July 2024

The critical path to decarbonise Australia's rail rollingstock

Transitioning the rail industry and its supply chain

Australasian Railway Association

GHD

Abbreviations

Accuse	Australian Carbon Credit Units
ACRI	Australasian Centre for Rail Innovation
AESS	Auto-Engine Stop Start technology
ARA	Australasian Railway Association
ARENA	Australian Renewable Energy Agency
AusRRIN	Australian Railway Research and Innovation Network
B5	Blend of five per cent biodiesel
B20	Blend of 20 per cent biodiesel
BEL	Battery-electric locomotive
BEMU	Battery-electric multiple unit
BET	Battery-electric tender wagon
BITRE	Bureau of Infrastructure and Transport Economics
CO_2	Carbon dioxide
CP	Critical path
CRCs	Cooperative Research Centres
DB	Deutsche Bahn
GDP	Gross domestic product
DCCEEW	Australian Department of Climate Change, Energy, the Environment and Water
DITRDCA	Australian Department of Infrastructure, Transport, Regional Development, Communications and the Arts
DTP	Victorian Department of Transport and Planning
EPA	Environmental Protection Agency
EU	European Union
FRA	Federal Railroad Administration
GHG	Greenhouse gases
HEL	Hydrogen-electric locomotive
HEMU	Hydrogen-electric multiple unit
HET	Hydrogen-electric tender wagon
ITMM	Infrastructure and Transport Ministers' Meetings
KPIs	Key Performance Indicators
LHET	Liquid hydrogen-electric tender wagon
MoC	Memorandum of Cooperation
MtCO2-e	Million tonnes of carbon dioxide equivalent emissions
NFSCS	National Freight and Supply Chain Study
NRF	National Reconstruction Fund
NRAP	National Rail Action Plan
NSDS	Network Specific Decarbonisation Strategy
NSW	New South Wales
NTC	National Transport Commission
OEM	Original Equipment Manufacturer
ONRIC	Office of National Rail Industry Coordination
ONRSR	Office of the National Rail Safety Regulator
PPA	Power Purchase Agreement
PV	Photovoltaic
QLD	Queensland
R&D	Research and Development
RIM	Rail Infrastructure Manager
RISSB	Rail Industry Safety and Standards Board
RSNL	Rail Safety National Law
SC	Supply chain
T&L	Transport and Logistics
TAFE	Technical and Further Education
TfNSW	Transport for New South Wales
WA	Western Australia
UK	United Kingdom
US	United States

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Executive summary

The Australian rail industry is at a critical juncture on its journey towards decarbonisation. In the next eight to 13 years, about half of the industry's rollingstock is expected to be replaced. For this next generation of rollingstock to embrace low and zero emissions technologies, urgent action is needed to develop clear pathways for a decarbonised rail network.

This report seeks to identify the key challenges associated with decarbonising rail operations and provide government, industry and other stakeholders with a shared understanding of the actions needed to progress the decarbonisation of rail operations nationally, and the supply chain challenges and capabilities that will need to be addressed to support the transition.

The report was commissioned by the Australasian Railway Association (ARA), with GHD engaged to deliver a critical path for the decarbonisation of rollingstock in Australia, supported by a supply chain capability framework. The report was informed by desktop analysis, collaboration with the ARA Rollingstock Decarbonisation and Heavy Haul Decarbonisation Working Groups and engagement with key government and industry stakeholders.

It sets out the actions needed to support the availability, uptake and implementation of low and zero emission technologies to address traction emissions related to diesel-powered locomotives which continue to be used for regional passenger, freight and heavy haul rail operations. Building on the findings and recommendations of the report **Journey to Net Zero – Inspiring climate action in the Australian transport sector** published in 2022, this report provides an updated and more detailed analysis of the evolving policy and technology context and the challenges and opportunities related specifically to the decarbonisation of rollingstock.

Maximising rail's competitive advantage

Rail has an important role to play in helping to decarbonise transport given its ability to move people and freight in a less emissions intensive way compared to road transport. Rail freight generates 16 times less carbon pollution compared to road freight, and passenger rail generates 30 per cent less carbon pollution than road travel.

Direct rail emissions were estimated to be four million tonnes of carbon dioxide equivalent (MtCO2-e) in 2021, contributing just 4.5 per cent of transport emissions in Australia, with the freight task contributing 95 per cent of this figure. The RISSB National Carbon Footprint Study found that traction energy was the most significant emission source, contributing about 90 per cent of rail operational (scope 1 and 2) emissions, of which freight contributed around 70 per cent and passenger rail the remaining 30 per cent. Freight locomotive emissions are dominated by diesel use, whereas passenger rollingstock emissions are due largely to electricity use.

National and state net zero strategies and plans generally promote the use of low-emissions transport options, supported by renewable energy targets and strategies and funding for research and development. The role of rail to support the decarbonisation of the economy is generally acknowledged, but clear transition pathways are typically lacking.

This presents an opportunity to develop the ecosystem required to enable the rail industry to adopt alternative propulsion solutions when the fleet is up for renewal. However, this will require urgent, coordinated action in the short term to develop a strategy to support this.

Without this, the rail industry could miss out on the opportunities to decarbonise its rollingstock. This could impact the rail industry's competitiveness and potentially lock in higher emitting technologies which would diminish rail's emission advantage and make achieving net zero emissions by 2050 more difficult and costly.

Rollingstock Decarbonisation Critical Path – Key findings

A fragmented industry with several challenges and barriers

The Australian rail network comprises over 41,000km of track on standard, broad and narrow gauges. Except for a small number of private railways, most of the Australian railway network infrastructure is government owned, either at the federal or state level. This infrastructure is leased to Rail Infrastructure Managers (RIMs) that operate "below rail" operations. The eight RIMs are diverse in structure and operation. The locomotives and wagons that run along the rail networks are operated by "above-rail" operators, with most rail freight trips typically spanning several networks. In certain instances, the "below rail" and "above rail" operator are the same entity (e.g., Sydney Trains, V/Line).

Australia's railways have mostly developed as separate networks with tailored standards suitable for their circumstances. This is reflected in the different rail gauges in use across Australia, and there remain different standards for rollingstock and components, operating rules for rail infrastructure and for communications and control systems.

An estimated 2,600 diesel-powered locomotives continue to be used in Australia across regional passenger, freight and heavy haul rail operations. While road vehicles have a lifespan of approximately 10-15 years, rollingstock are generally in service for an average of 25-30 years, which means the rollingstock purchased today has the potential to still be in use in 2050. The average age of the fleet in Australia was estimated by BITRE (2022) to be 14 years or less in mid-2021, which indicates that half the fleet may need to be replaced in the next eight to 13 years. This highlights the need for urgent action to accelerate the transition to new technologies.

Real-world trials are an essential step in this transition process. Rollingstock decarbonisation trials underway within Australia are primarily focused on battery-electric locomotives (BELs), with investigations into dual-fuel ammonia-powered locomotives and renewable diesel applications also underway. Such trials primarily involve mining operations in Western Australia and a heavy haul operator in Queensland. There are currently limited renewable diesel trials and no planned trials involving hydrogen-electric locomotives.

