidisation catalyst
EG	Example
EPA	Environmental Protection Authority
ESG	Environmental Social and Governance
EU	Europe
FCEV	Fuel cell electric vehicle
FY	Financial year
gCO_2	grams of carbon dioxide
GHG	Greenhouse gas
H_2	Hydrogen
H_2O	Water
HC	Hydrocarbons
HICE	Hydrogen internal combustion engine
HV	Heavy vehicle
ICE	Internal combustion engines
IPA	Infrastructure Partnerships Australia
ISC	Infrastructure Sustainability Council
IS Rating	Infrastructure Sustainability Council Rating Scheme
KWh	kilowatt-hour
LGA	Local government authority
LV	Light vehicle
LXRP	Level Crossing Removal Program
MCDDJV	McConnell Dowell Decmil Joint Venture
MFP	Mordialloc Freeway project
MPa	Megapascals
MRPV	Major Roads Projects Victoria
NGER	National Greenhouse & Energy Reporting
NOx	Nitrogen oxide
NRDE	Non-road diesel engines
NRMM	Non-road mobile machinery
OEM	Original equipment manufacturer
PM	Particulate Matter
RAP	Reclaimed asphalt product
tCO_2e	Tonnes carbon dioxide emissions
UN	United Nations
UQ	The University of Queensland
VMS	Variable message sign
ZEV	Zero emission vehicles

1 Introduction

The Roads Australia 2022 Fellowship Research Project explores how transport infrastructure sectors are evolving to meet climate change challenges.

The Sustainable Melbourne team has chosen to study the transport construction sector. The topic selected by the Sustainable Melbourne team is "zero emission heavy vehicles and plant in the transport construction sector".

Acknowledging the gaining momentum for domestic vehicles owners to shift from petrol and diesel-powered vehicles to electric-powered vehicles (including hybrid models), the Sustainable Melbourne team has considered how this translates to heavy vehicles and plant in the construction sector, now and in the future.

Sustainability is key focus for governments around the world. A key framework is the United Nations (UN) 2030 Agenda for Sustainable Development that includes 17 Sustainable Development Goals. In addition, commitments are being made from private industry and government bodies alike to be carbon neutral by 2050. But what does this mean for the transport and construction sector, and how practical is it to achieve these goals?

We explore the emerging alternative renewable energy fuel sources and their potential to be the future normal for both light and heavy vehicles. We will review the success that other countries are having in this space, and whether Australia is likely to be on a similar trajectory.

Finally, we review what hurdles need to be overcome for Australia to start making real progress in reaching carbon neutral targets. Are incentives required to achieve Australia's sustainability goals or will this change happen organically on its own?

These are the questions that we seek to answer within this report.

1.1 The challenge

The construction industry contributes around 23% of global carbon emissions. Roughly 5.5%[3] of those emissions are directly related to activities on construction sites, mainly through the combustion of fossil fuels to power machinery and equipment. It is these emissions from fuels used in construction that form the focus of this research. Emissions from construction sites also include transport of construction machinery and materials, transport of construction workers, energy use at the construction site, internal transport, storage, temporary works, transport of waste, and waste treatment and disposal.

Significant progress has been made on material recycling, reuse and reduction practices, which is a key focus for all government funded projects. Once recent development is the Ecologiq initiative which was introduced by the Department of Transport Victoria in 2021 and had their first Greener Infrastructure Conference in September 2022[4]. This conference achieved new milestones in bringing recycled products to market and promoting carbon emission reductions through material supply. However, low emission fuels were a notable absence. This appears to be a blind spot when it comes to industry focus in Australia. Is the same observation true in other countries overseas? We will explore these problems and more in detail throughout this report.

Our aim is to investigate the current state of play for the low emission fuels in the construction sector and provide recommendations on how this can be improved if Australia is going to keep pace with the rest of the globe.

2 Typical emissions on local projects

To set the scene for the rest of our investigations we first need a baseline. This baseline is used as a point of comparison for some of the metrics we review with regard to greenhouse gas emissions (GHG). To ensure that we set the bar high, we have chosen the Mordialloc Freeway project, which won Excellence in Environmental Outcomes Award for the Mordialloc Freeway Project at the Infrastructure Sustainability Council Gala Awards 2021[5].

2.1 The Mordialloc Freeway project

The recently completed Mordialloc Freeway Project (MFP) has been selected as the case study for this research project as it represents the current best practice in regard to sustainability in transport infrastructure construction.

The McConnell Dowell Decmil Joint Venture (MCDDJV) delivered the MFP in the southeast of Melbourne for Major Roads Projects Victoria (MRPV).

Commencing October 2019 and achieving Practical Completion in November 2021, the nine-kilometre-long freeway connects the Mornington Peninsula Freeway at Springvale Road in Aspendale Gardens to the Dingley Bypass in Dingley Village, creating a continuous freeway from Frankston to Clayton. Refer Figure 1.

Figure 1 - Mordialloc Freeway plan view (Credit: MRPV)

Figure 2 – Mordialloc Freeway project

Key features of the Mordialloc Freeway project include: • 9 km long multi-lane freeway • 6 grade separated road bridges • 8 km of shared user paths • 3 million tonnes of earthworks imported • 74 km of utilities relocated

This innovative project has been awarded the following accolades:

- "Contractor Excellence" Award by Infrastructure Partnerships Australia (IPA) at the 2021-22 Annual Infrastructure Oration & National Infrastructure Awards. The awards acknowledge the significant contribution organisations makes to the sector and in driving infrastructure forward.

- "Excellence in Environmental Outcomes" Award at the Infrastructure Sustainability Council (ISC) Gala Awards 2021. The awards celebrate sustainability best practices across Australia and New Zealand.
- "CCF Earth Award" Category 7 winner (for projects over $150M) at the 2022 Civil Contractors Federation (CCF) Victoria Earth Awards. These awards recognise projects that demonstrates excellence and innovation in the fields of construction, project and environmental management.

These awards recognise how the project team has made significant sustainability contributions within the transport construction sector, as reinforced by the following recognition from the Infrastructure Sustainability Council "The project implemented a range of world-first sustainability initiatives in response to Victoria's waste crisis and shortage of quarry materials, creating 'Australia's greenest freeway'."[6]

This project has been successful in leading change within the industry with respect to sustainability and creating a positivity legacy.

2.2 Project emissions

To establish a baseline for the industry best practise we must understand the total project emissions from the MFP and the emissions generated from construction plant and equipment.

The Sustainable Melbourne project team has worked with our industry partner McConnell Dowell, who have provided the following core data:

- Project reporting of energy data, including electricity and fuel use, for compliance with the National Greenhouse and Energy Reporting Act 2007 (NGER Act)
- Project ISCA (Infrastructure Sustainability Council Assessment)
- 1202-01-HSE-REG-1000-0006 Project Plant Equipment Register
- Project fleet vehicle fuel card monthly reports

The total project greenhouse gas (GHG) emissions for the MFP have been summarised in Figure 3.

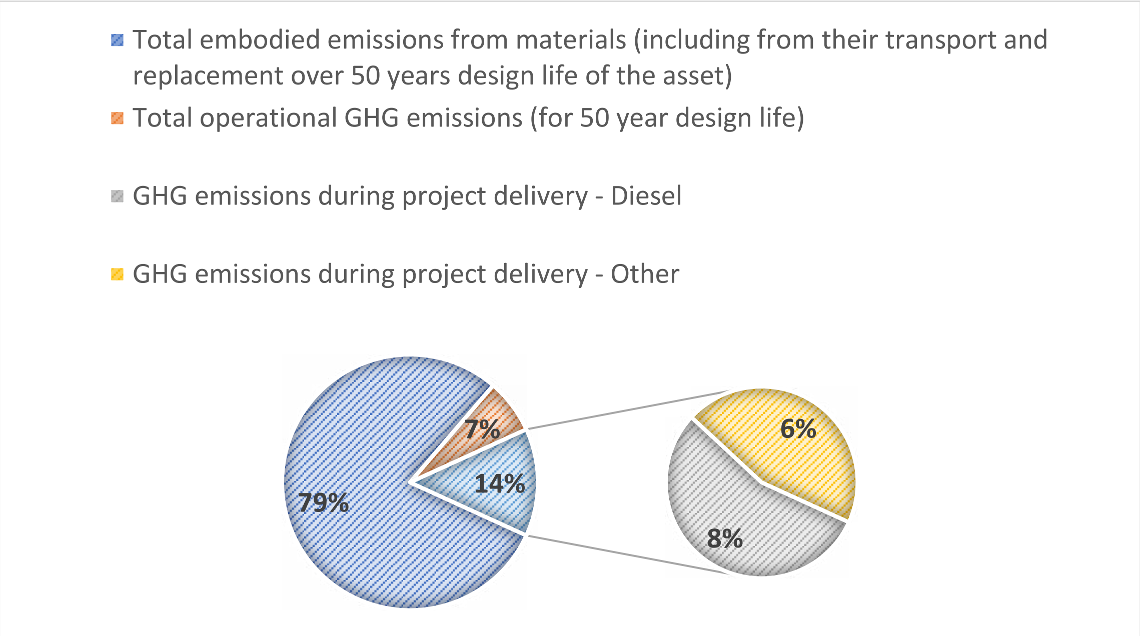


Figure 3 – Mordialloc Freeway project total emissions by type

As shown in Figure 3, 79% of the estimated total project emissions is attributed to embodied emissions from materials. The impact of sustainable outcomes in material use is well recognised in the industry, and there have been, and continue to be, measures put in place by government authorities to drive progress towards more sustainable material use, including policies such as the Recycled First Policy.[7]

The MFP put great focus on targeting these initiatives as the project was able to make some significant achievements around materials reuse and recycling, including:

- Approximately 700 tonnes of 75% recycled plastic rotationally moulded plastic noise walls;
- Using recycled materials in asphalt reduced project greenhouse gas emissions by approximately 2,843.6 tCO_2e;
- GreenPipe 100% recycled plastic drainage pipe replacing polyethylene or reinforced concrete pipes. This reduced project greenhouse gas emissions by approximately 100 tCO_2e;
- BDIM Green 100% recycled plastic geofabric (Approximately 55,800m^2 used) made from approximately 48,604 recycled plastic drink bottles;
- Emesh 100% recycled plastic fibre reinforcement (Approximately 13.4 tonnes used) replacing steel mesh. This reduced project greenhouse gas emissions by approximately 62 tCO_2e;
- High content supplementary cementitious materials (~45%) replacing Portland cement in concrete. This reduced project greenhouse gas emissions by 9,647 tCO_2e;
- Road base containing approximately 97% recycled materials including crushed concrete, crushed glass, and glass. This reduced project greenhouse gas emissions by 1,258 tCO_2e;
- Recycled crushed glass sand replacing virgin crushed rock for trench backfill; and
- Circular economy – reused abated soil on-site; and sent concrete, brick and asphalt to recycling facility to turn into road base.

Whilst material recycle and reuse yields high value in terms of embodied emission reduction, there are still reduced carbon emissions gains to be realised from construction plant and equipment via adoption of alternate zero emission fuel sources, further reducing the overall carbon footprint of transport projects.

2.3 Assessment of carbon emissions from construction machinery

As presented in Figure 3, 14% of the estimated total project emissions are attributed to the construction phase and 8%, of the estimated total project emissions are directly related to diesel fuel use. Further analysis has been undertaken to breakdown this information for the total onsite diesel, biodiesel and unleaded petrol fuel use by litre on the project and is presented in Table 1.

Table 1 - Total on site project fuel usage by fuel type

Fuel Type	Volume (litres)	GJ/kL[8]	Energy (MJ)	Emissions ($kgCO_2e/GJ$)	tCO_2e
Diesel	2,494,895	38.6	96,302,947	70.2	6760
Biodiesel (B20)	115,747	37.8	4,375,237	56.2	246
Unleaded Petrol	25,199	34.2	861,806	69.9	60

Figure 4 presents the fuel consumption (by fuel type) for half year from October 2019 to November 2021.

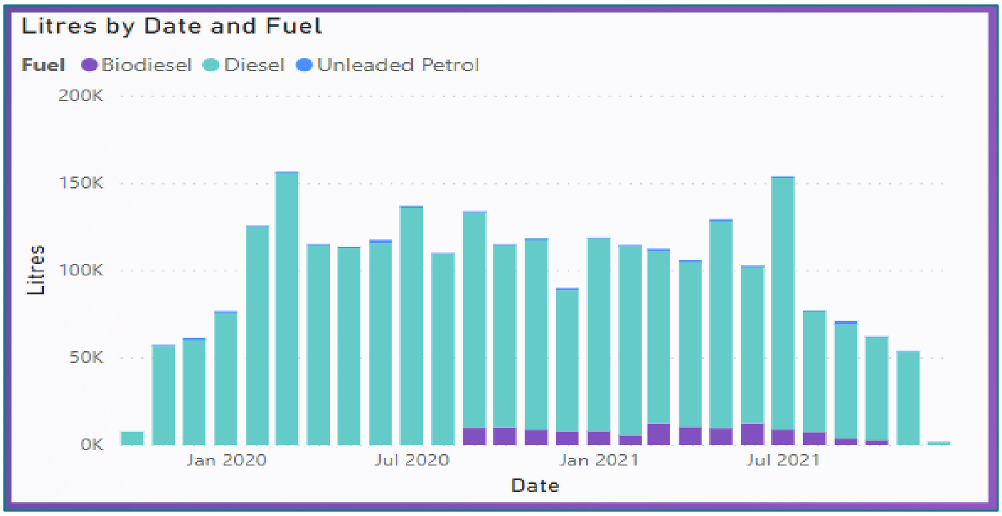


Figure 4 – Project fuel use by date and type

The fuel use data was further interrogated to identify what plant and equipment were the major contributors of this fuel use, and hence those which would lead to the most significant benefit for the transition to zero emission machinery.

The primary source of fuel use data was the National Greenhouse and Energy Reporting (NGER) monthly submissions provided by subcontractors each month. These reports only report a single figure by subcontract for the total fuel use for the month, and it does not give any further breakdown on fuel use per individual piece of equipment. Therefore, the Project Plant and Equipment Register was reviewed to establish what type of plant and equipment was generally used by each subcontractor, and through interpolation fuel use was categorised into the following construction works scopes:

Table 2 - Construction works categories

Construction Works Scope	Details
Civil and earthworks	Civil and earthworks, drainage, reinforced earth wall construction, equipment including excavators, rollers, graders, dozers. General materials handing including Franna cranes, telehandlers and forklifts.
Site trucks	Onsite truck and trailers, tandem trucks, watercarts
Generators and lights	Site generators, construction lighting
Staff light vehicles	Project staff light vehicles, commuting and onsite travel
Auxiliary services	Geotechnical testing, surveyors, traffic management, service proving
Concrete and structures	Bridgeworks, footpaths and shared user paths, noise wall installation, fencing, painting
Utility works	Utility relocations, electrical works
Roadworks	Asphalt works, pavement marking
Piling	Piling works, ground improvement, foundations
Environmental services	Arborists, asbestos consultants, environmental testing, street sweeping
Major cranes	Major crane hire

The breakdown of fuel usage by category is presented in Figure 5.

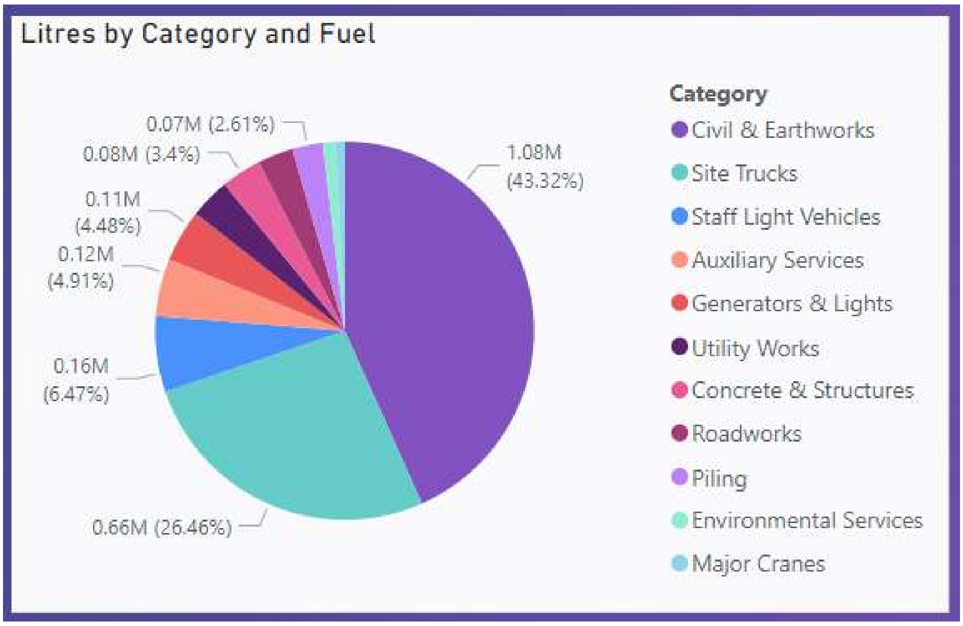


Figure 5 – Diesel fuel use on project by category

Based on this assessment, it was determined that the largest contributor to diesel fuel use on the Project are works categorised under civil and earthworks, and site trucks, accounting for 70% of the diesel use and equating to approximately 4,717 tCO_2e.

It is noted that the primary use of biodiesel on the project was in site generators and lights, with approximately 50% of the fuel use in this category biodiesel, and the other 50% standard diesel. This change was implemented approximately halfway through the project, as can be seen in Figure 4. This was positive change which diverted 115,747L of diesel and enabled a 68 tCO_2e saving in emissions.

While there was 68 tCO_2e savings in emissions achieved through the use of biodiesel, it should be noted that this accounts for less than 1% of the total carbon emissions from construction plant and equipment across the MFP. However, if all diesel use had been replaced with biodiesel, this number would be closer to a reduction of 1457 tCO_2e. The use of biodiesel only serves to reduce the carbon emissions of normal diesel by approximately 23% and is therefore not a solution for achieving a zero carbon emissions target in the construction industry.

2.4 Energy burn rates, refuelling times and efficiencies

The project plant and equipment register was analysed to establish the fuel usage and equivalent carbon emissions for the primary items of plant as shown in Table 3.

In regard to refuelling and impact on efficiency, the Project had Refuelling Solutions (i.e. mini tankers) visit the site each day to refuel all required plant, which would take on approximately 5 minutes each, and the visits were planned for break times where possible. Therefore, downtime due to refuelling did not affect equipment efficiency, and equipment never exhausted its fuel tank between refuelling. These refuelling times become relevant when assessing the viability of some of the other options explored later in this report.

Table 3 – Fuel use by plant type

Plant Type	Fuel Use (litres per hour) – medium use[9]	Fuel Use per day (8hrs) per unit	GJ/kL	Energy Use per day (MJ) per unit	$kgCO_2e/GJ$	$kgCO_2e$ per day
20t Excavator	17	136	38.6	5250	70.2	369
140M Grader	15	120	38.6	4632	70.2	325
D6T Dozer	25	200	38.6	7720	70.2	542
13T Padfoot Roller	11	88	38.6	3397	70.2	238
13T Smooth Drum Roller	11	88	38.6	3397	70.2	238
Dump Truck	20	160	38.6	6176	70.2	434

2.5 The baseline for construction

Table 1 and Table 3 above have established a baseline for future comparison in this report. The GHG emissions recorded on the MFP are likely to be lower than average for most construction projects, given the accolades it the project achieved. For the purpose of our report we are assuming this baseline to be indicative of the current industry norm for environmentally conscious construction.

It must be noted that the value of the MFP had a project value of $417 million, compared to the $69 billion to be spent by the Victorian Government on infrastructure between 2021 and 2024, which makes up approximately 18% of the total national spend on infrastructure[10]. The Sustainable Melbourne team believe that this project provides a good indication of the business-as-usual approach to GHG emissions on construction projects in Australia.

Figure 6 – MFP March 2020 importing 3 million tonnes (Credit: Victoria's Big Build)

3 Alternate fuel sources in Australia

In order to understand how the transport construction industry could reduce fuel emissions on projects like the MFP, it is necessary to understand the status of alternative fuel sources in Australia – which fuels are available, the constraints and challenges faced by the industry, and what is already being implemented. This section discusses the alternate energy sources to diesel that are currently being explored, including those that are already implemented and the new technologies that are on their way.

3.1 Biofuels

Currently, biodiesel is the go-to option when it comes to reducing GHG emissions for construction projects in Australia. Table 4 outlines the various biofuels on the market today.

Table 4 – Type of Biofuel available in Australia

Biofuel	Description
Renewable diesel	Renewable diesel is a synthetic form of diesel produced by hydro processing of fats, vegetable oils, and waste cooking oils. Unlike biodiesel, which is disliked by plant hire companies, renewable diesel is a direct substitute for diesel. Renewable diesel is a more expensive direct alternative and not currently commercially available in Australia.
Biomethane	Biomethane is a form of renewable natural gas and considered an alternative fuel for vehicles fuelled by natural gas. Natural gas is not a widely utilised fuel source when compared to diesel in the transport construction industry, meaning there is limited plant and equipment powered with biomethane, and a small number of biomethane plants in Australia.
Biodiesel	Biodiesel is a form of diesel derived and is a vegetable oil-based fuel that can be used without modifications to plant and equipment.
E10 Petrol	E10 is a petrol mixture that contains 10 percent ethanol. Ethanol is organic alcohol sourced from grains such as corn and sugar or food waste.

It must also be noted that biodiesel and other biofuels have several limitations and draw-backs as follows:

- Biodiesel has limited availability and is generally available only within 1 hr of capital cities.
- It is less pure than standard diesel, and the impurities lead to higher maintenance costs and shorter operational life of equipment. This results in many plant owners and operators being reluctant to use it in their equipment.
- Biodiesel is produced from organics and the crops required to significantly increase the market share of biodiesel are a limiting factor.

The following sections present a review of alternative fuel sources, technological developments and local and international policies that could be utilised in the future on similar construction projects to further reduce emissions. Further, Section 7 provides an assessment of the data presented in Section 2.3 and 2.4 to estimate emission reductions in the plant and machinery.

3.2 Electricity as a fuel source

Electric powered vehicles have been in development and use since the mid-19th Century. In the late 20th Century, there was renewed interest in electric vehicles and hybrid vehicles.

All-electric vehicles, also referred to as BEVs, have an electric motor instead of an internal combustion engine. In a BEV, the Onboard Charger takes the incoming AC electricity supplied via the charge port and converts it to DC power for charging the traction battery. The Traction Battery Pack stores electricity for use by the electric traction motor. The Electric Traction Motor uses stored power to drive the vehicle. Some vehicles use motor generators that perform both the drive and regeneration functions.[11] Figure 7 provides an illustration of the main components of an EV.

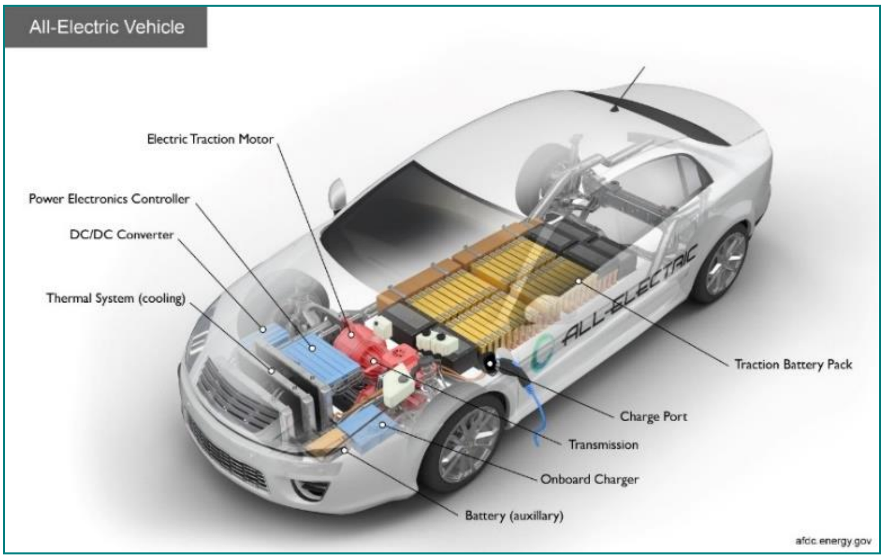


Figure 7 – Key components of an all-electric car

Because it runs on electricity, the BEV emits no exhaust from a tailpipe and does not contain the typical liquid fuel components, such as a fuel pump, fuel line, or fuel tank. The GHG emissions coming from a BEV are zero, however, its overall carbon footprint is dependent on green energy coming from the grid.

The same principal for the BEV also applies to the heavy construction plant, and there are already numerous options that have been developed worldwide that use this technology, as are outlined in Section 6. There are three primary obstacles when it comes to incorporating electric technology into the construction sector:

1. **Storage capacity** – While the power outputs of electric motors easily rival that of diesel, it is the sustained energy use where batteries fall short. Even the best technology today still requires plant in constant use to recharge twice per day, and is limited by the impracticality of carrying over-sized batteries.
2. **Charging times** – Re-fuelling with diesel will typically take 5 minutes (as detailed in our review of the MFP project). While recharging batteries can take 45 minutes for high powered charging stations.
3. **Charging station access** – The problem for many construction sites will be the accessibility to charging stations. Wheeled plant can easily return to centralised charging stations at the end of each shift. However, for tracked plant; bulldozers, excavators, and even rollers, this is not practical, and the charging station must be able to come to them. It then becomes necessary to develop specialised support vehicles that can either provide mobile charging facility or battery packs that can be swapped out of heavy plant to keep it moving.

3.3 Hydrogen as a fuel source

In order to understand the potential of hydrogen powered vehicles, it is necessary to outline hydrogen as a fuel source. Hydrogen is the most abundant element in the universe. However, the hydrogen molecule that is used for fuel hydrogen (H_2) does not commonly occur naturally due to its extreme reactivity. The only way to store hydrogen is as a liquid, which requires either extremely cold temperatures (-253 ˚C) or extreme pressure (1.24 MPa) to keep it in its liquid form. When in liquid form, hydrogen acts as a chemical energy carrier, similar to oil, that can be piped or transported to where it is needed. It stores three times as much energy per kilogram as conventional petrol, and when it "burns" in air it simply combines with oxygen to produce water again.

Hydrogen is naturally found in abundance in countless other materials around world, not least of which is water (H_2O), and is therefore available in an almost inexhaustible supply. Around the globe, hydrogen has been produced for a long time for use in ammonia fertiliser and production of hydrocarbons. The world currently produces approximately 70 million tonnes per year, however 96 percent of this is made from fossil fuels (mostly natural gas) and is far from carbon neutral.

The different types of hydrogen production are labelled by colour and presented in Table 5.

Table 5 – Types of hydrogen potentially available[11]

Common Hydrogen types currently available	
Grey hydrogen	Produced from reforming fossil fuels like oil and gas, accounting for 96 per cent of current global hydrogen production, but the process produces significant greenhouse emissions.
Blue hydrogen	Split from methane (natural gas) most commonly using steam methane reforming, and 85% of the carbon dioxide produced is captured and sequestered. This requires access to cost effective carbon sequestration, which remains challenging.
Green hydrogen	Hydrogen made from the electrolysis of water, powered by clean energy sources. It is technically possible to make green hydrogen today, but the cost remains commercially prohibitive.
Less common Hydrogen types	
Black / Brown	Produced from coal. It is a very polluting process, and CO_2 and CO are produced as by-products and released into the atmosphere.
Pink	Generated through electrolysis of water by using electricity from a nuclear power plant. (The same as green but produced from nuclear power).
Red	Red hydrogen is produced through the high-temperature catalytic splitting of water using nuclear thermal power.
Purple	Purple hydrogen is made using nuclear power and heat through combined chemo thermal electrolysis splitting of water.
White	White hydrogen is an extremely rare naturally-occurring geological hydrogen found in underground deposits and created through fracking. There are no strategies to exploit this hydrogen at present.

The costs associated with hydrogen production are potentially its most limiting factor. The development of green powered electrolysis is very much in its infancy, with scientists trialling new methods and prototypes to try and bring the cost of production down.

Pink, red and purple hydrogen would be an obvious choice if it were not for the severely unpopular nature of nuclear power, especially in Australia. The same issue is not such a problem for countries such as France, which already have a 69% reliance on nuclear power.

Figure 8 illustrates the cost of hydrogen production for the most common types. Blue hydrogen may yet prove to be the most likely successor with only 15% of the generated carbon being released.

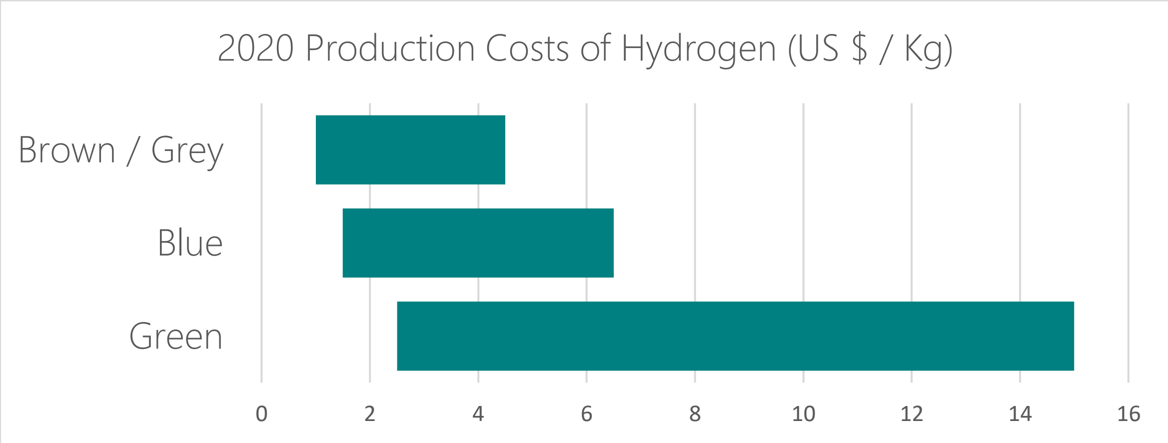


Figure 8 – Cost of hydrogen production [12]

It is important to note that getting hydrogen to market does not only require bringing the production costs down. There are multiple steps in the process and each of them have significant issues to be overcome including, compression, storage, and transportation.

Because hydrogen is so light and so volatile the cost of compressing and storing it safely are not straight forward. Some of the potential techniques for storage include low pressure tanks, cryogenics or underground salt caverns.

Transporting hydrogen is challenging because it requires enormous amounts of energy for liquefaction (almost absolute zero), it is small and light, it is hard to compress (in pipelines), leaks easily and disperses quickly. In addition to this, hydrogen turns most metals brittle. When hydrogen burns it does so at 2000 ˚C in air compared to 1000 ˚C for petrol and wood fires. This creates additional safety concerns that require increased controls for all users.

These safety concerns are coupled with hydrogen having a reputation for being dangerous. The Hindenburg disaster in 1937 involved the catastrophic combustion of a hydrogen airship, killing 35 of the 97 persons on board in a fiery inferno. This resulted in the end of the airship era and hydrogen has carried a negative reputation ever since. This reputation may impact on consumer willingness to adopt hydrogen as a fuel source.[13]

Figure 9 – Hindenburg disaster

Research into the various component parts of the hydrogen supply chain is important and should continue. Its potential is considerable; however, it is prudent to take a considered perspective of the technology as it is still a long way away from delivering on its potential.

3.4 Hydrogen to power electric motors or combustion engines

There are two options when it comes to incorporating hydrogen into the engines of a vehicle.

1. The first way involves a device known as a fuel cell electric vehicle (FCEV). The fuel cell converts hydrogen to electricity, which then powers the vehicle's electric motors, just like in a normal BEV. Figure 10 shows the key components of hydrogen fuel cell vehicles while Figure 11 shows the process that occurs in fuel cell vehicles that allows hydrogen to be converted to electricity.
2. The second way is hydrogen internal combustion engines (HICE). This is similar to a standard petrol or diesel combustion engine, except that hydrogen is the fuel source.

Either method has its advantages and applications where they are best suited. Internal combustion engines are the more efficient choice for plant that need to operate with high peaking load requirements like most heavy construction plant and large freight. On the other hand, FCEVs are most efficient with lower sustained load requirements, like domestic vehicles, smaller freight and construction rollers.

Fuel cell electric vehicles have the added advantage that they can also capture energy through regenerative braking, improving their overall efficiency.

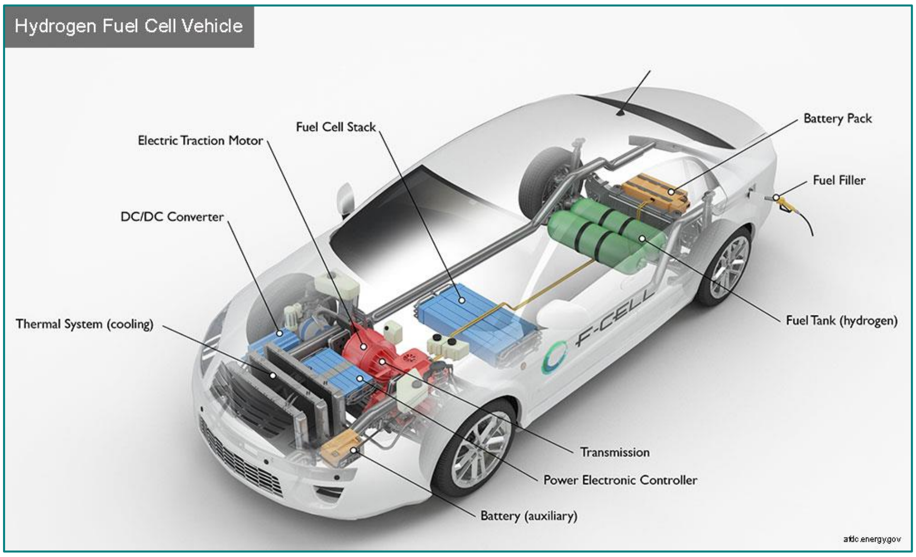


Figure 10 – Hydrogen fuel cell vehicle [11]

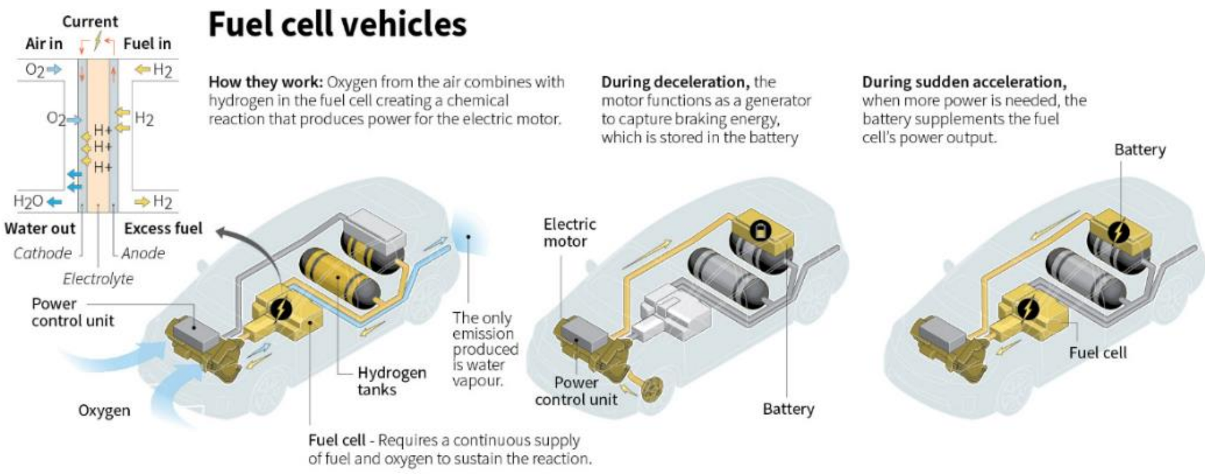


Figure 11 – Fuel cell converts hydrogen to electricity [14]

3.4.1 Hydrogen engines and fuel cells: similarities in emissions

Hydrogen engines and hydrogen fuel cells have similar emissions profiles. FCEVs, actually produce no emissions at all besides water vapor. This is a very attractive feature for vehicles operating in closed spaces or spaces with limited ventilation. Hydrogen engines release near zero, trace amounts of CO_2 (from ambient air and lubrication oil), but can produce nitrogen oxides, or Nox. As a result, they are not ideal for indoor use and require exhaust after-treatments to reduce Nox emissions.

3.4.2 Hydrogen engines and fuel cells: hydrogen fuel considerations

Hydrogen engines often are able to operate with lower grade hydrogen. This becomes handy for specific use cases. For example, on sites where hydrogen can be produced on site using steam methane reforming and carbon capture and storing (CCS). This hydrogen then can be used in hydrogen engines without the need for purification. The hydrogen engine's robustness to impurities is also handy for a transportation industry where the transition to high quality green hydrogen will take time.

3.4.3 Can hydrogen engines work in medium and heavy-duty trucks and buses?

Hydrogen internal combustion engines are appealing to vehicle makers for two primary reasons. First is their similarity with traditional internal combustion engines. Second is hydrogen's ability to power vehicles as a zero-carbon fuel. An original equipment manufacturer (OEM) can build vehicles with hydrogen engines that are very similar to existing internal combustion engines. Most of the vehicle's other components and software remain the same.

Hydrogen engines are also attractive to end users. Hydrogen engines look, sound and work like the internal combustion engines that mechanics across the world are used to. Their reliability and durability are equal to that of diesel engines. Commercial fleet operators can purchase vehicles featuring hydrogen engines without the anxiety that might come from investing in a brand-new technology.

Examples of hydrogen engines in the mobility and transportation sectors also go beyond medium and heavy-duty trucking. Hydrogen engines are also found in marine, construction, and beyond. Storing hydrogen onboard motor vehicles is safe and becoming more economical and practical.

3.4.4 Hydrogen engines and fuel cells: varying maturity levels

Internal combustion engines have been universally used for decades and are supported by extensive service networks. Rugged engines that can operate in dusty environments or that can be subjected to heavy vibrations are available in all sizes and configurations. From the perspective of vehicle manufacturers and fleet operators, the switch to hydrogen engine drivetrains involves familiar parts and technology. Risk-averse end-users will find comfort in the tried-and-tested, reliable nature of internal combustion engines.

So, it is not really the case that FCEVs and HICEs are competing with one another. The development of one supports that of the other, since both drive the development of a common hydrogen production, transportation, and distribution infrastructure. Both also involve the same vehicle storage tanks. They are complementary technologies that are part of reducing vehicle and transportation emissions towards the goal of net zero.[15]

Figure 12 illustrates the process for hydrogen fuel generation, storage and vehicle refuelling.

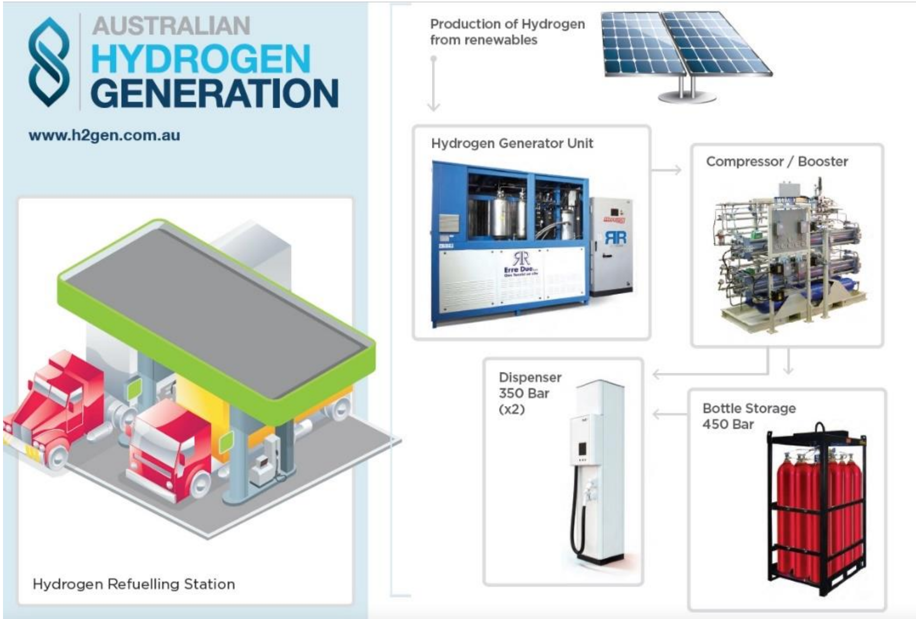


Figure 12 – Zero emission hydrogen generation and refuelling [16]

3.4.5 Advantages and disadvantages of EVs, FCEVs and HICEs fuel type

Electricity: is currently available already in the market today and there is a network of charging stations. The main disadvantage when it comes to using electricity for Heavy Vehicles is transportation of the power to the heavy plant, or vice versa, in transporting the heavy plant to the charging location.

Hydrogen: is less mature as an energy source for heavy plant. At a basic level the technology already exists in combustion engines that can readily be adapted to suit hydrogen as a fuel, the challenge is in the supply of hydrogen as a fuel. Specifically, this relates to green hydrogen, as both blue and grey hydrogen are not carbon neutral and therefore do not deliver the carbon neutral benefits, expected.

Table 6 outlines a summary of the key advantages and disadvantages of EV, FCEV and HICE.