In contrast to the domestic trials, many current international trials are noted to focus on the use of hydrogen electric locomotives (HELs) for passenger rail, with some planned for freight rail.

Although most low and zero emission rollingstock technologies are generally suitable within the broad category of rail tasks, the real-world feasibility of such technologies depends on the specific use case. Key considerations include operational requirements, technology readiness, and the costs to develop, test, gain approval, implement and operate the technology and the associated infrastructure. Rail operators will need to assess the specific performance requirements of their own operations to understand which technologies will be most relevant to them, and work with rail infrastructure managers and government to establish access to the required infrastructure.

Barriers to decarbonisation

// Regional passenger trains will be among those that need to transition to new technologies.

There are several challenges and potential barriers to overcome to support the decarbonisation of rollingstock in Australia:

- **The fragmented structure of the rail industry** means the benefits and costs of a harmonised approach to decarbonisation falls unevenly across industry players. This has led to a leadership vacuum and a lack of ownership of addressing decarbonisation, which could hinder industry collaboration on this issue.
- **Inconsistent approval processes between jurisdictions** increases the cost of designing, testing and training for new locomotives which could hinder the uptake of low and zero emission locomotives.
- **Barriers to co-investment** with the short-termism of state government budget allocation, individual private sector investments in trials, and the absence of co-developed R&D and decarbonisation strategies being potential contributors.
- **Procurement and local content policy variations** between the states that will increase the cost of low and zero emission technologies by limiting the market to individual states.
- The large proportion of **rail assets with long economic lives** (25-30 years) relative to other industries, which factors into the business case for investing in low and zero emission locomotives.
- **Low and zero emission locomotives are not yet commercially available** for a full phase out of diesel locomotives and the reliability of these technologies are still to be demonstrated in a commercialised form in Australia.
- **The lack of developed domestic hydrogen and renewable fuels markets**, with rail also expected to be in competition with other sectors seeking to secure supply. Performance constraints, storage and transport safety considerations as well as cost present challenges to the use of hydrogen-electric locomotives.
- **Existing infrastructure constraints** (e.g., overbridges, space limitations at depots) could increase the cost and complexity of implementing decarbonisation options.
- **Freight locomotives are increasingly designed by and sourced from overseas manufacturers** which could hinder the domestic supply chain's future ability to design and supply low and zero emission technologies.

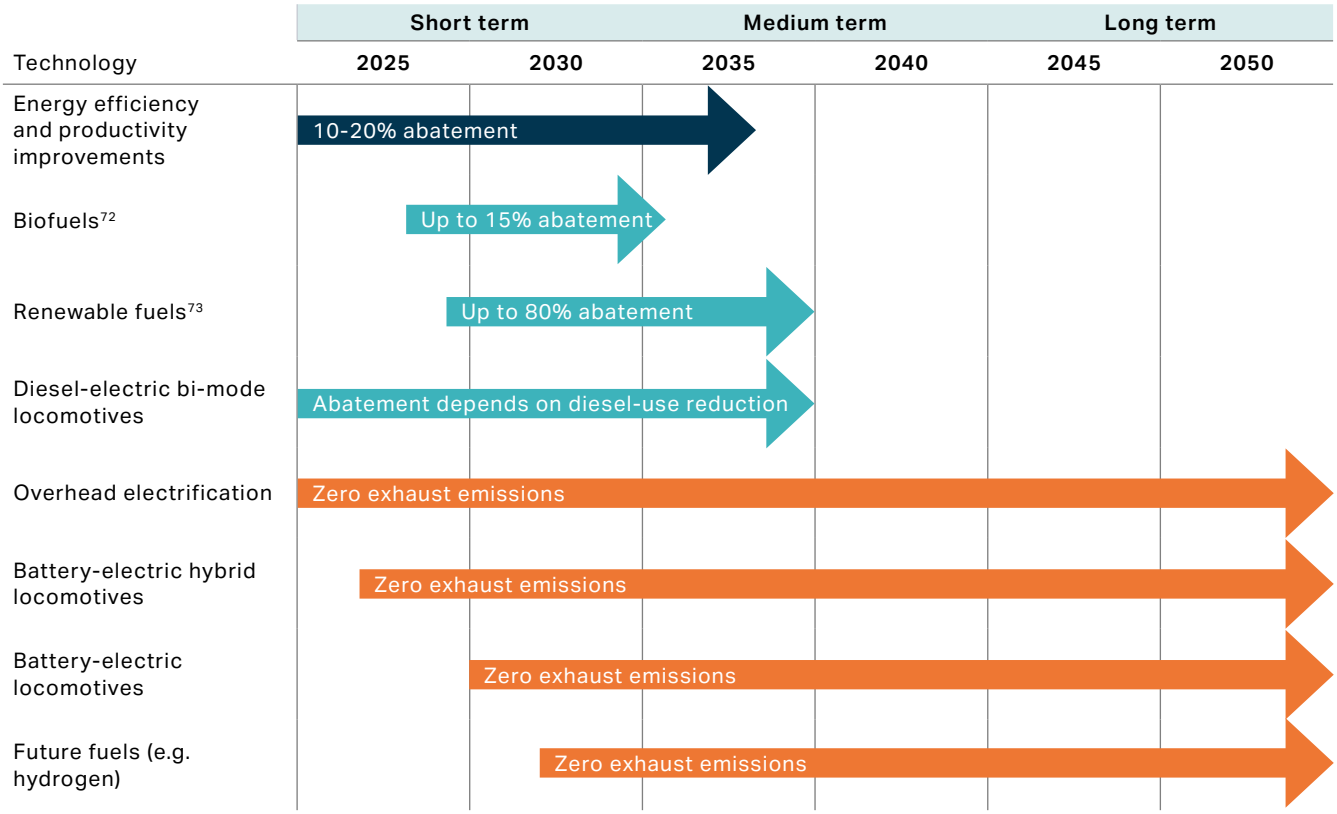
Given the unique characteristics of the local rail industry and the range of challenges and opportunities, a holistic and tailored plan is clearly needed to support the decarbonisation of rollingstock in Australia.

A phased transition to new technologies

Achieving interim emission reduction targets will require an operationally optimised mix of early emission reduction solutions (improved energy efficiency and transitional solutions such as biofuels). As the rail industry seeks to achieve net zero emissions, it will have to move past the limits of what low-carbon fuels and combustion engines can offer, and implement the widespread adoption of alternative propulsion technology:

- **Improved energy efficiency and productivity solutions**
  Energy efficiency and productivity improvements remain instrumental in contributing to emissions reductions in the near term and will continue to be important to ensure the efficiency and cost-effectiveness of rail.
- **Transitional solutions**
  Biofuels, renewable diesel and the use of bi-mode locomotives represent transitional solutions that can be increasingly deployed. This includes diesel-electric or battery-electric hybrid locomotives able to run on overhead power on electrified networks where available.
- **Alternative propulsion solutions**
  Electrification, along with battery, hydrogen and other zero emission alternative propulsion technologies, are emerging as a focus and long-term solution within rollingstock decarbonisation plans, both internationally and within Australia.

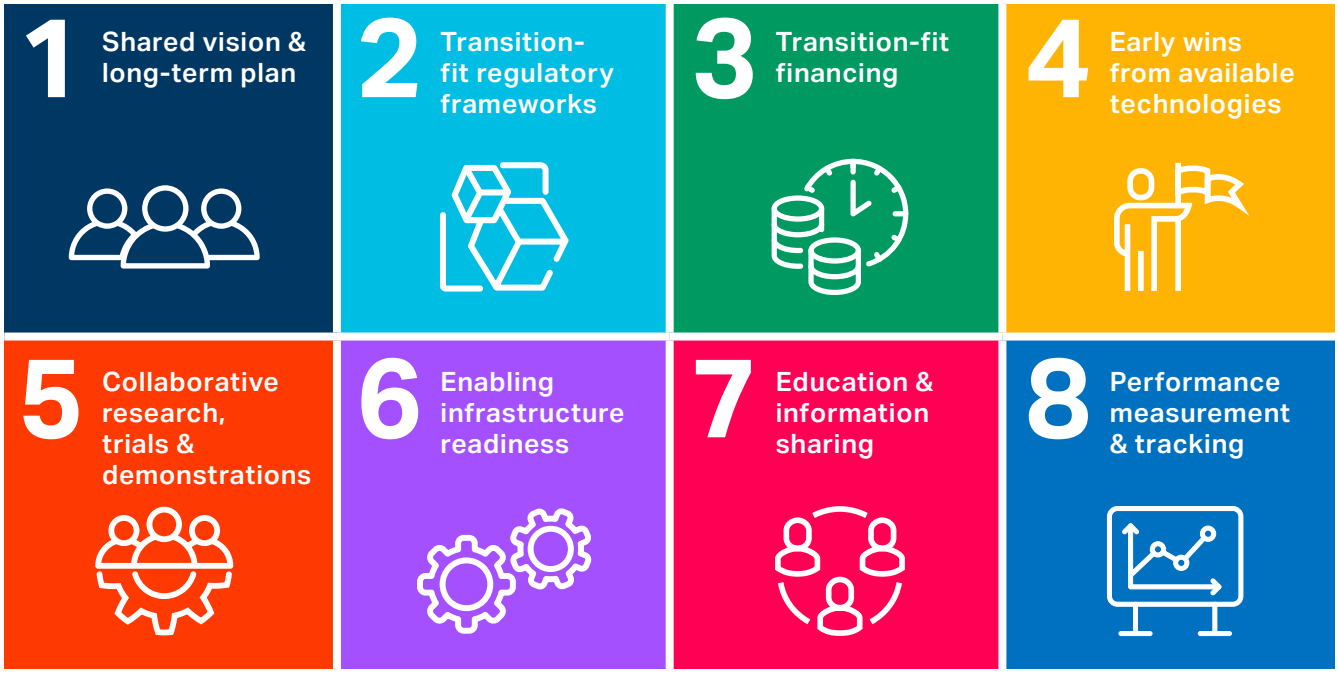
The industry's current understanding of the likely suitability and commercial availability of these low and zero emission solutions were used to develop a plausible pathway that outlines which technologies could be implemented when, as shown in the following graphic.



Most zero emission solutions are not expected to be commercially available until the medium term. This highlights the importance of transition fuels (e.g., biofuels, renewable diesel) for the rail industry to meet interim emission reduction targets. The unique structure of the Australian rail industry means that the deployed mix of low and zero emissions solutions will vary depending on specific use cases, leading to multiple possible technology pathways to decarbonise the rollingstock in Australia.

Rollingstock decarbonisation priorities

Based on challenges, opportunities and insights informed by the industry and the review of international best practice approaches, several priorities have been identified to help accelerate the journey towards rollingstock decarbonisation. Eight Critical Path (CP) priorities are recommended, with specific actions to address, as outlined in Table 1.



The average age of the Australian fleet indicates a significant renewal of rollingstock inventory over the next eight to 13 years, which suggests that a major procurement drive of alternative propulsion solutions will occur between 2030-2040. Therefore, early and coordinated action by industry and government will be needed by 2030 to support the transition and capture the emissions reductions and other benefits rail can provide. Hence, the actions outlined in Table 1 are to 2030 only.

Without early and coordinated actions to progress these priorities by 2030, the emissions advantage of rail could diminish, and Australia's efforts to achieve net zero emissions by 2050 will be negatively impacted.

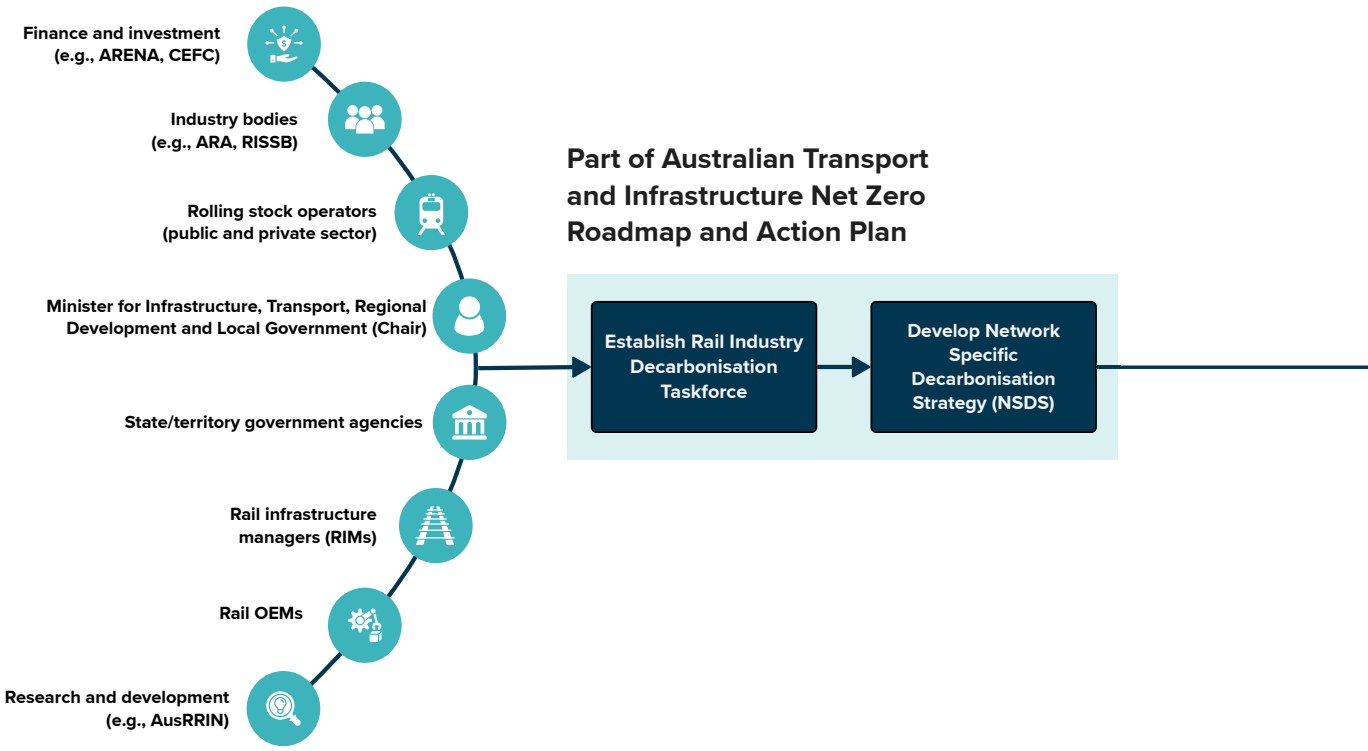
The effectiveness of these actions will rely on being undertaken in a coordinated, orderly and efficient manner. Therefore, developing a shared vision for the transition of the rail industry across industry and national and state/territory governments is a critical first step to guide these actions.