Table 6 – Advantages and disadvantages of different fuel sources

	Advantages	Disadvantages
EV	• Major construction OEMs are starting to electrify a diverse range of construction equipment • By 2030, 40% construction machinery (by energy use) is estimated to be electric; by 2040 this figure will rise to 60% • Electricity supply is national • Increased energy efficiency compared with diesel alternatives • Operational and maintenance savings are greater than the upfront additional purchase costs • Zero Scope 1 and 2 emissions when electricity is from renewable sources • Reduced local air and noise pollution.	• Grid electricity not always available on sites • Increased electricity use from electric equipment and associated charging requirements • Grid capacity constraints and peak loads mean energy storage may be needed to buffer the grid • Space for future energy storage equipment needed • Safety concerns for use of wired electric options in some mobile plant and machinery models • Unable to electrify all equipment and machinery, some expected to be electric after 2050, if at all.
FCEV	• Green hydrogen provides zero carbon option (made from renewable energy) • Reduced local air and noise pollution.	• Lack of model availability for hydrogen powered construction machinery and equipment

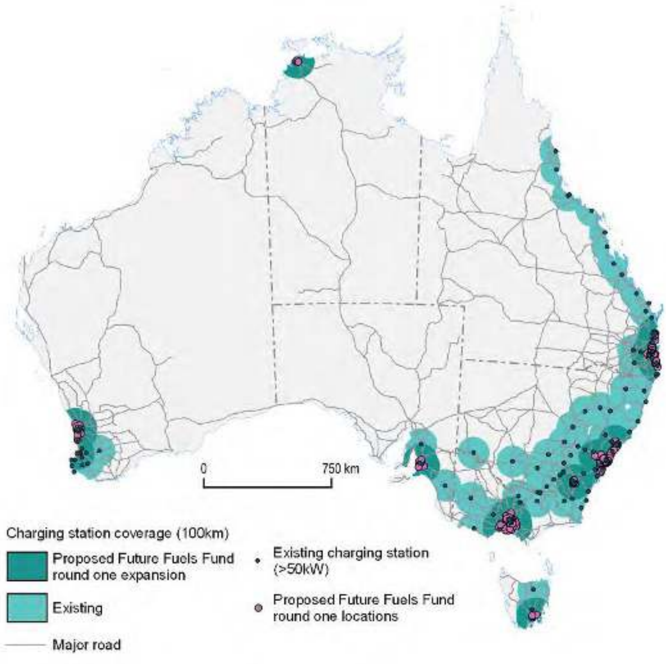
		• Grey and brown hydrogen (made from fossil fuels such as coal and methane) does not provide carbon emission reductions • Green hydrogen has very limited current and medium-term availability • Custom designed infrastructure needed to store hydrogen safely • Space for onsite storage of hydrogen fuel needed
HICE	Requires very little adjustment to a standard combustion engine.	• Green hydrogen has very limited current and medium-term availability • Custom designed infrastructure needed to store hydrogen safely • Space for onsite storage of hydrogen fuel needed

Figure 13 – Hyzon Motors, Hydrogen Powered Road Train. Credit: Forbes

3.4.6 Current availability of recharging and refuelling stations

3.4.6.1 Recharging stations

Australia is slowly developing a network of EV charging stations. As shown Figure 14, as of April 2022, there are 1580 regular AC charging locations, 291 public fast charging locations and a number of planned stations, primarily located along the eastern seaboard. To provide some international perspective, China has 1.419 million public EV charging stations across the entire country, with a another 87,000 built in May 2022 alone. [17]



There are several EV charging infrastructure and hardware providers operating within Australia, including Chargefox (currently our biggest network), Jet Charge, Tritium, EVSE, Schneider Electric, Keba, EVERTY, NHP Electrical Engineering and eGo Dock.

Table 7 provides a brief summary of the EV charging stations within each Australian state.

Table 7 – BEV charging stations by state[18]

State	Charging Stations
NSW	93 DC chargers and 463 AC chargers for a combined total of 556 charging points (the majority of these are around Sydney). As of the end of 2021, there are 10,026 battery-electric vehicles on the road in NSW, 0.05 charging stations per EV.
VIC	67 DC chargers and 363 AC chargers for a combined total of 430 charging points. The Victorian Government has announced a new program where all Victorian businesses can apply for a share of $1.5 million in grants to install EV-charging stations.
QLD	63 DC chargers and 262 AC chargers for a combined total of 325 charging points. Queensland also has what they call an "electric super highway" consisting of 31 fast-charging sites, allowing Queenslanders and tourists to confidently travel from Coolangatta to Port Douglas, and from Brisbane to Toowoomba in EVs.
WA	31 DC chargers and 202 AC chargers for a combined total of 233 charging points. In 2022, the Western Australian government has pledged to invest $22.6 million in new charging infrastructure across the state.
SA	14 DC chargers and 180 AC chargers for a combined total of 194 charging points.
NT	2 DC chargers and 14 AC chargers for a combined total of 16 charging points. No, that's not a lot.
ACT	5 DC chargers and 29 AC chargers for a combined total of 34 charging points.
TAS	18 DC chargers and 67 AC chargers for a combined total of 85 charging points

In terms of hydrogen refuelling stations, this is still in its infancy, with 3 stations currently operating across Victoria, NSW and Queensland. Figure 16 shows the locations of these stations, while Figure 15 provides a view of the ActewAGL station in Fyshwick in the ACT.

Figure 15 – Australia's first public hydrogen refuelling station[19]

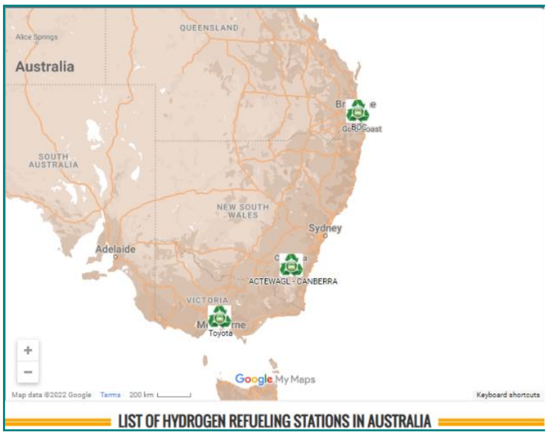


Figure 16 – Hydrogen refuelling stations in Australia

3.5 Sales of EV's in Australia

In order to understand how the transition of heavy vehicles and construction plant to electric or alternative fuel sources might transpire, it is useful to understand the status of the uptake of passenger EVs within Australia.

Figure 17 shows the sales of passenger EVs in Australia versus international sales, both since 2011 and in 2021. As can be seen, whilst the uptake in Australia has been slow, with only 40,000 vehicles sold in the last decade, it is picking up pace, with approximately half of those sales in the last year. Compared to the rest of the world, Australia's uptake is significantly lower than most other countries, with average sales at 9% of all vehicles against 2% in Australia[20]. In comparison, in Norway, which leads the world in terms of uptake of EVs, 74% of all vehicle sales in 2021 were EVs[21].

EV SALES SINCE 2011	40,000	16,000,000
EV SALES IN 2021	20,665	6,600,000
% OF SALES	2%	9%

Figure 17 – Passenger EV sales in Australia [20]

The recent increase in sales is a positive sign for the industry. Passenger, or light, vehicles represent 10% of Australia's total carbon emissions[22] and hence present a great opportunity to reduce emissions. In addition, there are a number of other benefits for consumers from EVs:

- EV drivetrains have improved efficiency when compared to Internal Combustion Engine (ICE) drivetrains. Hence, even if the electricity used to power them is from non-renewable sources, EVs have lower total emissions than ICE vehicles.
- When charged using sustainable electricity sources, EVs are effectively zero carbon emissions during operation.
- EVs have reduced maintenance requirements compared with ICE vehicles.
- Operating costs are lower as electricity charges are significantly lower than petrol or diesel for an equivalent driving range[23].

Despite these advantages, there are a number of barriers which are resulting in the slow uptake in Australia, which are shown in Figure 18.

These barriers are quite similar to the barriers that were faced during the transition from leaded to unleaded fuel, as outlined in section 3.8. In order to accelerate the uptake, the following initiative have been suggested to be implemented:

- Cost – the government could provide incentives via purchase incentives and modifications to existing government charges and vehicle tax subsidies. Further, JP Morgan have suggested that EV's will achieve price parity with ICE vehicles within the next decade[22].
- Range anxiety and charging availability – EV range is already acceptable for urban use and this issue will diminish with technical advancements and deployment of a wider network of recharging points[22]. Similar to the transition to unleaded fuel, significant capital investment will be required to provide sufficient EV charging infrastructure and upgrades to the energy network to enable the delivery of charging hubs and zero-emission bus depots[23]. This could come from both government and private investment.
- Dumping of inefficient vehicles – the combination of Australia not having light vehicle emission standards and other countries moving to ban petrol and diesel vehicles, there is the

risk in the medium term of Australia becoming a dumping group for high-emitting, cheap ICE which could undermine the uptake of EVs. However, this could be easily prevented by the Federal legislating on vehicle emission standards and mirroring the EV implementation plan with that of the EU or the US[23], in a similar manner to the transition from leaded to unleaded fuel.

- Petrol and diesel legacy vehicles – similar to the leaded fuel transition, the EV transition will be hindered by the legacy of ICE vehicles which could continue beyond 2050 without intervention. Hence, the Federal Government should legislate mechanisms that will encourage a quicker retirement of these vehicles, such as scrappage schemes or more stringent fuel quality and emission requirements[22].

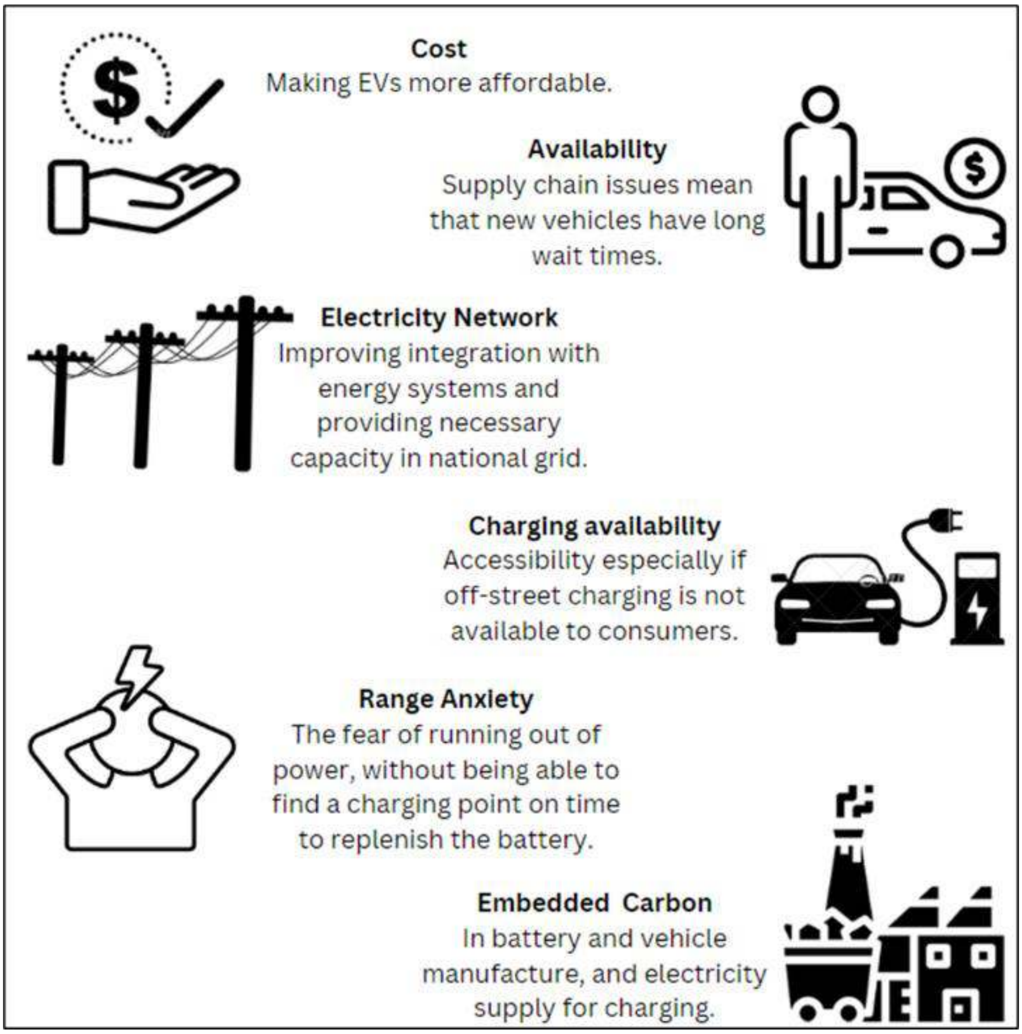


Figure 18 – Current barriers and potential solutions to EV uptake[22,23]

3.6 Comparison of light vehicle market to heavy vehicle market

The previous sections have focused on alternative fuels primarily for light vehicles. However, this research project is more focused on alternative fuels for heavy vehicles. Heavy vehicles make up just over 20% of the total 20 million vehicles registered in Australia[24]. Of those heavy vehicles, 84% were diesel engines, with the remainder being petrol. EVs made up less than 0.01% of heavy vehicle registrations in 2021. Hence, significant work is required to enable the transition of the heavy vehicle fleet toward net zero.

In addition to the heavy vehicle fleet, there is also the non-road fleet. These vehicles include:

- diesel-powered construction and mining equipment
- rail locomotives
- ports equipment
- ships
- agriculture equipment.

To provide some perspective, in the NSW Greater Metropolitan Region:

- there are around 100,000 or 15% of Australia's non-road diesel engines
- around 9,000 new engines are purchased every year
- non-road diesel engines account for about 5–10% of fine particle pollution[25]

EVs and sustainable fuel options are still developing the technology required to power heavy vehicles and non-road vehicles, which is outlined further in Section 3.5.

3.7 Comparison with the mining industry's journey to net zero

Another industry that is going through their own journey to net zero is the mining industry. There are a number of similarities between the mining industry and the transport construction industry, in terms of both industries relying on heavy vehicles/non-road vehicles to conduct their operations.

In terms of mining, it accounts for between 4% and 7% of global greenhouse gas emissions[26]. In order to accelerate efforts to decarbonise mining operations, the European Union plan to implement a carbon tax on mining imports from countries that are not doing enough to reduce their environmental impact. Due to this, Australian miners may not be competitive in Europe unless they take significant action to reduce their emissions[26]. Other imperatives driving the decarbonisation of mining are related to the incentives to decarbonise the supply chain. For example, car manufacturers driving metal mining companies to change their practices, as they seek to reduce carbon emissions throughout the automotive supply chain[27] while also re-carbonise operations associated with producing materials for batteries and EVs themselves[28]. This is being done via integrating sustainability requirements into purchasing activities and awarding processes.

Diesel-powered haul truck fleets are responsible for up to 80% of a mine's emissions, hence they are a priority for decarbonising efforts[29]. However, transitioning fleets away from diesel power and creating a zero emissions site creates several challenges:

- Vehicle requirements – mine trucks are much larger than traditional construction plant and electrifying them requires charging systems capable of delivering energy at unprecedented power levels during operations[29];
- Electricity supply – the power load of the electrical networks on mine sites be impacted and will require balancing and potentially upgrading. Additionally, mines will have to ensure they have reliable and affordable sources of electricity, and a source that is "green";

- Battery technology is still limited for mining trucks – this type of plant typically requires constant operation with minimal down time, and options for charging or battery replacement are still being developed; and
- Equipment manufacturers and battery providers are still in development, and it will take time to find willing partners for miners to assist in making this type of innovation scalable and affordable[29].

For Australia, its estimated that over $165 billion will need to be spent on new clean energy projects over the next 8 years in order to meet the goal of net-zero emissions by 2050. To reach this figure, Australia would need to triple its current annual spend of $7.7 billion for renewable energy projects[30]. Some examples of current investment and developments are as follows:

- Fortescue Metals Group have designed and built a world first hydrogen-powered haul truck, with site tests scheduled to begin by June 2023. Fortescue Future Industries plans to invest up to $600 million in FY22 with the investment largely on green fleet development and decarbonization technologies[26]
- BHP Group has partnered with equipment producer Caterpillar to develop zero-emissions mining trucks, with the goal of commercializing them this decade. They will focus on battery-powered vehicles, but they are also expected to explore hydrogen technologies. BHP plans to invest $100 million to $200 million a year for five years on climate-related research, such as reducing the use of diesel in mining trucks[26].
- Rio Tinto last year said it would invest $1 billion over five years toward achieving net-zero emissions[26]

In addition to these individual investments, as a clear point of difference between the transport and mining industry, mining companies are also joining forces to invest in and develop solutions to achieve their net zero goals. A couple of these collaborations are:

- BHP, Rio Tinto and Chile's state-owned Codelco have Komatsu as founding members of the Japanese manufacturer's decarbonization alliance [26]
- Charge On Innovation Challenge, which is a global challenge, launched in 2021 by BHP, Rio Tinto and Vale, with the aim to accelerate the commercialisation of effective solutions for charging large electric haul trucks. There are 8 finalists who are investigating a range of options ranging from dual charging systems (designed for stationary and in-motion charging), haul truck battery swap solution (utilizing an autonomous transfer robot that can swap batteries in 90 seconds), catenary and advanced battery technology which combines the proven rail industry technology with cutting edge battery chemistry and rapid charging solutions (to allow charging in just a few minutes)[29].

From this assessment of the mining industry and their approach to transitioning to net zero, it can be seen that the construction industry could benefit from a coordinated approach to investment in new technology and processes rather than individual companies each trying to solve it themselves.

3.8 Lessons from the transition to unleaded fuel in Australia

To gain a historical perspective, the transition from leaded to unleaded fuel should be considered to understand the impacts and considerations when making nationwide change to our standard fuel types.

In the final quarter of last century, the world was going through a significant change to fuels – the transition from leaded fuels to unleaded fuels. An assessment of this transition, and the challenges faced, is useful in terms of providing perspective to the current transition from fossil fuels to sustainable fuel sources.

As shown in Figure 19, by the mid to late 1970's there were several imperatives driving a shift from leaded fuel to unleaded:

1. Environmental issues – by the late 1970's there were concerns about increasing ozone levels in Sydney and Melbourne[31] causing serious environmental concerns, with leaded fuel use being the primary culprit.
2. Health issues – around the same time, there was significant international evidence being published about the harm to the cognitive function and behaviour of children from lead exposure, again attributed to leaded fuels[32].
3. New technology – by 1975 research and development had led to cars being produced with catalytic converters that ran on unleaded fuels. These were initially available in the US, but the technology spread throughout the car manufacturing industry[33].

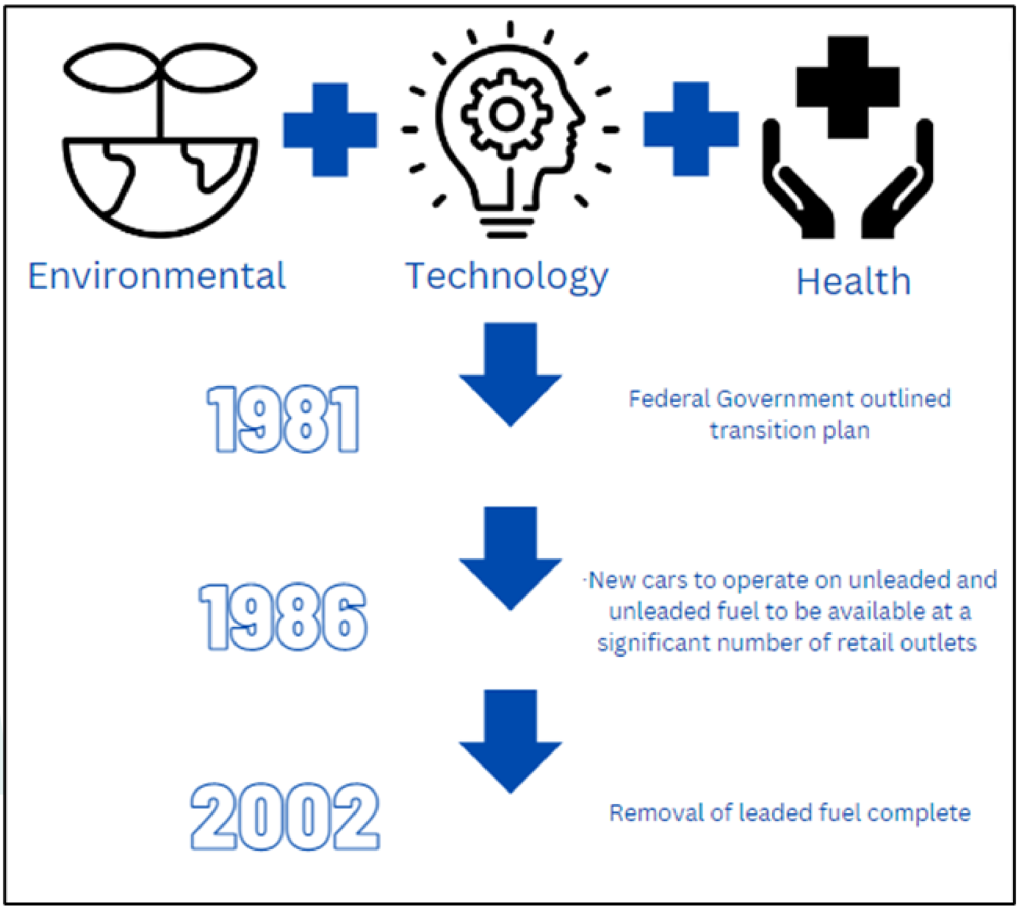


Figure 19 – Transition to unleaded fuel

These factors lead the Australian Government to start preparing for the introduction of unleaded fuel in 1979 and in 1981 they mandated that:

- New cars manufactured after 1 Jan 1986 were to operate on unleaded fuel and meet the equivalent of USA 1975 emission standards.
- Unleaded fuel was to be available at a significant number of retail outlets from 1 July 1985.
- Subsequently, it was determined that other vehicles were to be designed to operate as unleaded from 1988[31].