// Photo: Alstom. Hydrogen technology trials are prevalent overseas.

A shared, national approach is needed

A shared, national approach to decarbonising Australia's rollingstock is an urgent requirement to support the implementation of the critical path priorities. It is recommended that a **Network Specific Decarbonisation Strategy** be developed as part of the delivery of the Federal Government's *Transport and Infrastructure Net Zero Roadmap and Action Plan*. This strategy should seek to:

- Assess rail networks, tasks and rollingstock to inform access to electricity infrastructure and identify suitable locations for charging/refuelling facilities
- Consider both the preferred long-term solution and the most effective transitional arrangements (e.g. early introduction of bi-mode locomotives before transitioning to battery electric hybrid locomotives in the longer term), and
- Identify the preferred combinations of decarbonisation traction options across the national network to achieve the most cost-effective emissions reduction.



It is recommended that the strategy be developed by a **Rail Industry Decarbonisation Taskforce** that brings together a cross-section of senior stakeholders from across the rail industry and its supply chains to lead efforts to deliver net zero rail in Australia. It is recommended that the chair of the taskforce be the Minister for Infrastructure, Transport, Regional Development and Communities and the Arts, as they have the ultimate responsibility of delivering the Federal Government's Transport and Infrastructure Net Zero Roadmap and Action Plan. The remaining members of the taskforce should, at a minimum, include representatives from the following areas:

- State/territory government agencies
- Rollingstock operators
- Rail infrastructure managers
- Rail OEMs
- Research and development (e.g., AusRRIN)
- Industry bodies (e.g., ARA, RISSB)
- Finance and investment (e.g., ARENA, CEFC)

It is recommended that the development of the strategy be included as a priority focus as part of the *Infrastructure Transport Ministers Meeting (ITMM)* decarbonisation workstream. The strategy will help inform a number of additional actions to support the industry's decarbonisation pathway.

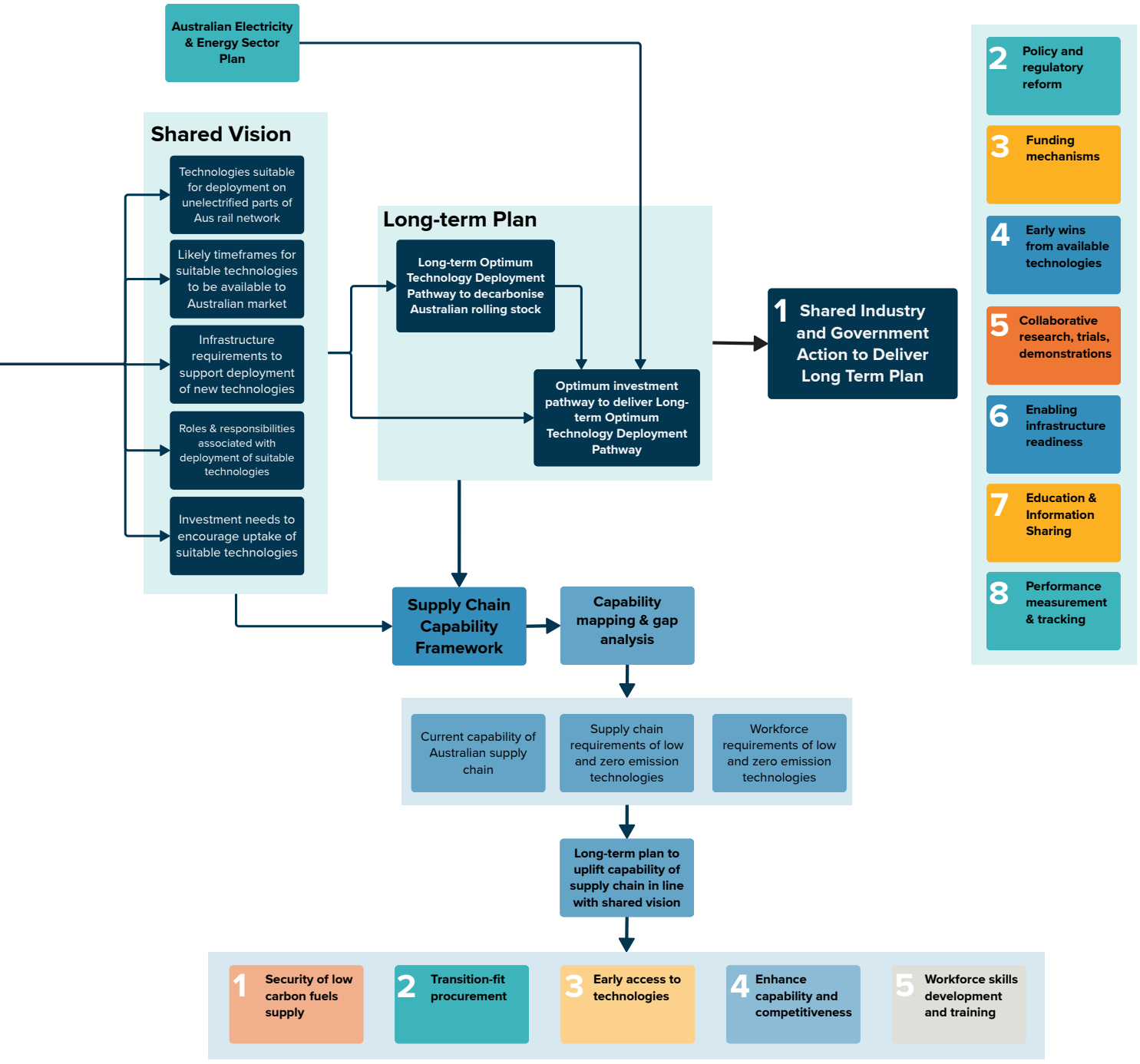


Table 1 - Critical path priorities and actions

The actions are assigned to either the Federal Government, state and territory governments or industry (including operators, manufacturers, industry bodies) as the stakeholder recommended to lead this action. Although these stakeholders have been identified as the lead, most actions will require collaboration, coordination and engagement across government and industry as described in the report.