To facilitate the transition from leaded to unleaded fuels, McFarlane and Cass[31] noted that there were a number of areas that required investment and support. These are shown in Figure 20.

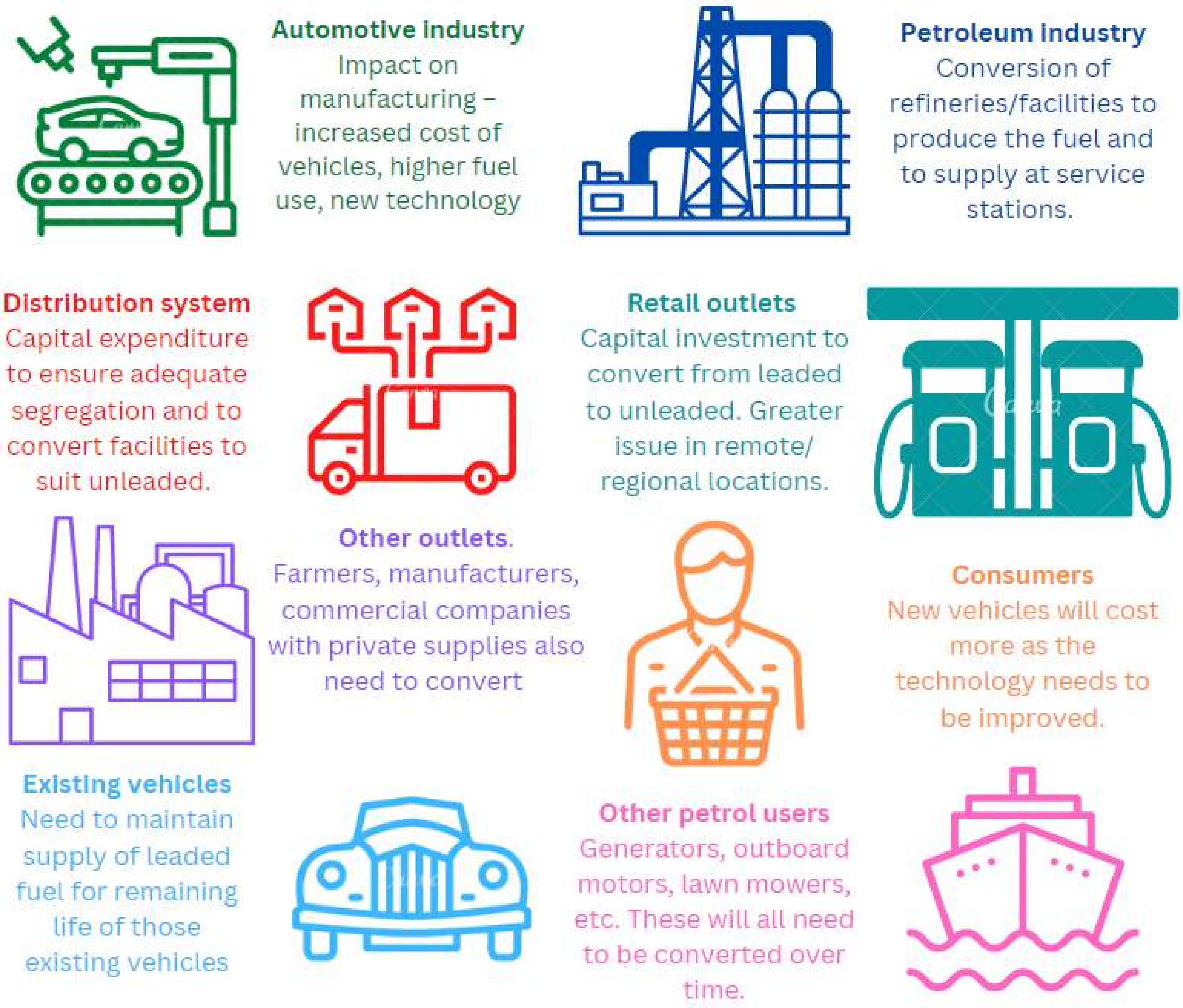


Figure 20 – Impact of transition to unleaded fuel on associated industries and consumers

Significant capital investment and government assistance was required to enable the transition, and it still took around 25 years for the phase out of leaded fuels to be complete by 2002[33]. Given the significant health and environmental imperatives for the transition from leaded to unleaded fuels, with the US Environmental Protection Authority (EPA) noting that "The elimination of lead from gas is one of the great environmental achievements of all time"[33] , it's vital that lessons are learned from this transition to help expedite the transition from fossil fuels to sustainable fuels. Electric Vehicles (EVs) in Australia.

Section 4 continues the review of the Australian market, in terms of what initiatives are being implemented to help achieve net zero across the transport industry, from government level to project level and company level.

4 Transport construction in Australia – status of sustainability initiatives

As outlined in Section 3, there are a number of low emission fuel options that could be used to reduce construction emissions on projects like the MFP. However, the implementation requires a range of changes within both the industry and overall supply chain. This section reviews the approach being used to move towards net zero by all parties involved in the transport industry, from the government level down to individual companies and projects.

4.1 Carbon emission targets

In terms of carbon emissions on a state-by-state basis, Figure 21 shows that Queensland and NSW are the two largest emitters, followed by WA and Victoria, with the remaining states and territories having a much smaller contribution and Tasmania already achieving net zero.

Transport infrastructure is estimated to contribute to around 70 per cent of national emissions; with around 15 per cent (or approximately 87 million tonnes of CO_2 per year) directly contributed through the delivery and operations of that infrastructure[34]. Out of that 15%, as shown in Figure 21, approximately 24% of those emissions are from construction processes and a further 8% from material transport. Hence, reducing emissions in those areas will have a significant impact on carbon emissions in general.

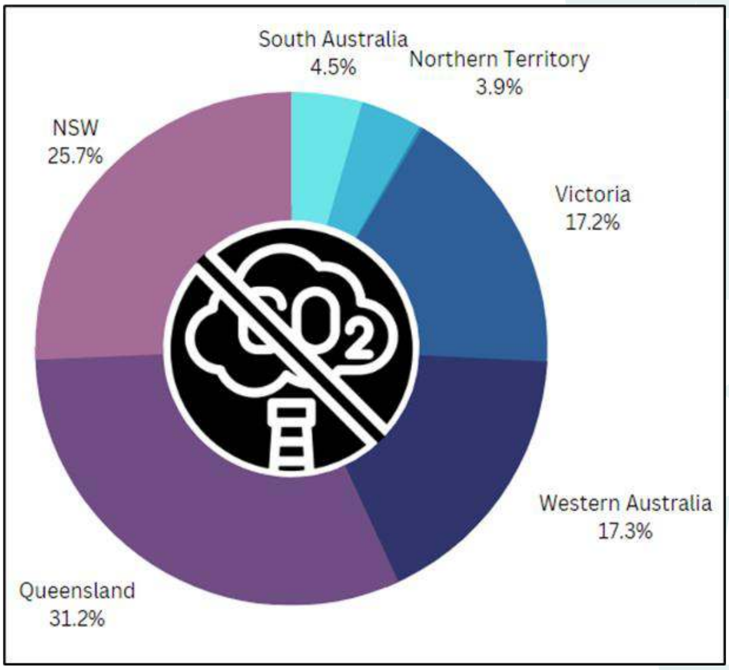


Figure 21 – Australia's carbon emissions per state[1]

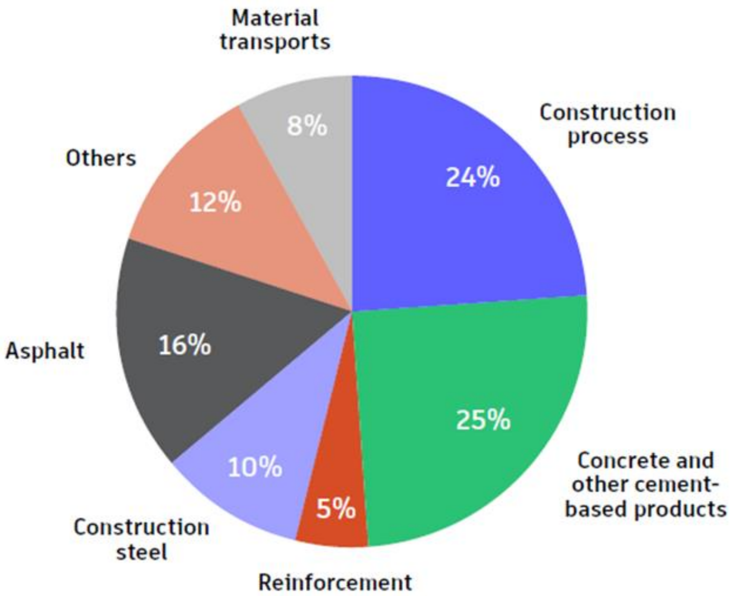


Figure 22 – Transport infrastructure construction emissions [34]

There are a number of drivers already in place that are helping to push the transition towards net zero in the transport construction industry. Firstly, as shown in Figure 23, each state and territory in Australia has set carbon reduction targets and a goal for net zero by, or before, 2050.

Figure 23 – State and territory emissions reduction and net zero targets[35]

However, beyond targets, there are not many other significant government-lead initiatives that are driving net zero within the transport industry. This provides opportunity for the industry to drive the initiatives for net zero.

4.2 Industry lead initiatives

4.2.1 Industry bodies

Within the transport industry, a number of industry organisations, such as Infrastructure Partnerships Australia, Roads Australia, Australian Constructors Association, Infrastructure Sustainability Council and Consult Australia, are looking to provide advice and guidance to the industry and government alike. Some of their recommendations are:

- Policy – harmonised decarbonisation policy for public infrastructure, aligning investment decision making with stakeholder expectations, embed sustainability and emissions-reduction in business-case development[34];
- Procurement – focus on procurement reform on productivity, and maximises long-term social, economic and environmental value[34];
- Technology – accelerate investment and uptake of new technology with incentives to catalyse innovation, productivity and holistic value delivery[34];
- Supply chain – build capacity, embed responsibility, incentivise innovation and fairly allocated risk. Encourage and reward collaboration and sustainable outcomes[34]
- Emissions – currently they are not being considered to an appropriate extent when deciding what is built. Emissions need to be considered in both the emissions embodied in the construction process and the emissions enabled by the infrastructure[36]
- Moving to outcome-based regulation would provide a clearer pathway for zero-emission technologies to be piloted and implemented in Australia[22].

Other jurisdictions are already moving in the right direction with the New Zealand Government currently reviewing a Draft Emissions Reduction Plan which proposes to mandate that energy use and embodied emissions are measured for all new projects, as well as improvement or maintenance contracts[37].

4.2.2 Project based initiatives

Locally, there are already sustainability targets being mandated for individual projects. A good example is Sydney Metro project, which has mandated the following targets as part of their Sustainability Strategy 2017-2024:

- Carbon and energy management
    - Achieve at least a 20 per cent reduction in carbon emissions associated with construction, when compared to business as usual.
    - Offset 25 per cent of the electricity needs for the construction phase of the project.
    - Achieve at least a 20 per cent reduction in carbon emissions associated with operations, when compared to business as usual.
    - Maximise the capture and reuse of energy generated from braking trains.
    - Design buildings (stations and stabling buildings) to achieve at least a 15 per cent improvement over performance requirements set out in section J of the National Construction Code.
    - Source 5-20 per cent of the low voltage electricity required at above ground stations from onsite renewable energy sources where feasible.
    - Offset 100 per cent of the electricity needs for the operational phase of the project.
- Supply chain
    - All principal contractors develop and implement sustainable procurement strategies[38].

These initiatives by Transport for NSW implement and build on the non-road diesel requirements of the NSW Government Resource Efficiency Policy[38].

4.2.3 IS based incentives on government funded projects.

The current state of play for government funded projects in Victoria is to incentivise contractors to reduce their carbon emissions by providing a performance bonus based on how many credits they achieve through the IS rating assessment. In the case of MRPV projects the maximum performance bonus a contract can achieve for its IS rating score is 10% of a potential performance pool and that performance pool is at most 3% of the principal's budget. Therefore 0.3% of the project budget is the absolute maximum a contractor could expect to achieve a 100% IS rating score.

Breaking down the IS rating score further, there are a total of 44 credits that can be achieved. However only 2 of those credits relate to reduction of carbon emissions from plant and machinery during construction. The other 42 credits include a range of elements including management processes, land usage, waste reduction, potable water use, ecology impacts, and stakeholder impacts. The IS rating score card assesses the contractor's performance against the 44 credits and provides a score out of 100. The default weighting for the energy credits is 10.5 points. However only half of this relates to renewable energy initiatives, while the other half relates to general reductions in plant usage. One third of the remaining renewable energy score can be achieved through investigation, without implementation. Therefore only 3.5 points relate to actually implementing the use of renewable energy initiatives.

In order to score the full 3.5 points, the contractor must have at least 40% of its energy usage come from renewable sources. The business-as-usual approach for achieving these credits is achieved through the implementation of conventional solar panels, biodiesels, and purchasing carbon credits to offset the impact. Implementing new technology is not even required to score these points.

To have access to this project bonus at all, various other delivery elements need go well, including hitting all targets relating to time cost and safety, so the sustainability initiatives cannot take priority over the primary aspects of project delivery. Table 8 presents a summary of the IS rating score for implementation of renewable energy initiatives.

Table 8 – IS rating score translated to project incentives

	Performance bonus portion of project budget	Sustainability portion of bonus	Renewable Energy implementation portion of sustainability
Percentage	3%	10%	3.5%
Weighted percentage of project value		0.3%	0.0105%

In summary, a construction project with a value of $100 million could potentially, at best, achieve a maximum incentive of $10,500 for successfully incorporating the use of renewable energy fuel sources for 40% of it's overall consumption. Exceeding the 40% target does not increase the reward incentive.

4.2.3.1 Baseline project IS rating score

As of October 2022, the MFP is still undergoing review of the IS As-Built rating, despite having achieved Practical Completion in November 2021. The project received an 'Excellent Rating' for its interim design submission and based on the As-Built submission the project team is confident they will achieve a 'Leading' As-Built rating which is substantially above the contractual requirement of 65 points[39]. The major items that lead to the Design to As-Built improvement in the score from Excellent to Leading was the extensive use of innovative recycled materials, which are noted in Section 2. The projects choice to implement these innovations was not driven by client incentive, as they well exceeded the score required by MRPV, but due to a culture of prioritizing sustainable and innovative outcomes.

4.2.3.2 Conclusion and recommendations to improve incentives

It can be concluded that the potential reward for scoring well on the renewable energy implementation is far too insignificant to warrant spending millions of dollars on research and development. A budget savvy approach is to undertake a cost benefit analysis on the IS rating score card and target those items that produce the highest scores, essentially the "low hanging fruit". Low emissions innovations cannot rely on the current incentive frameworks and need to be self-justifying – i.e. they need to generate cost and time savings to the project in their own right.

A more aggressive approach from the government to incentivise the use of reduced emissions fuels would be to adopt a similar approach to the forward spreading aggregate trucks in spray seal application. In this case the Victorian Government identified safety risks associated with reversing aggregate trucks, so to incentivise change, they updated their standards for bitumen placement to include bonus payments for the early incorporation of forward spreading aggregate technology, modified trucks that could spread aggregate from the front of the truck while the trucks were moving in a forward direction. These incentives started high and were reduced at the turn of each financial year until in July 2022, the requirement became mandatory. The early adopter incentives started as high as 5% of the value of the work being undertaken.[40]

Low emissions innovations cannot rely on the current incentive frameworks and need to be self-justifying.

When compared to the technology developments required with low emissions fuels, this is a massive bonus for a relatively small innovation. The forward spreading aggregate innovation was purely mechanical, while the incorporation of hydrogen fuel is chemical, mechanical, electrical, mining and refining, and requires substantial improvements across the entire supply chain. As can be seen from the review of the IS rating system in the previous sections, the incentives are almost non-existent.

Given the significant current spend and pipeline for transport infrastructure, with over $200 billion in the pipeline[36], there is a real opportunity to reap significant carbon reduction gains from a small investment of the overall spend.

4.2.4 Contractor based initiatives

Compared to the mining industry, where all the key players are committed to net zero and are investing large amounts of capital towards that goal, the large contractors in the transport industry have varied approaches to their net zero goals. Table 9 outlines the key commitments of the tier 1 transport contractors, based on publicly available information:

Table 9 – Key commitments of Tier 1 transport contractors

Contractor	Scope 1, 2 & 3	Notes
CPB[41]	• 20% reduction in Scope 1 and Scope 2 emissions by 2025, from a 2019 base Net zero Scope 1 emissions by 2038 • Net zero Scope 3 emissions by 2045	Sustainable construction is one of CPB's top 5 priority areas. CPB's net zero approach is based on reducing emissions by using efficient and low emission equipment, and offsetting emissions by purchasing carbon credits
John Holland Group[42]	Not stated	John Holland Group notes that their 2022-2025 Climate Change Strategy is well advanced and will be finalised in 2022 ESG Report
ACCIONA[43]	• 60% reduction in Scope 1 and Scope 2 emissions in the period 2017-2030 • 47% reduction in Scope 3 emissions in the period 2017-2030	
Laing O'Rourke[44]	• 75% reduction in Scope 1 and Scope 2 emissions by 2030 • Scope 3: No target, but Laing O'Rourke is working with the Centre for Construction Engineering and Technology at Cambridge University, on research into decarbonising construction	Laing O'Rourke has commenced converting all company offices and project sites to renewable energy tariffs, and transitioning to an all-electric company car fleet.
McConnell Dowell[45]	• Measure and verify Scope 1 and Scope 2 emissions and trial reduction initiatives • Industry led improvement on Scope 3 emission reporting	
WeBuild[46]	• 35% reduction in Scope 1 and 2 emissions from 2017 by 2022	

Scope 1 emissions are primarily from fuel consumption.
Scope 2 emissions are primarily from electricity consumption.
Scope 3 emissions are the indirect emissions associated with activities including material manufacturing, waste disposal, transport, and travel

4.2.5 Consultant based initiatives

When it comes to ESG and consultant offerings, consultants are committed to implementing innovative and practical ESG solutions, supporting clients, both asset owners and construction contractors, to reduce carbon emissions on projects through all project phases.

AECOM has developed the Sustainable Legacies program and ScopeX[47] and to has pledged achieve net zero business by 2030. ScopeX is AECOM's approach to reducing the carbon impact from major projects across all project phases, with a goal to achieve a 50% reduction (when compared to industry norms), achieved by considering materials, site locations, logistics and construction methods, in additional to renewable power sources.

SMEC works collaboratively to deliver holistic project outcomes. This includes successfully guiding and supporting several projects through sustainability ratings, such as Australia's Infrastructure Sustainability Rating Scheme and the Green Star rating. SMEC Australia partnered with South Pole, a global climate action expert, to offset a portion of their carbon footprint through the purchase of carbon credits.

GHD understands that climate change adaption and mitigation is one of the most important issues facing the industry, and seeks to explore engineering solutions to minimise negative impacts, and promote public safety and sustainable economic growth. GHD has committed to achieving carbon neutrality for Scope 1, 2 and 3 emissions by 2025[48].

Jacobs has reduced their carbon emissions by 45% since 2019[49] and are a carbon neutral organization. In their Climate Action Plan, Jacobs seeks to achieve net-zero greenhouse gas emissions across the value chain by 2040[49].

Aurecon recognises that the journey towards a more sustainable future is ongoing, and works with stakeholders respond to transition risks and physical risks presented and support in positioning to mitigate and adapt[50].