Priorities	2024-2025
1 **Shared vision and long-term plan:** Establish a shared vision across government and industry of rollingstock decarbonisation and set out a long-term plan for the transition	Develop a shared national vision for rollingstock decarbonisation through the creation of a national Network Specific Decarbonisation Strategy, to support a long-term plan and suitable targets for the transition of the rail industry. The strategy should be developed by a newly created Rail Industry Decarbonisation Taskforce and include clear roles and responsibilities, for the decarbonisation of the Australian rollingstock Seek and secure stakeholder support for rollingstock decarbonisation efforts
2 **Transition-fit regulatory frameworks:** Ensure policy and regulatory frameworks are fit for purpose to support the transition	RISSB to address rollingstock decarbonisation when harmonising existing standards for rollingstock manufacturing
3 **Transition-fit financing:** Secure and coordinate public and private sector investment to finance the transition	Government sector decarbonisation plans consider internationalisation of externalities associated with decarbonising the rollingstock Rail operators should investigate business strategies, carbon markets and cost-recovery opportunities to improve the financial feasibility of low emission technologies
4 **Early wins from available technologies:** Leverage available technologies to achieve early emission reductions	Continue to improve productivity and energy efficiency of existing locomotives and benchmark against best practice

Federal Government · State governments · Industry · \ Engagement · / Lead

2025-2026	2026-2027	By 2030
Ensure government sector decarbonisation plans address the priority actions needed and the financial instruments to support it, including incentives and technology support programs		Review and revise the long-term plan for rollingstock decarbonisation
Review and revise government procurement processes to ensure early and ongoing access to low/zero emission technologies RISSB to proactively develop national standards for new technologies and enabling infrastructure	Review impact of Safeguard Mechanism Reforms on rollingstock operator's decarbonisation plans	Streamline rollingstock approvals to encourage easier adoption of new rollingstock Conduct a review to determine whether further regulatory reform is required to accelerate the transition
Targeted funding for research to accelerate the technology and commercial readiness of low and zero emission rollingstock and assess their system-level impacts Targeted funding for improving the scalability and implementation of low and zero emission rollingstock Existing government investments in electricity and rail infrastructure should be informed by the national Network Specific Decarbonisation Strategy and seek co-investment opportunities to fill funding gaps		Commission an independent review to assess the efficiency, equity and cost-effectiveness of mechanisms being used to finance and incentivise the transition
Review government service level agreements to optimise freight productivity	Consider available technologies such as bi-mode locomotives and retrofit opportunities to support early progress	

5

Research, trials and demonstrations:

Collaboratively research, develop, trial and demonstrate low and zero emission technologies for Australian rail

6

Enabling infrastructure:

Assess, develop and ensure access to appropriate rail and energy infrastructure to support the transition

7

Education and information sharing:

Support technology assessments and decision making through information sharing

Share information on proof of concept trials and results of research into rollingstock decarbonisation technologies and measures

8

Performance measurement:

Establish evidence-based performance measurement to track progress being made and support forward planning

Partner with the research sector to deliver system-wide solutions to decarbonising the rollingstock to determine their suitability for real world applications in Australia		
Investigate and invest in self-generation and storage to reduce dependence on grid electricity, so reducing exposure to risk and price volatility		Develop a national approach for cross-border trials and joint investments in charging or refuelling infrastructure across the rail freight network Assess and support rail track upgrades that may be required to improve rail productivity and support new technologies Expand access to electricity infrastructure to support rail decarbonisation
Establish sharing and publication of freight task and rollingstock data to support data-driven decarbonisation planning and performance tracking	Establish key performance indicators (KPIs) and track progress being made to transition the rail industry	Review suitability of data and key performance indicators (KPIs) used to track progress being made to transition the rail industry

Supply chain capability framework – Key findings

Supply chain priorities

Our analysis for the rollingstock decarbonisation critical path demonstrated that technology alone is insufficient to decarbonise the rollingstock. Innovation, manufacturing, maintenance, skills or workforce constraints could negatively impact the availability and successful implementation of low and zero emission technologies by the rail industry.

The capacity of local manufacturers to support low and zero emission technologies in the future is a necessary consideration to support the rail industry's decarbonisation efforts in a competitive global landscape. With new technologies to be in high demand around the world, Australia's ability to develop local capability to build, maintain and operate low and zero emissions rollingstock will be key to our success.

Industry and government will need to work together to ensure there is adequate domestic capability to support the transition to emerging low and zero emission technologies and improve the competitiveness of the Australian rollingstock supply chain. This report has identified six Supply Chain (SC) Priorities to expand domestic supply chain capability, with specific actions to address outlined in Table 2.

The actions outlined are till 2030 to align with the rollingstock decarbonisation critical path. This is because the supply chain is a crucial component of the ecosystem that needs to be developed by 2030 to enable the decarbonisation of the rollingstock.

The effectiveness of the actions requires a robust understanding of the current capability of the Australian supply chain to meet future demand for emerging low and zero emission technologies in line with the shared vision for decarbonisation. Therefore, developing a **supply chain capability gap analysis** is a critical first step to developing a long-term plan that will guide these actions.

Table 2 – Supply chain capability framework priorities and actions

The actions are assigned to either the Federal Government, state and territory governments or industry (including operators, manufacturers, industry bodies) as the key stakeholder groups recommended to lead this action. Although these stakeholders have been identified as the lead, most actions will require collaboration, coordination and engagement across government and industry as described in the report.

Priorities	2024-2025
1 **Supply chain capability assessment and planning:** Understanding the current capability of the supply chain to support the development and access to low and zero emission technologies	Conduct a supply chain capability gap analysis and develop a plan to uplift capabilities focusing on low and zero emission technology ecosystems
2 **Low carbon fuels:** Actions to develop and support the domestic markets for low carbon fuels	Develop pilot projects to produce low and zero emission fuels for use in rollingstock operations
3 **Procurement mapping and coordination:** Greater coordination of public and private sector procurement to reduce costs of low and zero emission technologies and foster market for local manufacturing	
4 **Early access to alternative propulsion technologies:** Collaboration with domestic and international partners to uplift local capability to design and manufacture low and zero emission technologies	
5 **Enhance the capability and competitiveness of Australian rollingstock manufacturers and maintenance sector:** Assess opportunities and develop actions to capitalise on opportunities in the transition to improve the capability and competitiveness of the Australian rollingstock manufacturers and maintenance sectors	
6 **Skills development and workforce training:** Supporting training and skills development to develop future workforce required for the transition to low and zero emission technologies	

Federal Government | State governments | Industry | \ Engagement | / Lead

2025-2026	2026-2027	By 2030
/ ● Support industry to accelerate the commercial feasibility and support supply chains for low carbon fuels to address short-term decarbonisation effort ● / ● Work to secure supporting low-carbon and renewable fuel supply, e.g. biofuels, renewable diesel		● / ● Facilitate cross-sector coordination of hydrogen demand and supply
● / Coordinate government procurement processes across states to provide scale for growing local manufacturing for alternative power drives and fuels		/ Establish industry solutions and coordinate to ensure access to cost-effective low and zero emission technologies
● / ● Collaborate with local rollingstock decarbonisation manufacturers to develop low and zero emission technologies		● ● / Partner with international technology providers for early access to technologies
/ ● Provide greater certainty on future demand for specific low emission technologies / Define the scope of influence within the domestic supply chain	● / ● Identify key opportunities for Australian rail manufacturing in the global supply chain ● / ● Develop domestic manufacturing and OEM ecosystems for alternative power drives and fuels ● / ● Facilitate financing and investment in local rollingstock manufacturing R&D	
● / ● Collaborate to identify and address skill and workforce gaps / Develop programs to establish, retain and attract workforce	/ ● Provide funding to strengthen training and education programmes to close skill and workforce gaps	

// Regional passenger trains will be among those that need to transition to new technologies.