WSP supports clients with identifying ESG and sustainability metrics and targets, and developing strategies and action plant to support achieving ESG and sustainability objectives.

4.2.6 Best practice case studies

In terms of industry best practice, there are a range of initiatives that are being trailed and implemented with the aim of reducing road and non-road vehicle-based emissions. Table 10 provides a summary of recent project case studies.

Table 10 – Local industry best practice case studies

Project, Contractor and Location	Description	Initiatives	Outcomes
Sydney Metro Northwest – Tunnels and Station Civil Project **CPB John Holland Dragados (CPBJHD)** **Sydney, NSW**[51]	$1.15-billion Tunnels and Station Civil Project. Awarded June 2013. 15-kilometre twin tunnels, civil works for five new stations, two services facilities and an onsite precast facility	• Diesel-powered heavy plant and equipment was substituted with electric powered plant where practicable, including tunnel boring machines (TBMs), road headers, shotcrete rigs, jumbo drills, mini excavators and concrete pumps. • All diesel plant was either new, or fitted with new engines to conform to the latest European standards. • Use of low sulphur biodiesel (B5) and self-cleaning fuel to reduce particulate emissions • idling reduction programs, both onsite and offsite	Reduce diesel emissions using engineering design, procurement and behavioural change approaches
Blacktown City Council **Sydney, NSW**[52]	Blacktown City Council is the third largest LGA in Australia, and owns 370 major plant items, 270 lease cars and 1,000 minor plant items, with an overall value of $40 million. From 2007 the Council started adopting a number of measures to reduce its emissions.	• Fitting existing non-road plant with partial Diesel Particle Filters to a reduction in emissions up to 50%. • Fitting Diesel Oxidisation Catalyst (DOC) converters to 22 older on-road vehicles to upgrade to Euro 4 emission standards. • Biodiesel B20 (20% biodiesel and 80% petroleum diesel) for all the Council's plant and vehicles. • E10 petrol was introduced to all unleaded petrol cars. • Council ensured new tenders included a weighting which preferences the highest EU or US emissions standard available for non-road plant and equipment. • Council has a scheduled replacement program for both minor and major diesel equipment.	• Retrofit of diesel equipment alone saved about 105 kilograms of diesel PM emissions per year from Blacktown's non-road plant equipment. • Particle emissions from plant or machinery using B20 are known to reduce by at least 10%. • Reduced its dependence on diesel by substituting almost 90% of its diesel with B20 biodiesel and leasing electric vehicles (with electricity supplied by solar)
Solar Power at Commodore Mine[53]**, Downer Group, Queensland**	Downer Group implemented an off-grid power system at the field crib hut at Commodore Mine that had previously been fully powered by a diesel generator.	• The system consists of six solar panel banks connected to a containerised battery bank. The solar panels run the crib hut and charge the battery bank during the day. At night, the stored energy in the batteries is used and if it is depleted, the diesel-powered generator automatically starts until the solar panels generate energy again.	• It is estimated that this system has resulted in a 65–80% reduction in diesel and carbon dioxide emissions. • The Downer Group will investigate opportunities to utilise this off-grid power system at other projects.

Project, Contractor and Location	Description	Initiatives	Outcomes
South Eastern Program Alliance, Laing O'Rourke, Melbourne[34]	The Hallam Road Level Crossing Removal Project has implemented a number of initiatives to pursue the aim of net zero carbon on their site.	• B5 biodiesel used in various plant. • Biodiesel fuel used in back-up generators rather than using standard diesel generators. • Solar power was used for site sheds. • Electricity for the project was sourced from a green energy product to achieve carbon neutral certification.	• These initiatives enabled a saving of ~72% of CO2 against the baseline carbon footprint
Vehicle management technology and decarbonization, Acciona, Spain, New Zealand and Australia[34]	Reducing fuel consumption of the earthmoving equipment. Fleet management technology is being applied across 12 projects in Spain, New Zealand and Australia and will improve productivity by: Minimising idling, Reducing inefficient activities, Assessing driver behaviour, Avoiding unnecessary fuel-burn.	• Through the installation of GPS enabled equipment and vehicle telemetry monitoring, ACCIONA has been able to assess in real time the efficiency of their operations and make adjustments as required. • Fleet planning has been found to contribute to the largest reductions in fuel-burn, and hence carbon emissions. • Improvements in this has enabled projects to assess workflows and reduce fleet size or reprioritize vehicles in areas where inefficiencies have been identified. • The monitoring has also provided the ability to identify how hard each vehicle is working so the vehicle size can be optimized to suit the workload	• Early indications suggest that insight provided by the use of this technology has resulted in a 5-7% reduction in project carbon emissions associated with fuel use • This approach has also been applied to ACCIONA's light vehicle fleet and they are working to transition to a hybrid alternative where appropriate. This change is estimated to save approximately 3,700T of CO2 over the next 5 years
Novo Rail Alliance, Laing O'Rourke and RCR Infrastructure O'Donnell Griffin, Sydney [34]	Annual diesel fuel requirement >52,000L for site accommodation power Team has reviewed several initiatives to reduce diesel burn and GHG emissions.	• Reduce the size of generators by 60% based on data from energy metering and to optimise the load and running time by coupling it with GPS' PowerCube; a purpose-built industrial battery. The hybrid system cycles between the generator operating at optimal capacity until the battery is charged, then turning off while the power demand is met by discharging battery. • In addition, B5 biodiesel blends have been introduced to fuel the generators.	These initiatives have resulted in an approximately 60% reduction in the project's site accommodation fuel consumption directly reducing CO_2 emissions equivalent to 80 tonnes of CO_2

4.3 Turning targets and proposals into reality

Reviewing the initiatives proposed and undertaken in Table 9 and Section 4.2.5, it can be summarised that the Tier 1 contractors and consultants are committed to their sustainability goals and making a difference. It can be summarised from Table 10, that in most cases those differences rely on solar panels for site sheds, optimising efficiencies, and increasing the use of bio-fuels where possible. As discussed in our review of the MFP project in Section 2, the change to bio-fuels will only reduce the GHG emissions by up to 23% at best. Using solar panels to power site offices, has a similarly minor impact on the overall emissions created during construction. None of the above commitments relate to the use of BEV's or Hydrogen powered vehicles.

In 2021 Lendlease, now ACCIONA, partnered with the University of Queensland to research the transition to fossil fuel free construction and propose a pathway forward[54, 55]. The reports that were published as part of this research acknowledged that achieving net zero by 2040 is highly unlikely and that achieving the same goals by 2050 will require a very aggressive approach to the advancement of technology and rollout across the industry. This is reflective of the assessment by mining industry, as outlined in Section 3.7, where it's estimated that over $165 billion will need to be invested in clean energy projects over the next 8 years in order to meet the goal of net-zero emissions by 2050.

The solution relies on the broad-spectrum rollout of the zero emissions emerging fuel sources identified in Section 3, and the incorporation of the new heavy plant and equipment that has been developed internationally to use those fuels. This is not a pipe-dream, but is a developing reality in other parts of the world – just not yet realised in Australia.

5 Zero emissions developments in construction plant

We have identified 2 major databases of zero emissions plant available world-wide.

- Low and Zero Emission Construction Machinery and Equipment Database, April 2022, by the University of Queensland[56]
- Bellona Database: Emission-free Construction Equipment (by manufacturer), July 2022[57]

Together they identify at least 90 items of construction plant that are currently available and more that are in prototype development. This includes notable manufactures such as Liebherr, Kubota, Komatsu, Kobelco, JCB, Hitachi, CASE, BOMAG, Caterpillar, and Volvo. We have taken a few highlights as follows:

5.1 New battery electric heavy plant

The developments in EV technology are occurring more and more rapidly, with many significant technology leaps occurring only in the last 2 years. While most of the Battery Electric Plant that is currently available is either under 15T in weight or requires a direction connection to mains power. There are a few options for larger plan that has broken this trend.

In 2019, Caterpillar, along with Pon Equipment, unveiled an all electric26-ton excavator with a 300-kWh battery pack, that weighs 3.4 Tonnes. The machine can operate for up to 7 hours between charging, and is currently in operation by Veidekke in Norway.[58]

Figure 25 – Caterpillar, along with Pon Equipment, unveiled an all-electric 26-ton excavator

The R1700 XE battery electric LHD is a high productivity, zero-emission loader with the industry's only onboard battery. It charges safely, eliminating the need to handle or exchange batteries, and does so in less than 20 minutes when paired with two of the durable and mobile Cat MEC500 chargers. One of the key characteristics is the mobile charging unit that can be taken to the R1700 XE[59]

Figure 24 – R1700 XE battery operated loader

Figure 26 – MEC500 charging unit

Heavy equipment manufacturer, Liebherr has just introduced the world's first battery-powered crawler cranes; LR 1200.1 unplugged and LR 1250.1 unplugged (shown in Figure 27). The batteries within this crawler crane are placed in such a way as to counterbalance the machine while it is lifting heavy loads of up to 250 tons. The lithium-ion battery pack can be recharged on a conventional electrical supply in around 4.5 hours or just 2.25 hours with a 125 Amp supply. Based on data collected from typical lifting cycles, the battery is said to be designed for four hours of lifting operation. The new cranes can also be operated while plugged into the electricity supply

Figure 27 – Liebherr LR 1250.1 unplugged – the first battery-powered crawler crane in the world

5.2 New HICE and FCEV heavy plant

Far less common that the Battery Electric Plant is the current status of development in Hydrogen Heavy Plant. Despite the previously discussed advantages for Hydrogen as a viable fuel source for heavy plant operation, there are still only a few current examples worldwide.

JCB is one of the leaders in the development of zero and low carbon technologies and has developed the construction industry's first hydrogen powered excavator. The 20-tonne 220X excavator is powered by a hydrogen fuel cell and has been undergoing rigorous testing at JCB's quarry proving grounds for more than 12 months.

Figure 28 – Hydrogen powered excavator

Netherlands company Mourik produced its first functional hydrogen powered 30T excavator which started construction work in October 2021.

Figure 29 – Mourik 30T hydrogen powered excavator

A number of manufacturers have been working on developmental research to replace diesel generators, and hence eliminate carbon emissions, have resulted in trials of several different types of hydrogen powered generators, listed in Table 11. Whilst these generators are still in the trial phase, it is expected that they will become available for use in the next 10 years.

Table 11 – Hydrogen powered generators

Diesel Generator Replacement	Manufacturer	Technology	Availability / Trials
Hydrogen Fuel Cell Kit	Siemens Energy	Hydrogen Fuel Cell kit with a Battery Energy Storage System	Being trialled at the Viking Link Interconnector project, UK – Used on a site in Lincolnshire, England to build a sub-sea link between the UK and Denmark
HydroX-Cell Generator	AFC Energy	Hydrogen Fuel Cell	Trial – Spanish infrastructure company Acciona will power an unnamed construction site in Spain using the HydroX-Cell Generator
Hydrogen Power Generator (GEH2)	EODev	Hydrogen Fuel Cell	Made in France and trialled at a few different sites in Europe
Hydrogen Fuel Capable Electric Power Generator (Cat G3516H)	Caterpillar	Gas generator set specifically configured to use 100% hydrogen (or green hydrogen) for fuel	Demonstrator units in North America and Europe with initial deliveries in late 2022

As seen above, the technology for Battery Electric Heavy Plant is well advanced, and the Hydrogen powered plant is kicking off. The majority of progress in the development of zero emission construction practises is occurring overseas. Next, Sustainable Melbourne will review how and why this is the case, and why Australia is less advanced than other countries.

6 The international market

It is now common practice for developed countries to acknowledge action is required to manage climate change and have agreements or targets in place to achieve varying levels of emission reductions. However, very few regulatory bodies have extended these emission reduction targets to the construction industry and even fewer to the actual construction machinery and plant. This section looks at where the international market is with respect to reducing emissions in construction machinery and plant, what technologies have already been utilised, as well as what international governments are doing to support and encourage / enforce the implementation of zero emission plant and equipment.

6.1 International case study: Oslo's Olav Vs gate pilot project

6.1.1 Project overview

In September 2019 the city of Oslo, Norway began construction on the Olav Vs gate pilot project which had ambitious targets of achieving zero emissions.

The scope of the project was to transform an existing congested street and taxi rank into a new urban environment that would appeal to both locals and visitors. The entire street was excavated to create a new city space with no traffic. Existing materials were replaced, the underground infrastructure was upgraded, and new trees were planted. The relocated taxi rank was upgraded with Oslo's first charging station for electric taxis and the existing parking spaces were replaced with delivery bays and disability parking.

By substituting electric plant for conventional diesel engines not only were the emissions reduced but the general public observed a noticeable reduction in ambient noise pollution from the site. Businesses and residents were able to continue their business with less disruption than a typical construction site. Additionally, workers reported improved communication on site as a result of lower noise levels and the working environment also felt a lot safer.

Figure 30 – Electric excavator on Olav Vs gate project (Credit: KlimaOslo)

The Olav Vs gate pilot project was able to save 35,000 litres of diesel and the equivalent of 92,500 kg of CO_2 by using electric construction equipment[60]. The project didn't quite achieve the ambitious target of 100% emission free due to requiring a propane burner that couldn't be substituted. The 99% reduction in emissions compared to a traditional project was still celebrated as a success by the City of Oslo and demonstrated to the world that an emission free construction site is already possible.

6.1.2 Project procurement strategy and initiatives

To gain an overview of the available options and technical solutions for an emission free construction site, the project began by performing extensive market research. At the time, the supply of electric construction plant was limited, but it was possible to acquire electric excavators and wheel loaders. However, there were very few construction companies that had their own electric machines which would have limited the number of companies able to tender with confidence in securing this plant. To ensure the few existing machines were available, the city of Oslo entered a separate contract with a construction equipment rental company which was willing to purchase the machines for their rental feet with a guarantee that they would be used in the pilot project. The tender documents for the pilot project's construction contract then specified that the winning contractor was required to use the zero-emission machines from the rental company.

Figure 31 – Electric equipment on Olav Vs gate project (Credit: KlimaOslo)

Another concern raised by the local contractors was the uncertainty around electricity supply and consumption. This was a new concept, and the full cost impact was difficult to estimate. To address this, Oslo specified in the tender documents that the city government, as the project owner, would pay for electricity used during the construction phase, this cost would end up on the final bill for the project regardless, and by covering this cost up-front they were able to lower the project's risk profile.

Oslo's procurement methods for this pilot project have now evolved into published strategies and policies which are being actively shared through international organisations setup to increase knowledge around zero emission construction projects.

6.1.3 Machinery utilised on site

Norway's power generation is at least 98% renewable [61] which makes it the ideal testing ground for electric powered machinery over other alternative fuel sources. The City of Oslo identified this early in the project planning phase and through collaboration with industry were able to source several different units, some identified below:

- Zeron 17.5 ton excavator battery electric + cable operated[62]
- Zeron 9-ton excavator – battery electric
- Wheel loaders – battery electric

The project was also able to secure the rental of a larger 25-ton battery electric CAT Z-Line prototype excavator for a short period[60].

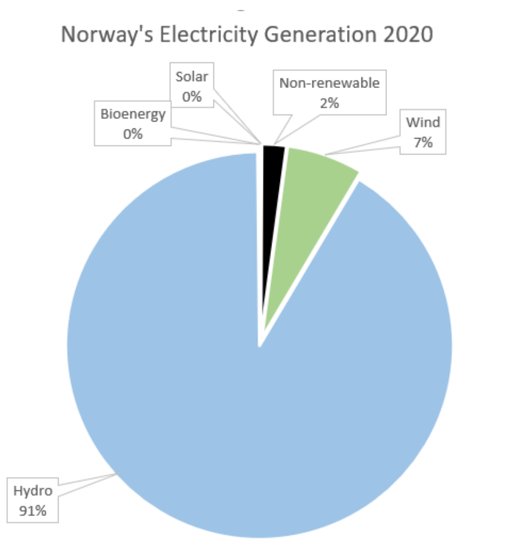


Figure 32 – Norway's electricity generation sources 2020 [61]

The battery and battery and cable electric excavators were hailed as being key to the success of the project. The Nasta AS excavators were redesigned and rebuilt Hitachi diesel powered excavators. The conversion procedure includes removing the existing fuel tank and diesel engine, and fitting an electric motor and drive, together with an energy management system, battery and charging solution, and a power connection.

The pilot project proved that using electric construction machines is possible for almost all activities of a small roading project.

6.2 International policies for non-road diesel emission reductions

Policies for road-based combustion engine vehicles are becoming more common around the world with large manufacturers on board with a plan to transition to zero emission vehicles because of the increasing restrictions. Polices for non-road diesel emissions have been in place in several major countries for some time but have a slow uptake around the world. These policies typically cover non-road mobile machines with combustion engines such as:

- construction machinery (excavators, loaders, bulldozers, etc.)
- small gardening and handheld equipment (lawn mowers, chainsaws, etc.)
- agricultural & farming machinery (harvesters, cultivators, etc.)
- locomotives and inland waterway vessels

These types of policies are generally the first step in a transition to reduce emissions as they place restrictions on current technologies and increases the incentive for suppliers to transition to other fuel sources. Two examples of major regulations are below.

6.2.1 European Union

The Non-Road Mobile Machinery (NRMM) regulation 2016/1628[63] is the most applicable piece of legislation at the European level for the construction sector. The EU has regulated NRMM emissions since 1997, with this legislative file being the latest to regulate NRMM emissions in this way. As of January 1st, 2017, the EU's 2016/1628 Regulation, imposes emission limits for NRMM engines for different power ranges and applications. It also lays down the procedures that engine manufacturers have to follow in order to obtain type-approval of their engines, which is a prerequisite for placing their engines on the EU market. The implementation of the regulation is expected to have long term benefits such as protecting the health of EU citizens, protecting the environment, and improving air quality, ensures a good functioning market for NRMM engines and avoids unfair competition from non-compliant low-cost products.

The EU has transitioned through five stages of reduction since 1997 to get to the current regulations. Each of the stages have requirements for emissions of carbon monoxide (CO), hydrocarbons (HC), nitrogen oxides (HOx) and particulate matter (PM). Stages I to V were gradually introduced to different sized engines and to an increasing breath of machinery types. Each stage typically has a transition timeframe before all new engines or replacement engines to demonstrate compliance.

Table 12 - Generalised NRMM emissions standards for EU Stages (130 ≤ P ≤ 560)[64]

STAGE	EMISSIONS (g/kWh)			
	CO	HC	NOx	PM
I	5	1.3	9.2	0.54
II	3.5	1	6	0.2
III	3.5	0.19	2	0.025
IV	3.5	0.19	0.4	0.025
V	3.5	0.19	0.4	0.015

6.2.2 United States of America

NRMM are generally referred to as Non-Road Diesel Engines (NRDE) in North America. The US EPA announced emission standards for NRDE for the first time in 1994. Similar to Europe, the US NRDE standards regulate air pollutants such as CO, HC, Nox and PM with a tiered implementation regiment.

The Tier 1-3 standards are met through advanced engine design, with no or only limited use of exhaust gas aftertreatment. The Tier 4 standards require that emissions of PM and Nox be further reduced by about 90%. Such emission reductions can be achieved using control technologies, including advanced exhaust gas aftertreatment. In 2021, the California Air Resources Board held a public workshop on the development of Tier 5 emission standards that will seek to further reduce Nox and PM emissions by 50-90%, depending on the engine power category, in the 2028-2030 timeframe.

A comparison of the timeline of implementation of policies from the EU and USA are presented in Figure 33 below which shows they have taken a similar approach to significantly reducing emissions of non-road mobile machinery and diesel engines.

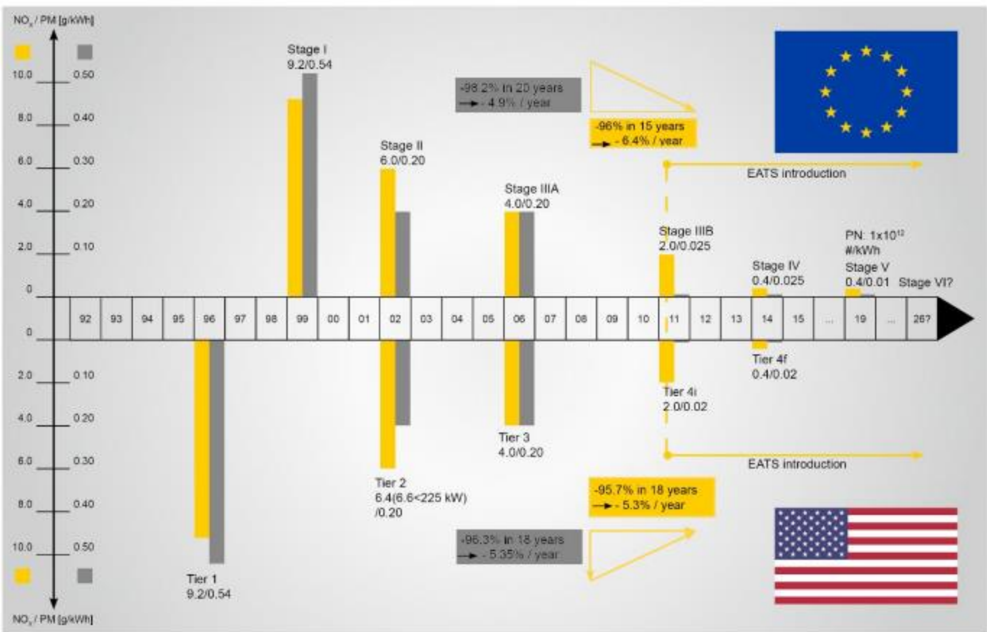


Figure 33 – Comparison of EU and USA NRMM regulated reductions[65]

Figure 34 is a visualisation of where countries have implemented non-road emissions policies and how they approximately compare to the stage/tier system implemented by the EU and the USA.