Contents

Introduction

National, state and territory governments in Australia have committed to net zero emissions by 2050 or earlier, which reflects a shared vision of transitioning towards a low-carbon economy.

Australia has legislated targets to achieve net zero emissions by 2050 and to reduce greenhouse gas emissions by 43 per cent below 2005 levels by 2030. Interim targets vary widely between states and territories with the trend towards legislated targets and the ratcheting up of ambition. Meeting these targets will require economy-wide decarbonisation, including the timely transition of the transport sector with continued economic and population growth driving increases in passenger and freight activity in Australia[1].

Under market trends and supported by government policy, Australia is experiencing a rapid increase in the uptake of battery electric light duty road vehicles. Land transport technology solutions, government policy and industry business models are still evolving to support the availability and uptake of low and zero emission technologies for road and rail freight. Road transport is currently a focus for governments' decarbonisation policies and actions in Australia, as it accounts for 85 per cent of transport sector emissions[2], with this share set to grow to meet the increase in freight task (26 per cent)[3] and population growth (48 per cent) between 2020 and 2050[4].

Even if this increase in road modal share is coupled with the decarbonisation of the road fleet, the growth in road vehicle activity will increase congestion, the likelihood of road accidents, and air pollution from brake and tyre wear[5]. The combination of these factors will significantly impact freight productivity and the effectiveness of national supply chains. In contrast, rail's ability to move more people and freight in a safer, more efficient and less emissions intensive way can meet the growing freight and passenger task whilst also supporting net zero objectives, realising co-benefits (e.g., health benefits from reduction in accidents and air pollution) and improving supply chain effectiveness. Expanded passenger and freight rail also has a role to play in facilitating a greener supply chain for customers and consumers. Policy objectives and strategies to improve rail mode share are addressed in **The Future of Freight** report published in October 2023 by the ARA and the Freight on Rail Group.

Achieving net zero emissions will require holistic policies, including the shift of transport tasks to energy efficient and lower emission intensity modes like rail, and a focus on transitioning both road and rail transport to zero emission technologies. Rail traction is the single biggest source of greenhouse gas emissions in the rail industry. While passenger rail has made substantial progress in electrifying services, diesel-powered locomotives continue to be used for regional passenger rail and remain the dominant motive power for the freight fleet in Australia. Without early and coordinated actions to decarbonise passenger and freight rollingstock, the emissions advantage of rail could diminish, and Australia's efforts to achieve net zero emissions by 2050 will be negatively impacted.

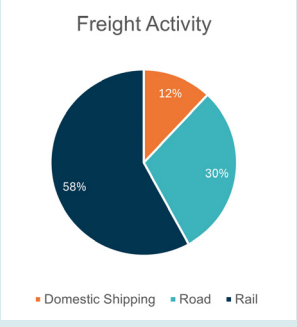
This report considers the current landscape the rail industry operates within and focuses on measures needed to increase the availability and uptake of low and zero emission technologies by the rail industry to address traction related emissions. Locomotives are long-lasting capital assets, and delays to fleet transition will hinder the rail industry's ability to contribute to and benefit from the net-zero emissions economy.

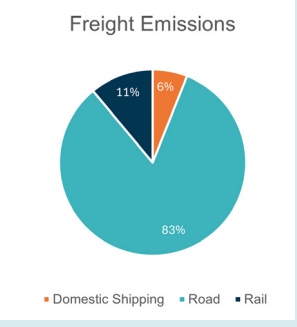
A critical path setting out a coordinated set of policy, regulatory, investment, technology uptake, supply chain and workforce actions by government and industry is required to guide the decarbonisation of Australia's rollingstock with a focus on diesel-powered locomotives that continue to be used for regional passenger, freight and heavy haul rail.

Box 1. Rail has an important role to play in helping decarbonise the transport sector

Rail freight services generate 16 times less greenhouse gas emissions than road freight and delivers improved safety outcomes across the freight network[74 75].

Rail emissions were estimated to contribute 11 per cent of freight emissions nationally in 2021-22, despite transporting 58 per cent of all freight in this year[76].





Purpose, scope and approach

This report was commissioned by the ARA, with GHD engaged to work with the association and its RollingStock Decarbonisation Working Group and Heavy Haul Decarbonisation Working Group to deliver a critical path for the decarbonisation of rollingstock in Australia, supported by a supply chain capability framework.

Purpose

The purpose of this report is to provide government, industry and other stakeholders with a shared understanding of the actions needed to progress the decarbonisation of rail operations, and the complexities or challenges that will need to be addressed to support the transition to net-zero.

The rollingstock decarbonisation critical path sets out process, policy and investment considerations, and clear steps to be progressed by industry and government. The critical path is intended to identify plausible pathways to support the national 2030 and 2050 net-zero targets through rollingstock decarbonisation. The supply chain capability framework provides recommendations on how we upskill and ensure we have local capability to support the transition to alternative energy and low emission technologies.

Scope

The study addressed the decarbonisation of rollingstock fleets in Australia, taking into consideration, but not addressing, the broader decarbonisation of the rail sector. Freight, heavy haul and unelectrified passenger networks (primarily regional) were in scope, and specifically operational emissions associated with the use of diesel-powered rollingstock in Australia. While reductions in the carbon intensity of the electricity grid will support the decarbonisation of electrified rail, the study also identified opportunities for energy efficiency improvements. The focus was on the pace of change required to meet 2030 and 2050 targets, and opportunities and challenges the industry may face over this period.

The following was out of scope for the study:

- Emission sources and mitigations within the rail sector unrelated to rollingstock operations;
- Embodied carbon emissions within rollingstock and related rail infrastructure;
- Surveys to collect data from primary sources to support the compilation of a complete rollingstock inventory; Information was however collated from published studies and public sources to identify the number of diesel-powered locomotives in use in Australia and estimate the asset age profile of these assets;
- Modelling of business-as-usual emissions and projection of emission reductions for critical pathways. Reference was instead made to rail emissions from previous, published studies to inform the study;
- Techno-economic assessments of technology solutions and development of marginal abatement cost curves;

Measures to improve mode share. Policy objectives and strategies to improve rail mode share were addressed in **The Future of Freight** report published in October 2023.

Approach

The study comprised desktop analysis, engagement with the ARA and its working groups and consultation with government stakeholders as outlined below.