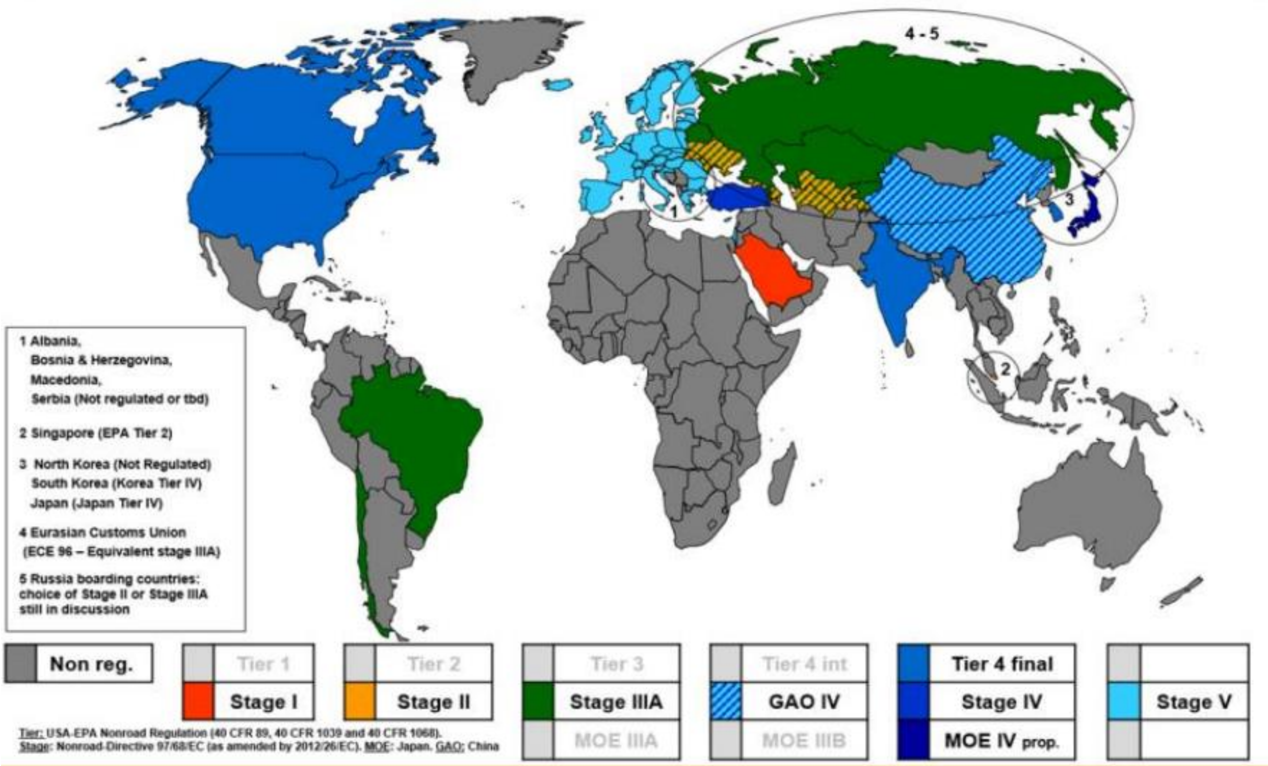


Figure 34 – NRMM emissions regulations 2021[65]

Both the EU and USA regulations go a long way in terms of improving air quality for health benefits, but they do not directly address CO_2 GHG emissions. They progressively reduce air pollutant emissions, thus phasing out equipment with the most polluting engines over time. Not taking the impact of fossil fuels into consideration when regulating emissions from NRMM and NRDE is a significant omission, especially given the large amount of CO_2 being emitted but not accounted for.

6.3 Emission targets and policies

Several cities and some countries have taken their commitment to reducing construction phase emissions seriously and committed these to published targets, signed agreements, and are implementing policies to achieve said targets. Several examples are discussed below.

6.3.1 Norway

In Oslo, non-road and construction site emissions account for a significant portion of the city's total emissions which are shown in Figure 35. This prompted the city to adopt extremely ambitious targets through their Climate and Energy Strategy, paving the way for other municipalities. Now Bergen, Trondheim, Stavanger, Drammen, Tromsø and Kristiansand have followed effectively creating a coalition of cities moving toward construction site decarbonization.

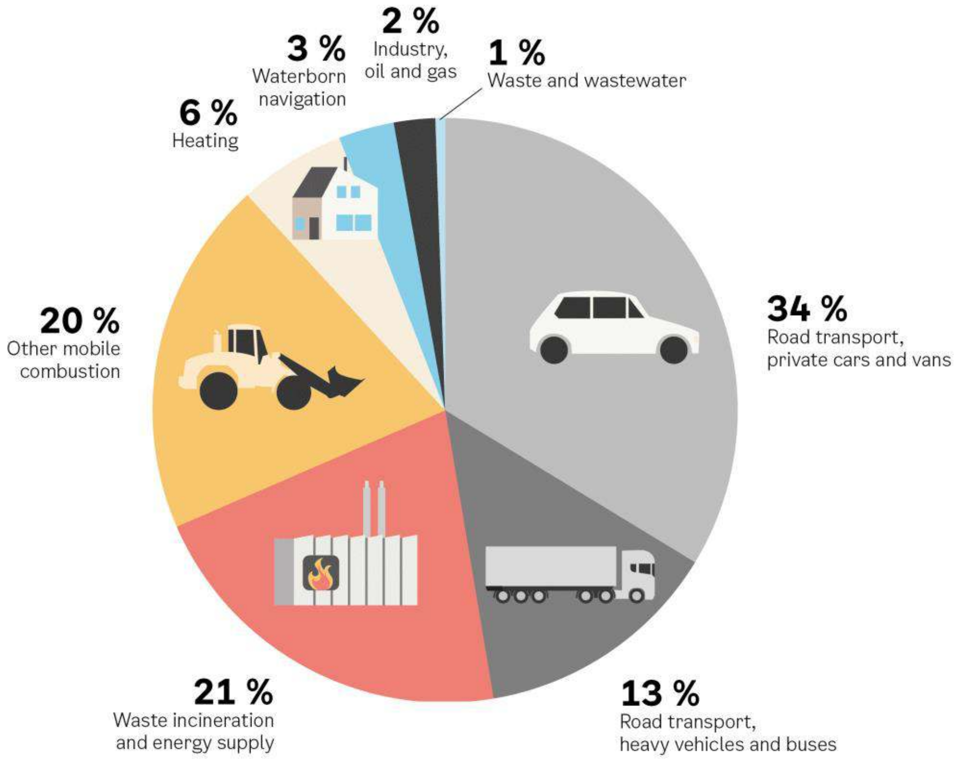


Figure 35 – Oslo's emissions percentages by source. Source: KlimaOslo

By 2021, the municipalities' building and construction activities will be fossil free. This requires that machinery will be either electric or powered exclusively with fuels made from renewable raw materials such as biodiesel. A fossil free construction site uses no fossil fuel powered construction machinery. While this includes electric machines, so far in Oslo criteria requiring a fossil free construction site usually results in the use of biofuels. This means there are no CO_2 emissions. However, biofuels still generate other local pollutants like particulate matter (PM2.5) and nitrogen oxide (Nox). These requirements are currently being enforced through procurement policies put in place since 2019.

By 2025, the municipalities' building and construction activities must be emission-free. A zero-emissions construction site is cleaner and represents a more ambitious goal. It requires all processes on the construction site to use zero-emission technologies like battery or cable-electric (which is zero-emission when coupled with a clean energy grid) or hydrogen. These technologies don't produce any emissions of CO_2, particulate matter or Nox.

By 2030, all construction activities in the cities will be emission-free, both public and private. By this time, ten plus years of experience brought forward through public procurement will have created enough knowledge to allow for a large-scale deployment of zero–emissions machinery.

To achieve the ambitious targets the City of Oslo first published a new procurement strategy in 2017 requiring all municipal projects to use, where possible, electric technology for all vehicles and construction machinery. The following year, the municipal and national-level governments released a joint statement announcing their intention to require biofuels or electric technology for all future projects.

In 2019, Oslo published common tender criteria for all municipal construction projects that specify the 2017 procurement strategy's requirements for clean construction technology in detail. At minimum, all projects are required to use construction machinery and vehicles which run on sustainable biofuels or biogas. The use of electric technologies is incentivised in the competition criteria.

The standard weighting for environmental criteria in all building and construction tenders is 30%[60] and at minimum, 20%. Half of this environmental weighting is for electric construction machinery and transport to and from the construction site – totalling 10% to 15% of the award criteria.

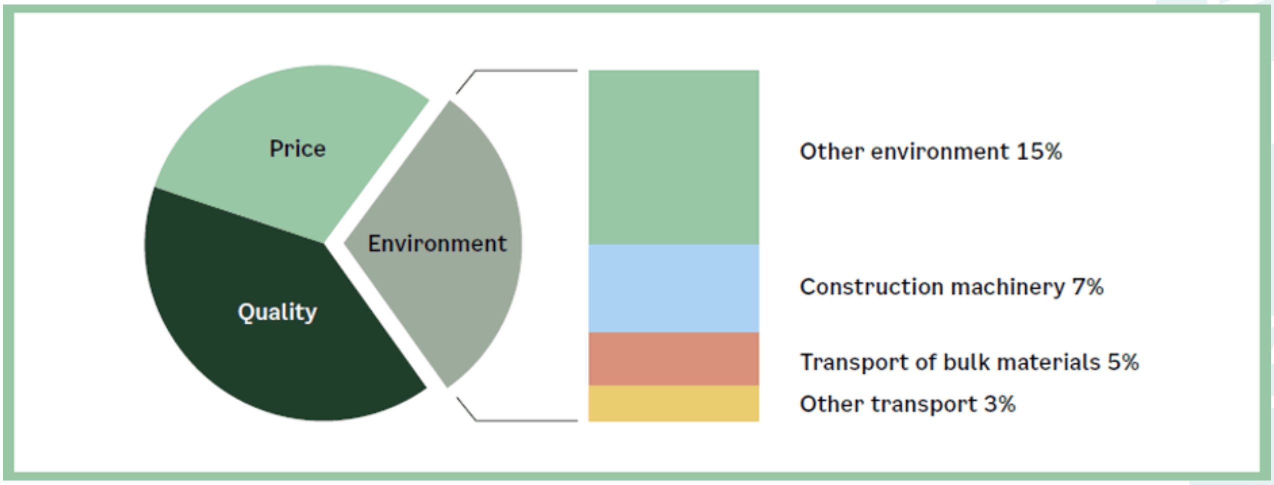


Figure 36 – Oslo's common tender criteria weighting. Source: KlimaOslo

In sectors where the city represents a large share of the market, public procurement is a powerful tool for change. Cities can use their purchasing power to create demand for clean technologies, drive innovation and create new green jobs. By having predictable municipal processes and giving clear long-term signals on the future direction of construction standards, particularly through the procurement strategy, cities build confidence in the market and lower the risks associated with innovation and investment. In Oslo, this helped the city government to be bold in their demands to the market – and it was surprised how quickly the market responded to its drive towards fossil-free construction.

The City of Oslo's Climate Agency recently engaged a third party carry out a survey of emission free building and construction sites for Oslo Municipality's projects. The results indicate that the development towards emission-free building and construction sites is progressing rapidly, although some barriers and challenges remain. The conclusion – that all the municipality's building and construction sites shall be emission-free by 2025[66].

This mapping shows that it is unproblematic with smaller electric machines and equipment. But there are some challenges relating to energy supply and charging logistics when multiple, large construction machineries operate at the same time. It is reported that electric construction machineries generate less noise, less pollution, better air quality and a better working environment. The results show that there are different understandings of what an emission free building or construction site involves, and that definitions of these terms should be standardised.

The key barriers and challenges identified in the survey report are extracted in Table 13 below.

Table 13 – SINTEF survey barriers and challenges identified[66]

	Barriers and challenges	Possibilities and solutions
Emission-free construction machinery and vehicles	Long distances to disposal sites outside Oslo necessitate the use of vehicles using biofuel or fossil fuel.	Effective local utilisation of masses, and improved charging infrastructure for larger vehicles (outside Oslo).
	New market with few available electric machinery and vehicles.	Make the demand for electric machinery and vehicles visible and collaborate nationally and internationally to affect supply.
	Electric construction machinery has a lower load capacity and heavy electric vehicles have a shorter range – they do not always have enough energy or available electricity to last a full working day.	Adapt work routines, better charging solutions (e.g., rapid charging) and ensure enough electricity supply on the construction site.
	Several emission-free machines are not being used as much as desired.	Follow up contractors actively to ensure they use emission free machineries when they are available.
	Competition for projects is decided according to offers on the machine fleet.	The framework for following up contracts can be further developed with larger weight on documenting the use of emission free construction machineries, instead of today's model that emphasises the composition of the machine fleet.
Electricity supply	Complex process for arranging temporary electricity supplies, especially 400 V – this may lead to delays.	Good process for involving power grid operators in early planning and throughout the project.
	Charging problems – limitations of the supply grid may lead to increased charging times.	Consider the composition of the machine fleet by choosing battery and cable/battery-powered electric machinery to resolve charging capacity problems. Other ways to reduce the load on the supply grid may be through the use of a battery container, the use of district heating to heat and dry structures and arranging one's own energy generation in a building project's early phase.
Charging logistics	Use of cable/battery-powered construction machinery can present challenges related to building site logistics.	Early assessment of which machine types are to be used (battery, cable/battery) to allow suitable arrangement of the building site.
	There may be several different charging systems for different machines.	Appoint a person responsible for charging logistics on the building site. Use a battery container that can be kept continuously charged from a 230 V supply, but rapid-charge machinery at 400 V or more from the battery-based mobile solutions.

6.3.2 C40 cities

The mayors of Oslo, Los Angeles, Mexico City and Budapest have pledged to halve emissions from all construction activities in their cities by 2030, in collaboration with leading companies and innovative business communities.

The mayors also commit to lead by example on clean construction, using their purchasing power and normalising the use of zero emission construction machinery, and demanding transparency and accountability in their supply chains. They aim to achieve this by embedding clean construction policies into design and planning, procurement, and contracting processes, as well as building codes.

By signing the C40 declaration, mayors promise to approve at least one net-zero emission flagship construction project by 2025 and to produce annual reports on their progress.

6.3.3 Finland

The Finnish Green Deal aims to achieve 100% fossil free construction sites from 2025. The green deal agreement focuses on emission category requirements for heavy machinery and transport as well as promoting low-emission motive power types. The purpose of the agreement is to increase the proportion of low-emission heavy machinery and to promote the introduction of new practices and tools both on construction sites and in procurement processes.

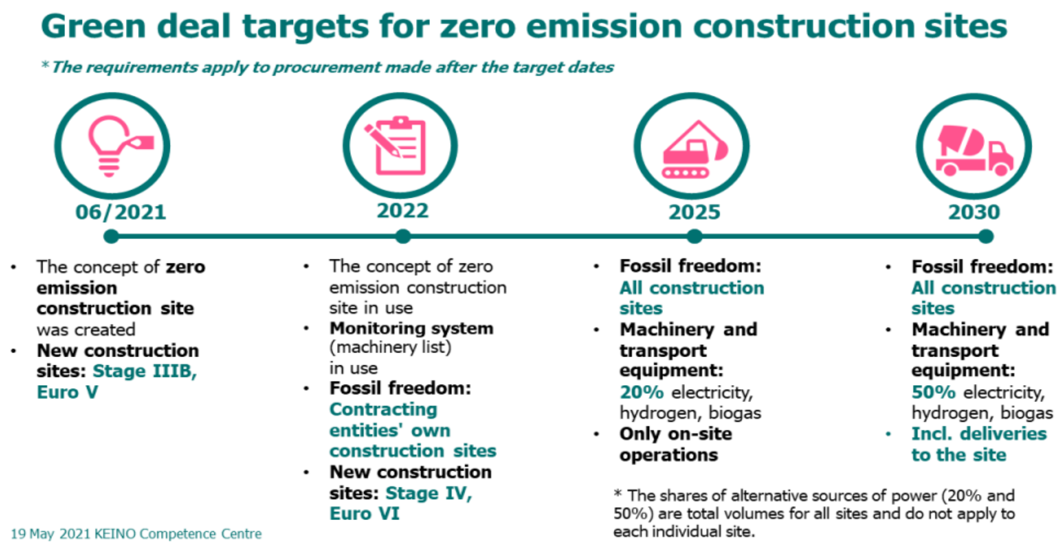


Figure 37 – Green Deal Targets. Source: KEINO

6.3.4 London

The city of London has set a target of having zero emissions from construction machinery by 2040. The city is planning on meeting these requirements by re-organising non-road mobile machinery fleet and replacing equipment which does not meet these standards.

6.4 Organisations contributing to furthering zero-emission construction

6.4.1 Big Buyers for Climate and Environment

Big Buyers for Climate and Environment is a European Commission Initiative for promoting collaboration between big public buyers in implementing strategic public procurement for sustainable solutions. The cities in the working group on zero-emission construction sites were working together to develop and pilot innovative procurement actions to promote alternatives to traditionally diesel-driven NRMM used to carry out public construction works (such as diggers, excavators, wheel loaders, etc.). The working group will exchange on pilots and jointly aggregate demand to accelerate the transition to zero-emission construction sites.

6.4.2 Bellona Foundation

The Bellona Foundation is an independent non-profit organisation that aims to meet and fight the climate challenges, by identifying and implementing sustainable environmental solutions. Bellona have an active database[57] of Emission Free Construction Equipment that has a range of useful data that is updated regularly. They also publish regular articles and fact sheets to share international developments in the transition to zero emission construction sites.

Some of their key recommendations the Bellona Foundation make for the transition to zero emissions construction sites are highlighted below.

Implementation/Revision of NRMM Standards

- Increased standards ensure a better quality of life for workers
- GHG emissions should be considered as part of the Non-Road Mobile Machinery standards

Support schemes for purchasing machinery

- Electric machinery has higher upfront costs compared to diesel
- Financial support can facilitate the early adoption of these technologies, driving down purchase prices in the long term

Green public procurement rules

- Public authorities (at the local and national level) are in charge of a major part of the construction works and public procurement represents 14% of EU GDP
- Adopting public procurement rules which demand the use of zero emission machinery ensure a reliable market for stakeholders willingness to invest in electric equipment

Public support in setting up power connection

- Setting up a power connection able to recharge or directly power all the machinery on a construction site can be both challenging and expensive
- Public authorities can temporarily take responsibility for this, reducing uncertainty and creating better conditions for adoption

Phase out date for diesel machinery

- Adopting a clear phase out date for the purchase and use of diesel machinery at the local, national or EU level sends a strong market signal
- Companies are more willing to invest in new technologies in case these ensure them priority in a market segment

Support R&D

- Electric construction machinery draws benefits from technology development in recent years, especially in the car industry. However, using electric drivetrains in construction machinery is a relatively new application requiring further research.
- Targets public support for research, development and deployment can decrease risk and ensure faster innovation and adoption.

6.4.3 C40 knowledge hub

C40 is a network of mayors of nearly 100 world-leading cities collaborating to deliver the urgent action needed right now to confront the climate crisis. Together, they can create a future where everyone, everywhere can thrive. They have numerous resources shared on their knowledge hub, but one particular resource is the Clean Construction Policy Explorer[67] which is an interactive dashboard showing how cities around the world are supporting the transition towards a resource efficient and low to zero-emissions construction sector.

7 What does success look like?

This section will explore the potential benefits to reduced emissions by looking at the different fuel sources identified in Section 6 to Section 3 by looking at each fuel source at an individual level and extrapolating the data based on the sample project identified in Section 6. Specifically, this section will investigate the development in the EVs for a quantitative analysis based on current EVs available to the market used on a typical construction project. Due to the limited availability of hydrogen powered vehicles currently on the market, this comparison was not included due to the lack of data.

7.1 Baseline fuel usage CO_2 emissions

Section 6 exploded the existing CO_2 emissions generated from a typical road project, the MFP, to establish a baseline to compare against.

7.2 Typical electric vehicle power usage

The comparison made in this section will look at using the typical fleet mix used on a construction site, by using the MFP as an example project, and looking at the comparative vehicle emissions if this fleet were able to be replaced with electric vehicles.

The University of Queensland (UQ) has provided data[56] on construction machinery currently available to market. A snapshot of data used for comparison is provided Table 14. This table illustrates the vehicle types that are available with a battery electric power source and the typical daily energy usage.

Table 14 – Battery electric construction vehicle typical daily energy usage

Vehicle	Typical daily energy usage
Backhoe Loader	8hr / 90 kwh
Excavator (<7t)	8 hrs / 45 kwh
Excavator (7t – 45t)	8 hrs / 430 kwh
Wheel Loader	8 hrs / 351 kwh
Scissor Lift	8 hrs / 2 x 5.75 kwh
Compactor (Vibratory Plate)	6 hrs / 422 kwh
Road Roller	The battery-electric road roller's carbon emissions are reduced by approximately 236 kg per day, a reduction of 42,000 kg a year compared with a petrol or diesel-powered roller
Drill Rig	265 kw
Crawler Crane	8 hrs / 250 kwh battery
Dump Truck / Dumper	8hrs / 44 kW
Bulldozer (D6 XE Caterpillar)	6 hrs / 161 kW

Table 14 shows the typical daily usage for electric construction machinery. This electricity needs to be sourced from either local power generation or from the national power grid. The assumption of this study is that electric vehicles will be powered from the national power grid.

7.3 Power generation for electric vehicles

A key factor to explore of converting to a worksite to Electric Vehicles is the additional requirement to source power from the power grid. A review of comparable emissions for energy use is thus required. Current trends in the energy generation market indicate a movement towards more renewable based power sources. This trend will mean that over time the use of power supplied from the grid will result in lower emission outcomes.

7.4 Where does the grid currently get its power from?

The Australian electricity grid currently generates power from a range of renewable (no emission) and non-renewable power sources. The mix between these sources is changing over time as investment in renewable energy sources is increased.

Figure 38[68] shows total Australian electricity generation and renewable electricity generation in terawatt hours between 1979-80 to 2019-20 and calendar year 2020. Total electricity generation in Australia in 2020 was around 265 terawatt hours and renewable generation was 65 terawatt hours making a mix of 20% renewables.

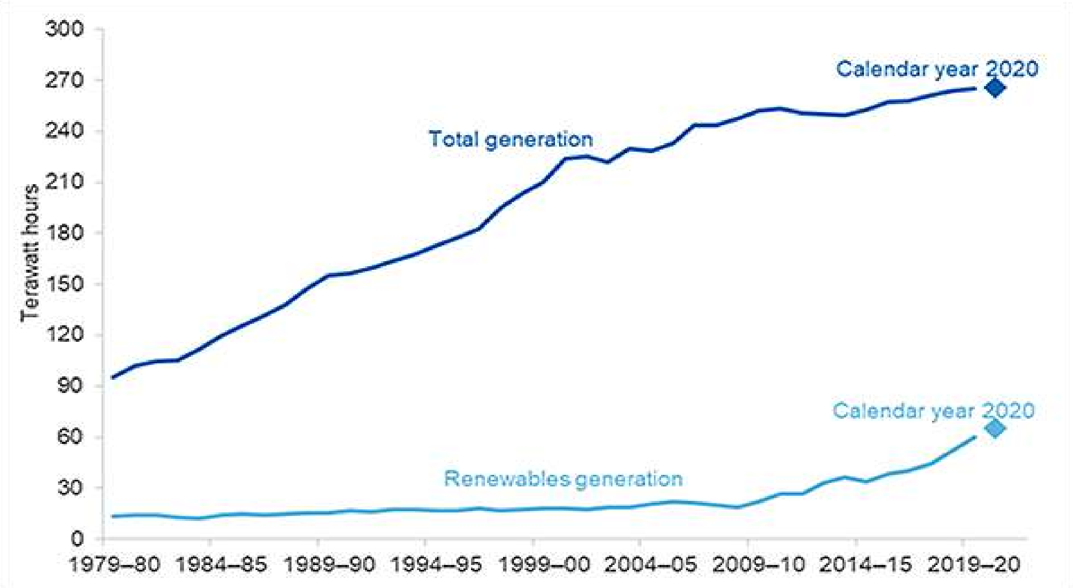


Figure 38 – Australian electricity generation. Credit: Dept' of Industry, Science, Energy and Resources

Figure 39 presents the Australian electricity generation fuel mix in from 1994/95 to 2019/20 as well as the calendar year 2020. Fossil fuels contributed 76% of total electricity generation in 2020, including coal (54%), gas (20%) and oil (2%). The share of coal as a form of electricity generation has declined from 83% in 1999-00 while the shares of natural gas and renewables has increased. Renewable from of energy contributed 24% of total electricity generation in 2020.

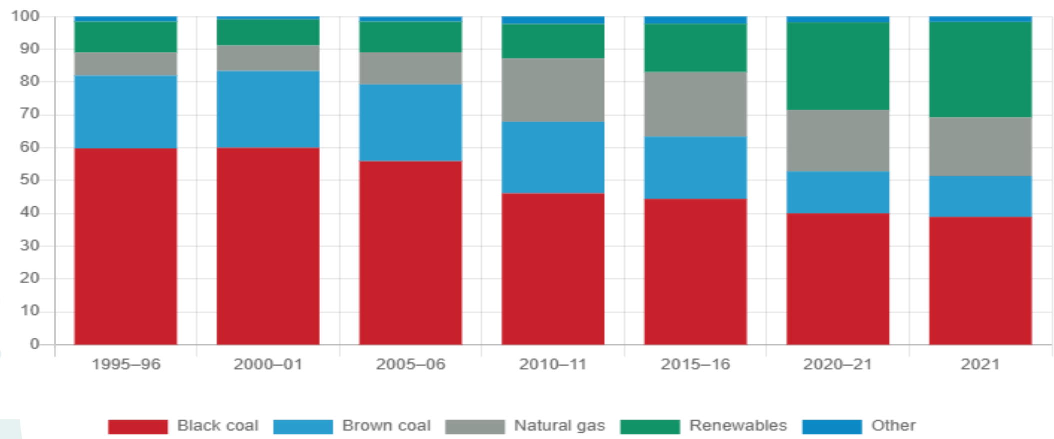


Figure 39 – Australian electricity by source. Credit: Dept' of Industry, Science, Energy and Resources.

7.5 How much CO_2 does 1 kWh produce in Australia from the power grid?

The power sector in Australia emitted 656.4 grams of carbon dioxide per kilowatt-hour (gCO_2/KWh) of electricity generated in 2020. This number is expected to decrease between now and 2050, where expected emissions are predicted to be 98 gCO_2/KWh[69].

The above figures allow us to compare a comparison in current and future emissions compared to existing diesel and unleaded fuel usage. Refer Table 15 below. This comparison compares the EV values with the values from Table 3 of this report.

Table 15 – Comparison in current and future emissions

Vehicle	Energy usage / Day (kwh)	2020 Emissions (kg CO_2/ day)	2050 Emissions (kg CO_2/ day)	Sample project CO_2 emissions (kg CO_2/ day)	2020 % Reduction	2050 % Reduction
Excavator (7t – 45t)	430	282.3	42.1	369	81.8	88.6
Backhoe Loader	90	59.1	8.8	325	57.5	97.3
Wheel Loader	351	230.4	34.4	542	57.5	93.7
Compactor	422	277.0	41.4	238	-16.4 (increase)	82.6
Dump Truck	440	289.0	43.0	434	33.4	90.1
Average					**27.2**	**89.1**

The comparison presented in the above table shows that if a typical construction site, MFP for this comparison, was to adopt a fleet of EVs for use, the reduction in CO_2 emissions would be in the order of 27.2% based on current grid supply power and potentially as much as 89.1% based on the likely future energy production mix in 2050.

7.6 What is the effect on the power grid due to the increased demand?

The above analysis assumes that the power is readily available from the power grid. In practice, this is not the reality. The power grid will require upgrades to supply such increases in demand. Electricity grid constraints are an obstacle to the long-term electrification of construction activities. Constraints include lack of capacity and the ability to manage 'peak loads' from individual construction machines such as cranes. State governments and electrical utilities will play a central role in grid transformation required to meet future higher loads of many industries, including construction.

A previous study[70] investigated the potential rise in electricity demand due to recharging of EV batteries was calculated as a function of time and location. The rise in electricity demand was compared with actual electricity consumption. The analysis showed the average rise in electricity demand was 8% compared to actual energy consumption in 35 LGAs of NSW. This rise in electric energy demand was calculated for 82% of weekday and 81% of the weekend vehicle commuter trips with trip lengths less than 35 km/trip. The results also showed that the rise in demand for electric energy is likely to be higher in regions where population density is low, with a few exceptions.

This shows that measures will need to be undertaken to increase the supply on the energy grid if the demand of supplying energy to Electric Vehicles is sourced from the power grid.

The following chart (Figure 40) shows how the impact of Electric Vehicles has been projected by AEMO (Australian Energy Market Operator). The total power consumption in Australia in 2023 is at 180,000 GWh per annum, with EV's consuming a meagre 173 GWh (<0.1%). By 2050 AEMO project that these numbers will change to a total grid consumption of 353,000 GWh per annum, with EV's consuming 79,000 GWh (22.4%). The growth rate from EV's is also expected to outpace any other sector with an average annual growth of up to 25% compared to other sectors which will average <5%. These may seem like some intimidating numbers when it comes to grid impact, however the benefit of EV's is that charging can be undertaken off-peak. The biggest demand when it comes to power generation is managing the peak demands. EV's are expected to stay below 5% of the demand required[71].

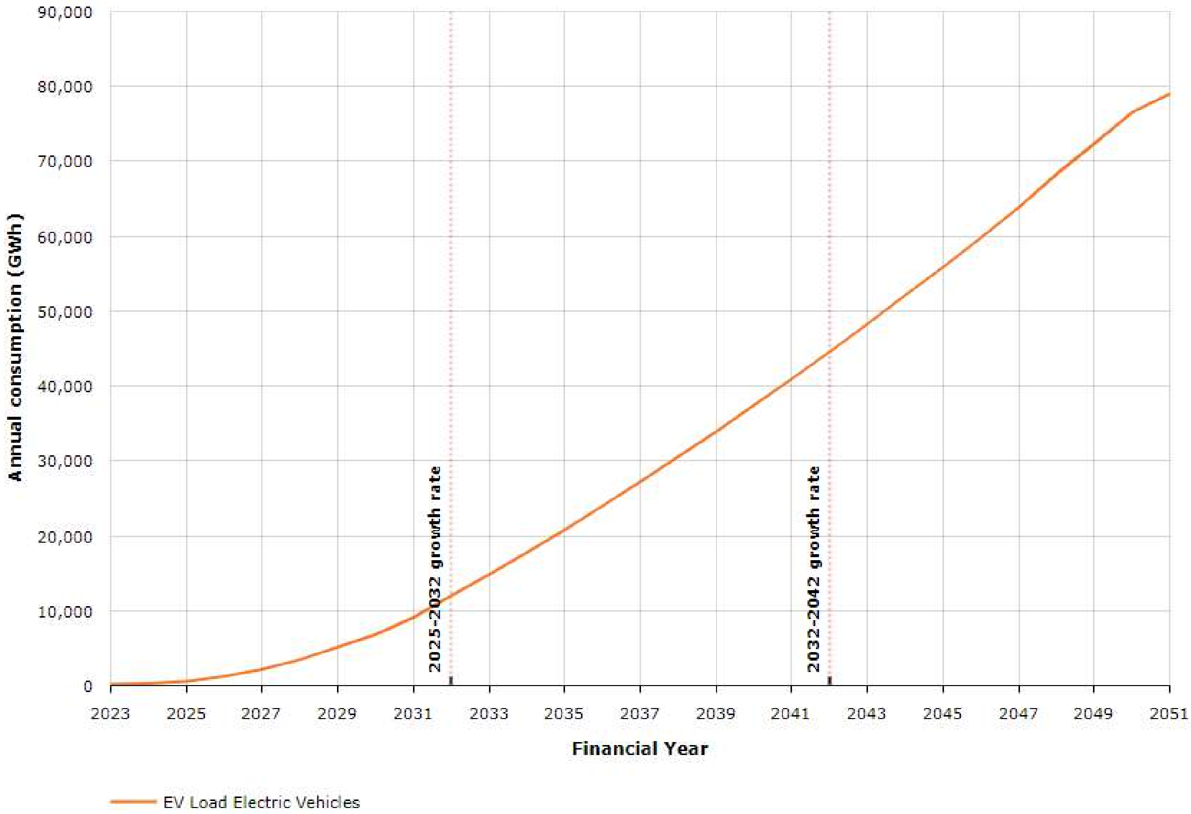


Figure 40 – Electricity supply grid projections from AEMO (September 2022)[71]

7.7 What does this reduction in CO_2 emissions mean?

If the above noted potential reduction in CO_2 emissions was applied across the construction industry, which currently accounts for approximately 18.1%[72] of CO_2 emissions, then the potential reduction for emissions across Australia is potentially 16.1% by 2050 if all construction was to convert to electric vehicles. This order of reduction is significant at a national level.

(While the above focuses on carbon emissions specifically, the other GHG emissions are impacted by the same reduction factors, and therefore result in the same percentage savings).

7.8 What are the benefits of going net zero for a business?

Besides the reductions in missions, there are other benefits that companies that adopt a conversion away from fossil fuels-based vehicles to electric vehicles. Key benefits are shown in Table 16.

Table 16 – Key benefits to business

Business Area	Description
Business reputation	• Marketing • Strategic advantage in bidding • Attraction of staff
Reduced costs over the long term	• Renewable energy sources typically have high set-up costs but lower ongoing costs which could help reduce cost to business over the long term
Attracting investment	• Favourable business from government and other companies that want to build business reputation.
Security and resilience	• No reliance on the wholesale international markets for fuel. • Energy can be sourced from local set-up of solar farms next to site. • Advantage for remote sites.
Social procurement / sustainability targets	• Meeting contractual requirements for government contracts with machinery and infrastructure that is already in use if adopted early.

Figure 41 – Wind farm – wind, a typical renewable energy source

8 What are the steps to achieve net zero and what is the timeframe?

Much work has been undertaken previously and recommendations put forth with a view of reducing emissions for non-road diesel engines. The Australian Government Department of Agriculture, Water and the Environment produced a discussion paper in October 2020 titled *Non-road diesel engines – evaluating a national approach to manage emissions*. NSW EPA has prepared a report *Reducing Emissions from Non-road Diesel Engines (2014)*. More recently, Lendlease in collaboration with UQ has investigated the pathway to fossil fuel free construction (2022), and Roads Australia together with industry leaders prepared The Journey to Net Zero report (2022) including recommendations. The NSW Department of Environment, Climate Change and Water, and Australian Government Department of Environment, Water, Heritage and the Arts prepared *Cleaner Non-road Diesel Engine Project – Identification and Recommendation of Measure to Support the Update of Cleaner Non-road Diesel Engines in Australia (2010)*. These aforementioned reports capture not only non-road diesel vehicles in the construction sector, but also in the mining, agriculture, marine, forestry and industrial sectors, and provide recommendations to reduce emissions, which are very relevant to the lineal transport construction industry.

The demand for electric and hybrid vehicles in Australia is at an all-time high[73] and the uptake of electric vehicles in Australia has increased with demand surpassing supply[74]. The momentum in Australia behind taking more action on climate change is increasing and stakeholders, shareholders, financiers and alike are demanding change.

Figure 42 – M80 upgrade Blaxland bridge (Credit: MRPV)

It is also recognised that particle emissions from diesel plant impacts not only the environment and climate change, but also contributes to adverse health effects such as respiratory and cardiovascular illnesses[75] and has been reported to be a carcinogenic increasing the risk of lung cancer [75].

Whilst the Australian Government has committed to reducing emissions t, emissions from non-road plant and equipment driven by combustible engines remains unregulated and a significant contributor to adverse environmental and health effects.

Reportedly, due to the unregulated state of non-road diesel engines in Australia, these engines account for about 70% of the diesel fuel consumption and about half of the particle emissions[75].

This section presents an understanding of the current local regulations and standards, local constraints and challenges, opportunities to further reduce particle emissions with respect to plant and equipment in the transport construction space, technological advancements required and timing.

8.1 The current Australian regulations and standards

Unlike road vehicles, in Australia there is currently no regulation or standard that limit emissions from non-road diesel engines. As summarised in Section 6, regulated emission limits for non-road diesel engines have been in force in the US and Europe since the mid-1990s. China, India, Japan, Canada, Brazil, and Russia also have regulated emission limits for non-road diesel engines.[76]

Figure 43 – Echuca-Moama bridge project (Credit: MRPV)

Reportedly the implementation of regulated emission limits in US and EU has significantly reduced emissions over the past 10 years[76], and while Australia has historically benefited from the importation of engines compliant to US or EU standards[76] and this has contributed to reduced emissions, Australia is at risk of increased receipt of non-compliant engines as more and more countries implement regulations and non-compliant engines are diverted to countries without regulations. A review of new engines and equipment being sold in Australia suggests that a significant number of engines do not achieve US or EU regulations [75], and whilst the lack emission regulations and standards and competition in the marketplace for cost effective plant remains, there is little incentive to utilise alternate fuel sources.

Construction sites are largely ignored when it comes to emissions, this could be attributed to the construction phase on transport projects being short in duration when compared to the operation of the asset. Secondly, measurement of emissions is not clear-cut, primarily due to a lack of understanding of emission data for construction plant and equipment.

The Australian Government (Department of Climate Change, Energy, the Environment and Water) in collaboration with the NSW Government (Departing for Planning, Industry and Environment), under the National Clean Air Agreement has undertaken an evaluation of a national approach to manage non-road diesel engines. At the time of writing, the evaluation had been finalised and the final report received by Department of Climate Change Energy, the Environment and Water was under consideration, however the evaluation was not publicly available. Advice from the Department indicates that the Department is planning to brief the relevant federal minister on the report findings and seek authority on the next steps. The Department is intending to share the cost benefit analysis with the states and territories, and then decide on whether to move to implementing (non-road diesel

> A review of new engines and equipment being sold in Australia suggests that a significant number of engines do not achieve US or EU regulations with respect to diesel emissions.

engine) regulations, however it appears that there is no commitment on timing for this.

It is noted that the stakeholder engagement for the evaluation included mining, forestry, manufacturing and agriculture as well as construction industries and that there is opportunity to undertake more targeted engagement within the transport construction sector.

8.2 The current challenges

A high-level summary of the current constraints and challenges faced in the transport construction industry impeding the technology advancement and uptake and plant and equipment with alternate fuel sources are as follows:

8.2.1 Local manufacturing capability

The Australian manufacturing industry has been on the decline with the closure of local manufacturing businesses leading to reduced capability. Diesel engines are not manufactured locally in Australia meaning they are either imported as stand-alone units or as components to equipment[76]. As a result, this means it can be cost prohibitive to import complete zero emission heavy vehicles and diminishes the availability of zero emission plant and equipment locally.

Importation of an electric excavator from Sweden is speculated to cost in the order of $800,000 (compared to about $445,500[77] locally for a conventional 36t excavator).

8.2.2 Conversion of existing plant and equipment

The cost of converting existing equipment to alternate fuel sources is reported as expensive, and several factors come into play such as the remaining life of plant, the opportunity for return on investment and uncertainty of plant performance as well as current lack of supporting infrastructure (such as readily available batteries, charging points etc).

The process to convert existing diesel engines to an alternate renewable fuel source, including non-direct costs such as loss of productivity, hampers the progress of decarbonisation in the transport construction sector, and by extension, other industries such as agriculture and forestry.

Research suggests it is more cost effective and efficient to import new engines utilising alternate fuel sources rather than retrofitting in-service diesel engines[75]. However, implementing a progressive conversion strategy, whereby plant that can be easily converted is converted is still progress towards zero emissions.

8.2.3 Technology advancement and refuelling technology

The surface and underground mining industries have progressed with trialling and implementing alternate fuel sources to operate mining fleet. Non diesel fuel sources are common in underground mining operations as they reduce the need for ventilation. Alternate sources commonly include electric (overhead conductor) or tethered electric vehicles. As discussed in Section 3, mining companies are investing in fully electric or hybrid electric mining plant, and businesses are exploring strategies to optimise the placement of refuelling locations (such as battery swap locations) to improve productivity and reduce downtime.