Desktop analysis and discussion paper preparation	Workshops and stakeholder engagement	Critical path report preparation and publication
• Collated information on rollingstock decarbonisation trials and technologies and did an initial assessment of the likely suitability of technologies. • Considered the policy, investment, skill and supply chaim implications of potential technologiy solutions. • Used information from published studies to estimate the number of diesel-powered locomotives in use. • Identified key opportunities and challenges the rail industry may face and considered learning from overseas rollingstock decarbonisation strategies. • Synthesised finding in a Discussion Paper to support workshops with ARA working groups and engagement with key stakeholders.	• Held workshops with ARA Rollingstock Decarbonisation and Heavy Haul Decarbonisation working groups to discuss challenges and opportunities related to rollingstock decarbonisation and supply chain capability in Australia. • Surveyed working group members on the importance of specific policies and actions to support rollingstock decarbonisation and supply chain capability. • Engaged with key government and other industry (not represented on ARA working groups (to identify related initiatives and collaboration opportunities. • Captured advice from the working group workshops and stakeholder engagement sessions to inform the drafting of a critical path report.	• Integrated information and advice from the workshop and stakeholder engagement sessions to draft the Rollingstock Decarbonisation Critical Path report, including a Supply Chain Capability Framework. • Circulated the draft Critical Path report to ARA working groups for feedback and advice. Held a workshop with working group members to support deliberations. • Integrated feedback to prepare the final draft Critical Path Report and circulated this to the ARA Rollingstock Decarbonisation and Heavy Haul Decarbonisation working groups for final comments. • Addressed final feedback and prepared the final Rollingstock Decarbonisation Critical Path Report.

Current landscape

Rail operations and rollingstock

The Australian rail network comprises over 41,000km of track on standard, broad and narrow gauges. Except for a small number of private railways, most of the Australian railway network infrastructure is government owned, either at the federal or state level. This infrastructure is leased to Rail Infrastructure Managers (RIMs) that operate "below rail" operations. The eight RIMs in Australia are diverse in structure and operation. The locomotives and wagons that run along the rail networks are operated by "above-rail" operators. There are 15 passenger and 18 freight operators that are responsible for most services across Australia. Most rail freight trips do not occur on a single network but typically span several networks.

An estimated 2,600 diesel-powered locomotives are operating in Australia. Whereas the passenger rail task is largely electrified, Australia's freight rail task is predominantly diesel[6]. The average economic life of rollingstock is estimated to be between 25 to 30 years[7]. The average age of the locomotive fleet in Australia was estimated by BITRE (2022) to be 14 years or less in mid-2021, with almost 60 per cent of locomotives being less than 20 years old. This indicates that half the fleet may need to be replaced in the next eight to 13 years.

This presents an opportunity to develop the ecosystem required to enable the rail industry to adopt alternative propulsion solutions when the fleet is up for renewal. However, this will require urgent, coordinated action in the short term to develop a strategy to support this.

Australian rail operations and emissions

41,461 kilometres of track in Australia on three gauges: **standard**, **broad**, and **narrow** gauge

50 above rail operators

8 below rail operators

58% of total freight task in 2021

4% of total passenger task in 2021

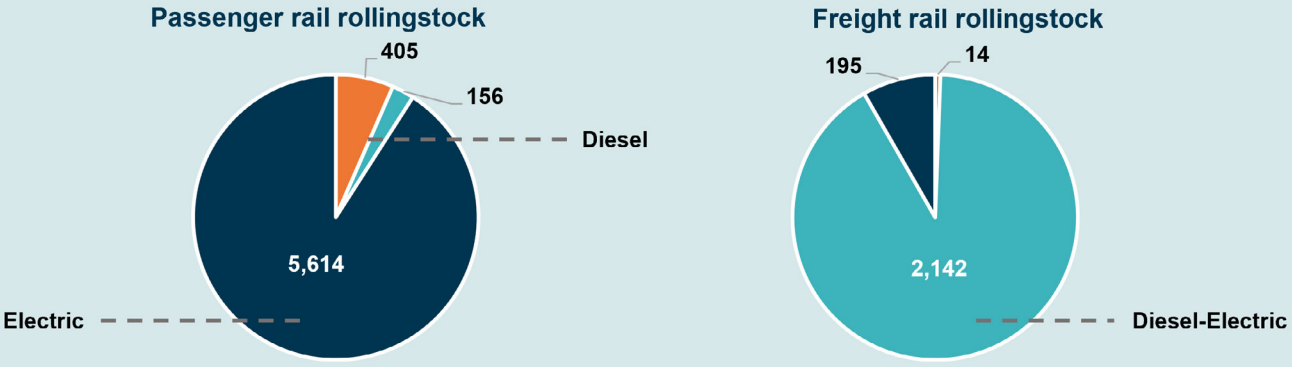
4.1 **$MtCO_2e$ rail emissions** in 2021

95% of 2021 scope 1 rail emissions are from diesel **freight** locomotives

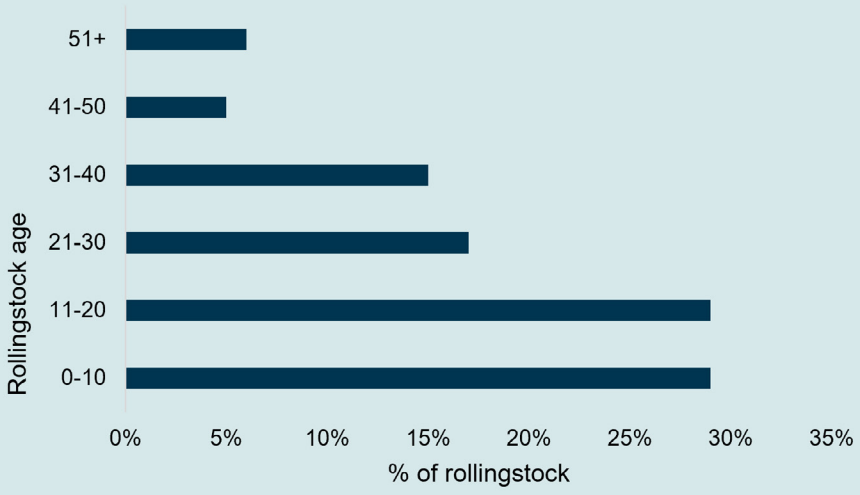
27% reduction in rail emissions forecasted between 2021 and 2035 due to reduction in rail task and Safeguard Mechanism reforms.

Australian rollingstock

There are an estimated **2,600** diesel-powered rollingstock in Australia currently, with the majority of these covering the Australian freight rail task.



The average age of the locomotive fleet was estimated to be **14 years or less** in mid-2021 (BITRE, 2022), with almost 60% of locomotives being less than 20 years old.



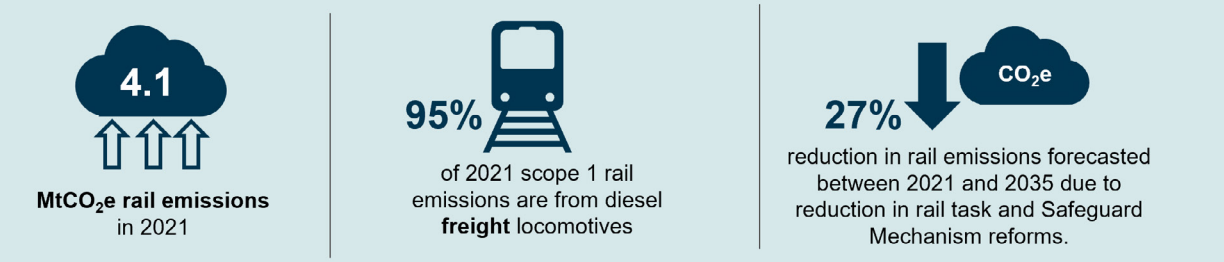
National rail emissions outlook

Direct (scope 1) rail emissions were estimated to be 4 million tonnes of carbon dioxide equivalent ($MtCO_2$-e) in 2021, contributing 4.5 per cent of transport emissions in Australia[8].