Figure 44 – Solar powered lighting plant (Credit: Generators South Australia)

Regarding refuelling technology, the technology to support portable charging / recharging infrastructure, electric and hydrogen energy sources for heavy vehicles is in development as touched on in Section 5.

The very nature of transport projects and the construction cycle means that permanent establishment of refuelling locations to support construction is unlikely to be viable unless the infrastructure is retained for operation purposes.

With respect to light plant and vehicles, alternate fuels sources are becoming more and more common. For example, mobile solar powered generators housed within 20-foot shipping containers have been adopted on rural and remote projects[78] to power site offices and sheds, nearby lighting plant, VMS and alike, eliminating the need to transport thousands of litres of diesel to site as well as reducing the projects carbon footprint.

With further development of this technology and increased supply of such plant, there is potential to power light construction plant and equipment via alternate fuel sources on metro, regional and remote sites.

8.2.4 Transport (lineal) construction

As mentioned previously, the lineal nature of transport project means that construction sites can be considerably long with multiple worksites open at one time. For example, the MFP was 9km and interfaced with existing road infrastructure at on/off ramps and the end interchanges. Other transport projects such as Metropolitan Ring Road (M80) upgrade (widening), and Citi-Tulla widening required maintaining live traffic necessitating multiple traffic lane switches to enable construction to progress. Construction progresses in a logical way, working around live traffic and switching / adjusting or pivoting as necessary or as unplanned interruptions occur.

The very nature of transport projects and the comparatively short duration of the construction phase can mean the investment to establish (heavy vehicle) charging infrastructure may not be cost or program effective unless the infrastructure is retained for operation purposes or is portable.

Mining operations are planned, and broadly speaking, the movement of plant and equipment is by comparison predicable, meaning the haul routes are known and the extraction and tailing sites are understood. The life of a mine can extend decades, whereas the construction phase of a transport project varies and is by comparison short, in the case of the MFP the construction phase was two years.

Figure 45 – Civil construction site (Credit: MRPV)

In the case of rural and remote projects such as the Newell Highway upgrade program and Bruce Highway upgrade program,worksites can extend several hundreds of kilometres, meaning that plant and equipment in these locations need to be self-sufficient and reliable.

8.2.5 Plant ownership

As demonstrated on the reference project, the MFP, owners of plant and equipment are generally subcontracted onto projects to complete works or plant is hired from equipment rental companies, the primary contractors own very little plant themselves, meaning the project and contractors have less influence over plant investment decisions.

Furthermore, the turnover of plant and equipment requires consideration. Adopting sound maintenance practices, depending on usage, the life of an item of plant or equipment can be up to 10 year or longer, thus the turnover of a fleet of existing plant and equipment not only requires significant investment, but could potentially take decades. As mentioned in Section 3, the transition from leaded to unleaded fuel in Australian for cars took almost 20 years and was achieved via conversion of existing cars and manufacturing of new cars.

In addition, the skillset required to maintain alternate fuel source plant and equipment is different to that required to maintain diesel plant and equipment, an Environmental Social and Governance (ESG) opportunity to train people in this field perhaps.

8.2.6 Financial incentives

There is very little in the way of financial incentives to encourage a meaningful shift to alternate fuel sources in the transport construction sector. Currently there are incentives to increase the uptake of electric vehicles in the public domain such as the Victorian Zero Emissions Vehicle (ZEV) subsidy (effective May 2021), and develop public charging infrastructure stations[79] and financially sustainability incentives such as Victoria's Recycled First policy, however whilst fuel subsidies for heavy vehicles off public roads[80] remain, at the time of writing, no meaningful state or federal incentives or programs were identified to specifically encourage the update of alternate fuel sources for non-road diesel vehicles which includes construction plant and equipment.

The drive to implement plant and equipment utilising alternate fuels sources and reduce reliance on fossil fuels is predominately driven by the individual business striving to make a positive change and reduce climate impacts as highlighted in Section 3.

8.2.7 Knowledge gap

A survey of businesses in the construction, mining, ports, airports, waste, and manufacturing industries undertaken to inform the Environ Australia 2010 Cleaner Non- Road Diesel Engine Project report indicated that most companies surveyed are unfamiliar with the EU and US emission limits for non-road diesel engines. Informal discussions with those in the industry through this research project support that there is little industry (or publicly) wide awareness of the unregulated nature of non-road diesel engines concerning particle emissions. Whilst generally, awareness of construction activities and impacts on climate change has increased in recent years, a knowledge gap still exists. This is reinforced through industry events driving sustainability being centred around recycle, reduce, reuse and the circular economy, there is little discussion around particle emission limits from construction plant and equipment.

Reportedly, the primary reasons for non-road diesel equipment emissions not being subject to emission limits include[76]:

- Non-road diesel equipment is perceived to represent a minor source of air emissions when compared other activities such as manufacturing, on-road vehicles etc.
- Lack of best practice guidance on managing emissions.
- Absence of financial incentives to encourage a move towards decarbonisation.
- The methodology to calculate and report emissions is reportedly complex and currently undefined.

In addition, it is understood that there is a lack of information on the air emissions performance of non-road diesel equipment.

8.3 The opportunities

To support the reduction of carbon emissions in the transport construction sector and move towards decarbonisation, there are several opportunities that can effect positive change. It is recognised that the greatest impacts will come from widespread industry changes as seen by improving safety on construction sites through the 1990s and 2000s, what were once safety initiatives are now business as usual.

> The greatest impacts will come from widespread industry changes as seen by improving safety on construction sites through the 1990s and 2000s, what were once safety initiatives are now business as usual.

Managing air quality amidst the Victorian Big Build is largely focused on managing dust[81], and environment and sustainability policies tends to focus on recycling initiatives, as such there is scope to drive reduced carbon emissions on transport projects during the build phase.

These opportunities are elaborated on further in the following sections.

8.3.1 Policies, target, incentives, and penalties

8.3.1.1 Carbon emission regulation

The establishment of non-road diesel regulations based on existing overseas standards is the preferred approach to effectively address emissions from this sector.

The discussion paper *Non-road diesel engines – evaluating a national approach to managing emissions (October 2020)* commissioned by the Australian Government states that consideration of national non-road diesel emissions regulations requires an impact assessment be carried out, with a detailed cost benefit analysis to assess the merits of regulation and involve thorough stakeholder consultation on possible options[76]. The paper goes on to say that compliance timeframes (if implemented) should be tailored to reflect local circumstances, with progressive implementation of more stringent emission limits to minimise potential economic impacts and maximise compliance with regulations[76].

There is opportunity for Australia to leverage the existing overseas regulations (EU, US), learn from the changes adopted, and implement a phased introduction of emission regulations suitable for Australia. And there is no major reason that this cannot be phased in by industry (construction), enabling the changes to be extended to other sectors such as agriculture and forestry.

There is an appetite for change within the transport construction sector as highlighted in Section 4, and opportunity to invite industry to contribute to developing a strategy to implement emission regulations.

A quick win is to implement this requirement for new engines imported into Australia. Whist this does not decarbonisation the industry, it is a forward step towards emission reduction. It is acknowledged that there will then be a need for operation and maintenance upskilling.

Implementation of regulation will require a phased introduction on penalties for non-compliance.

Another way to encourage the update of alternate fuel sources is to implement a zoning approach, that is, new construction sites within specific areas (zone) with high emissions like the inner-city areas, must achieve targeted reduced carbon emission targets associated with construction plant and equipment. This can then be phased to regional built-up areas and so forth.

8.3.1.2 Financial incentives

Sectors of the market that are not government funded, are less likely to be incentivised, yet make up a significant portion of the construction market

Between 2011 and 2014, the NSW Government provided almost $806,000 in subsidies to retrofit 141 diesel machines with partial diesel particle filters, which is estimated to have reduce emissions by 37 tonnes until 2024[82]. The initiative was seen as successful.

Similarities can be drawn from the incentives implemented in recent years on major road projects in the Victorian transport sector and their effectiveness in making progress in the areas of sustainability (recycle, reduce and reuse) as well as social procurement (increased participation from smaller groups and businesses). It could be said that some sustainability practices are becoming more and more business as usual on transport projects and there is a lot of momentum within industry to leave a positive legacy.

In additional to regulations, industry requires financial support (or penalties) to effect change. This can be delivered through:

- Carbon targets for state and / or federally funded projects
- Phased in reduced subsidies on diesel for non-road diesel plant and equipment
- Subsidies to convert plant with diesel engines to an alternate fuel source (i.e. electric)
- Financial support for investment in electric plant and equipment

Re-baselining current environmental KPIs and incentivise will encourage further innovations within industry.

When a project or business places a price on carbon, this can help build a business case for investing in alternate fuel sources. ACCONIA has an internal price of carbon which can be leveraged to support procuring hybrid site vehicles to reduce onsite emissions. Range anxiety is real and needs to be investigate in context of construction sites and programs. Electric scooters for staff movements are also an option however there may be some safety concerns.

8.3.2 Light vehicles, small plant, and trucks

The change to electric vehicles is underway, as is the change to alternate fuel sources for small plant and equipment such as lighting plant and message boards as well as trucks / transports.

The fuel consumption on the reference project for light vehicles, lighting plant and generators through the construction phase was about one (1) million litres of diesel (excludes biodiesel and unleaded fuels). This presents an opportunity to reduce diesel fuel consumption by about 43% by substituting diesel driven vehicles, lighting plant and generators with electric vehicles and solar lighting plants and generators. Clearly this is subject to adequate supply.

Whist light vehicles are on-road vehicles, as the uptake of electric vehicles continues, fleets are turned over and widespread charging infrastructure implemented, the positive impacts to transport construction projects by way of reduction to carbon emissions will be evident.

Electric logging (b double) trucks are currently being trialled in South Australia[83], Toll has been trailing a delivery truck on the road network in NSW. These developments in technology present opportunities for deliveries to / from construction sites including quarry deliveries, disposal of spoil as well as material deliveries to be completed by electric trucks.

8.3.3 Innovation and sharing knowledge

The Victorian level crossing removal project (LXRP) program of works has been successful in sharing innovations supporting progress and sharing of knowledge in the industry via the innovation program, known as The Hive. There is opportunity to build on this model and create a space for sharing knowledge on zero emission vehicles and construction to support positive advancement. In addition, there may be opportunity for projects to share charging infrastructure.

The learnings and progress in the mining industry can be leveraged and applied to construction as relevant.

8.3.4 Renewable diesel

As identified in Section 3, renewable diesel is a synthetic form of diesel produced by hydro processing of fats, vegetable oils, and waste cooking oils. Unlike biodiesel, which is not preferred by plant suppliers, renewable diesel is a direct substitute for diesel. Opportunity exists to provide incentives to increase the use of renewable diesel, or disincentives for continuing the use of diesel.

8.4 Other indirect benefits

Noise

A benefit of implemented non-diesel plant and equipment on transport construction sites is also the reduced noise generated. The implementation of electric buses in Sydney are noticeably quieter. On construction sites, this can mean reduced risk of industrial hearing loss, improved communication by virtue the environment is quieter. By extrapolation, this may mean work sites can operate longer hours leading to increased productivity and reduced project durations.

Social Procurement

Build upon enterprising businesses bringing social procurement strategies into the sustainability space. That is, build upon programs whereby disadvantaged people are trained to maintain / service zero emission plant and equipment.

Innovation
Whilst manufacturing in Australia has been on the decline, there is opportunity to establish manufacturing plants to support the production of zero emission plant and equipment locally.

Reimagining vehicles
The opportunities are endless. Zero emission vehicles could be adapted to charge power tools on work sites, recreational equipment as well as feed back into the electrical grid power to manage peak demands.

8.5 The technology advances required

8.5.1 Electricity
Whilst there are challenges associated with the uptake of alternate fuel sources in the transport construction sector, the uptake of electric vehicles within Australia is gaining momentum and appears to be limited by supply rather than demand as demonstrated by the rapid sale of the Hyundai electric vehicle, - reportedly 18,000 Australians had registered an interest, and the 109 vehicles available sold out in less than 7 minutes[74].

The electricity generation and distribution network need to be considered holistically. Electricity is not the only alternate fuel source, and while coal remains the primary fuel for electricity generation, it could be said that moving to electric plant and equipment, including in the transport construction space, moves the problem from one carbon emitting source (diesel) to another (black / brown coal).

The changes needed to support electric vehicles has been studied and the opportunities are plentiful, but what is clear is that the increased demand needs to be managed and planned, and by extension, this applies to the transport construction sector where electricity from the grid is to be relied upon. Typically, power demand peaks in the mornings and evenings, and work sites that operate during these peaks whilst concurrently drawing electricity from the network will place stress upon the electrical network unless adequately planned. There may also be opportunity for sites to be putting electricity back into the grid.

> *"40% of construction machinery and equipment (by energy use) can be replaced by electric by 2030"*

8.5.1.1 Technological development of vehicles
Range anxiety, charging infrastructure including compatibility, the safety of batteries including handling, productivity as well as investment cost are current concerns regarding the move to electric plant and equipment. In addition, the supply simply is currently not available to support the market.

8.5.2 Hydrogen
The UQ Lendlease report notes that hydrogen has a long way to go, and that there is a lack of availability of hydrogen driven plant and equipment. Significant investment is required to support advancement of hydrogen driven construction plant, as well as the safe transportation of compressed hydrogen. To decarbonise the construction sector, hydrogen will need to be produced in the form of green hydrogen.

8.6 The risks
Risks to the implementation of zero emission vehicles in the transport construction sector include:

- Low uptake due to lack of regulation and financial incentives.
- Non standardised implementation of charging infrastructure, similar to the Apple verses android phone charger which has been different since the evolution of smart phones however is now being standardised in Europe.
- Generation of new waste products (redundant batteries and charging infrastructure).
- Inadequate power availability in the electrical grid to charge electric zero emission vehicles.
- Safety associated with the transportation of compressed hydrogen.
- Inadequate technology advancement to support efficient delivery of projects.

9 Conclusion

The topic provided by Roads Australia is a broad topic with multiple potential avenues to research. We have focused on emissions form heavy vehicles in the civil construction sector but found that we have also had to refine our research to keep it on point. The following section identifies our key findings, exclusions, and recommendations to both Roads Australia and the industry as a whole.

9.1 Exclusions

In undertaking research on zero emission heavy vehicles and plant in the transport construction sector and interrogating the fuel usage data for the baseline project (MFP), the following was excluded from scope:

- On-road diesel engine vehicles
- Manufacturing of plant and equipment
- Building / vertical construction
- Tunnels / ports / airports

Australia no longer has the capacity to manufacture heavy plant and equipment, as such capturing emissions associated with manufacturing is challenging.

Whilst transport construction can include vertical infrastructure such as stations / over station development, this paper focuses on lineal construction consistent with the baseline project (MFP).

9.2 Summary of findings

Sustainable Melbourne established from the baseline project (MFP) that the construction delivery makes up 14% of the GHG emissions on a typical construction project. However, it is the most overlooked when it comes to new initiatives and technology in the local Australian industry.

The use of biodiesel is the current go-to to reduce these carbon emissions, however the implementation of this is limited and will not provide the solution needed if the industry is to reach its Net Zero targets. Table 17 provides the typical carbon emissions of the baseline project by percentage, noting that this represents 0.1% of Australia's infrastructure spend.

Table 17 – Typical carbon emissions for baseline project, value $417 million

Fuel Type	Volume (litres)	tCO_2e	% tCO_2e
Diesel	2,494,895	6760	95.7%
Biodiesel (B20)	115,747	246	3.5%
Unleaded Petrol	25,199	60	0.8%
Total	2,635,841	7066	

The 68 tCO_2e saving achieved through the use of biodiesel accounts for a <1% of the total carbon emissions from construction plant and equipment. If all diesel use had been replaced with biodiesel, then this number would be closer to a reduction of 1457 tCO_2e, approximately 23%. It is clear that achieving a zero-carbon emissions target in the construction industry will not be achieved using biodiesel alone.

The various Australian state governments have all announced commitments to reach Net Zero targets by 2050. However, there is very little by way of incentives that will drive this change. Leaders in the construction industry are setting their own targets but initiatives that make a substantial difference are currently limited. The solution to reach Net Zero will require the nationwide rollout of both electricity and hydrogen as alternative fuel sources for heavy vehicles.

Electricity is currently available already in the market today and there is an expanding network of charging stations. A notable disadvantage when it comes to using electricity for heavy vehicles is transportation of the power to the heavy plant.

Hydrogen is less mature as an energy source than electricity. At a basic level, the technology already exists in combustion engines and fuel cell electric. The challenge is in the supply of hydrogen as a fuel, specifically green hydrogen, which is produced from renewable energy sources such as wind and solar.

The implementation of regulations in US an EU for no road diesel plant has reduced emissions over the last decade. Zero emission plant exists overseas, and as identified in Section 6, projects have been delivered successfully utilising zero emission plant.

The comparison presented in the Section 7 shows that if a typical construction site, MFP for this comparison, was to adopt a fleet of EVs for use, the reduction in CO_2 emissions is estimated to be in the order of 27.2% based on current grid supply power and potentially as much as 89.1% based on the likely future energy production mix in 2050.

If the above noted potential reduction in CO_2 emissions was applied across the construction industry, which currently accounts for approximately 18.1%[84] of CO_2 emissions, then the potential reduction for emissions across Australia is potentially 16.1% by 2050 if all construction was to convert to electric vehicles.

Figure 46 – MFP, The 400-metre twin bridges over the Waterways wetlands, credit: VIC Big Build

9.3 Recommendations to Government and Roads Australia

The UQ Lendlease report states that "40% of construction machinery and equipment (by energy use) can be replaced by electric by 2030", perhaps ambitious, it can be argued that what gets measured gets done.

Table 18 presents a summary of recommendations and timing to support the update of zero emission vehicles in construction.

Table 18 – Recommendations

	Recommendation	Time frame (years)	Notes
1.1	Advocate for implementation of a national emission standard for new non-road diesel engines with a view to phase out new non-road diesel engines at some point in time.	0-2	Consider zoned implementation approach, and / or applying to the importation of new engines / items of plant.
1.2	Identify construction plant suitable for transitioning to zero emissions and prioritise conversion.	0-1	This includes on-road vehicles and small plant and equipment. Consider a commitment on lease back duration to provide security to plant owners.
1.3	Develop a strategy for phasing out of plant and equipment reliant on fossil fuels		Phasing out of plant will require technological advancement, to inform timing
1.4	Continue to invest in technological development of alternate fuel sources such as hydrogen, electricity, and mobile storage.	0+	Ongoing
1.5	Develop financial incentives and policies to increase the uptake of zero emission plant and equipment in construction	2+	This can be state and / or federal level
1.6	Identify potential transport project(s) and advocate for zero emission plant and equipment targets and KPI regime	0-2	Implement and test policy project by project
1.7	Further engage with industry to identify barriers in the transport construction sector and develop strategies to overcome	0-2	Consider engaging with the mining industry regarding transition strategies
1.8	Develop industry standards for equipment to avoid multiple / different parts such as charging plugs.		This requires technological advancement
1.9	Support the decarbonisation of the electricity network Australia wide	0+	Requires a holistic approach
1.10	Advocate for financial relief via grants and/ or exemptions for the importation of zero emission plant	2+	
1.11	Advocate for state and / or federal investment in mobile charging sources to support charging electric vehicles on construction sites	0-2	
1.12	Investigate opportunities for local manufacturing of zero emission fuel engines, batteries, refuelling facilities etc		May require advancement in technology for heavy vehicles
1.13	Re-baseline IS rating targets with respect to emission reduction	0-4	Collaborate with ISC
1.14	Consider the skills needed to support operation and maintenance of zero emission plant and equipment and advocate for upskilling		Requires technological advancement
1.15	Support knowledge sharing locally and internationally	2	
1.16	Consider advocating for phased reduction in fuel subsidies for non-road diesel plant		Requires engagement with industry
1.17	Consider introducing carbon pricing on projects	0-4	Currently implemented within ACCONIA projects

9.4 Close

The Australian construction industry is making progress towards a net zero carbon emissions future. There are leaders internationally that are making strong progress in the development of technology that Australian construction businesses can leverage off.

The benefits in reducing carbon emissions are significant and an area that has not been on the forefront of environmental sustainability until recently. The benefits to business are greater than just the carbon mission reductions and include business reputation, reduced costs over the long term, attracting investment, security and resilience, health benefits and meeting social procurements/sustainability targets.

The advances in technology in recent years make the switching to electric vehicles for construction machinery a reality. Across other sustainable fuel sources, including hydrogen, there is still development to be undertaken. Emission reductions in the construction industry is a key area where improvements to environmental impacts can be made as the technology advances are recent and yet to be rolled out widely across the industry.

The change in Australia is inevitable, and with it comes opportunities to reimagine the delivery of transport infrastructure.

> ***Without change there is no innovation, creativity, or incentive for improvement. Those who initiate change will have a better opportunity to manage the change that is inevitable***
>
> *William Pollard*

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