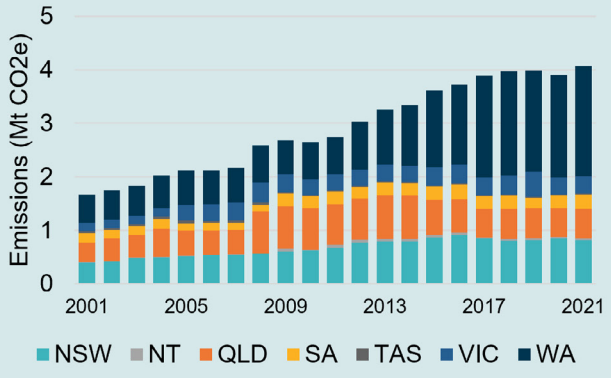
The freight task contributes about 95 per cent of scope 1 rail emissions and largely accounts for rail emissions having more than doubled over the past 20 years as the national freight task has grown. Freight and heavy haul rail operations in Western Australia were responsible for much of the6 growth in emissions over the past decade, with Western Australia's rail emissions comprising about half of national railway emissions in 2021.[9]

Rail emissions are estimated to have peaked in 2023 and are projected to reduce to about 3 $MtCO_2$-e by 2035. This is based on BITRE's central forecast that there will be lower rail freight growth due to slower project growth in iron ore and coal exports, combined with anticipated emissions reductions achieved under the Safeguard Mechanism reform.[9,1] Commodity forecasts informing BITRE's freight task projections are however uncertain, particularly in later years, with a potential growth in rail emissions under higher commodity growth scenarios. BITRE's freight task projections also do not consider the potential impact of mode shift of freight task from road to rail to meet growing freight demand for non-bulk commodities.

Australian rail emission outlook

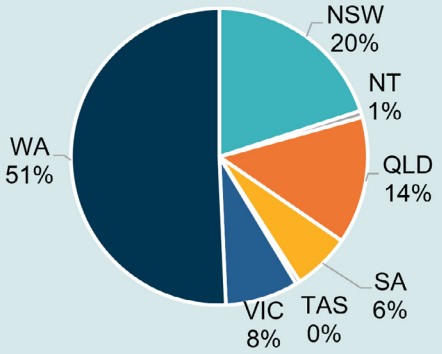


Rail emissions by state and territory



Rail emissions by state and territory (2001-2021)

Rail emissions by state in 2021



Contribution of state and territory rail emissions to national rail emissions in 2021

1 Emissions from rail operations are addressed under the National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015 for industries emitting more than 100,000 tonnes CO2-e per year. The emissions baselines of Safeguard facilities are expected to decline on a trajectory consistent with achieving Australia's emission reduction targets of 43% below 2005 levels by 2030 and net zero by 2050.

The RISSB National Rail Carbon Footprint Study provides additional information on greenhouse gas emissions from the Australian national rail network including indirect (scope 2) emissions from electricity use. The rail industry's scope 1 and 2 emissions were estimated to be 6.9 MtCO2-e in 2021-22. Traction energy was found to be the most significant emission source, contributing about 90 per cent of rail operational (scope 1 + scope 2) emissions, of which freight contributed about 70 per cent and passenger rail the remaining 30 per cent. Freight locomotive emissions are dominated by diesel use (scope 1 emissions, 90 per cent), whereas passenger rollingstock emissions are due largely to electricity use.

Despite rail's disproportionately small contribution to national transport emissions when compared to the volume of the country's freight and passenger traffic rail facilitates, RISSB raised concerns over the rail industry's competitiveness in the absence of decarbonisation.[5]

Rail manufacturing and operation supply chain

Australia used to manufacture a lot of rollingstock domestically pre-2000[9]. Over recent decades, rail freight transport buyers have increasingly imported rollingstock and components from overseas manufacturers. In recent years, Australia is estimated to have exported about $60 million worth of rollingstock and components while importing around $1.4 billion worth each year, with the domestic manufacturing demand primarily driven by public capital expenditure[10]. As a result, local railway equipment manufacturers are focusing on long-term maintenance and repair contracts, and on the manufacturing of high-value and niche railway equipment to remain competitive. Some large-scale manufacturers have also moved their manufacturing operations overseas to improve production capacities and competitiveness, although regulatory and policy changes have offset these offshoring trends to some extent.

The rail rollingstock manufacturing and repair industry currently employs over 7,000[11] people and was estimated to have contributed $515 million to the Australian economy in 2019[12]. Local manufacturers benefit the economy through more labour opportunities and greater contribution to the GDP. For every $1 million spent by the rollingstock manufacturing and repair industry, about 1.32 jobs are created, including direct and indirect roles[15]. The rail rollingstock manufacturing and repair industry spends five times more on intermediate inputs than wages, which boosts employment especially for labour intensive industries such as iron and steel manufacturing. This demonstrates that the domestic rail rollingstock manufacturing industry can play a significant role in boosting activity across the supply chain.

The capacity of local manufacturers to support low and zero emission technologies into the future is therefore a necessary consideration. Any innovation, skill or workforce constraints impacting local industry will negatively impact the availability of such technologies.

Evolving policy context

The **Journey to Net Zero – Inspiring climate action in the Australian transport sector** report published in 2022 provided an overview of the broader policy context and drivers for change. It addressed policy trends towards sustainable transport, resource efficiency and the need for a circular economy, the shift towards electrification, investment in sustainably produced biofuels and the development of a zero-emissions hydrogen industry. This section provides an update to that report, with a more detailed consideration of the evolving rail and net zero emission policy contexts with specific implications for the decarbonisation of rollingstock.

Australia's railways have mostly developed as separate networks with tailored standards suitable for their circumstances. This is reflected in the different rail gauges in use across Australia, and there remain different standards for rollingstock and components, operating rules for rail infrastructure and for communications and control systems. Parts of the rail industry are vertically separated[2], with below-rail operators (managing the track and infrastructure) distinguished from above-rail operators (responsible for trains and rollingstock).

Harmonisation of rail-related standards and requirements, and removal of red tape, may support increased investment, economies of scale, reduced cost, minimised risk and improved reliability, safety and interoperability. Challenges to be addressed and efforts to improve national consistency, efficiency and reduce regulatory burden are therefore relevant when considering pathways to rollingstock decarbonisation.

There are increasing efforts to improve national consistency, efficiency and reduce regulatory burden in the rail industry where standards, operating procedures and procurement approaches differ between states and amongst rail infrastructure managers (Box 2).

2 Except for metro systems which are integrated.

Box 2. National rail strategies and policy reviews

Significant policy developments are already underway to address challenges within the rail industry and improve rail's potential contribution to the national freight task.

The **National Freight and Supply Chain Strategy** (NFSCS)[13] provides a framework to improve freight system performance across all states, networks and modes. This 20-year strategy, agreed with industry in 2019, commits all Australian governments to action, with a national vision for freight systems and domestic and international supply chains to contribute to a strong and prosperous Australia to 2040 and beyond. The strategy's goals are to be achieved by taking national action through five-year action plans.

The first five-year **National Rail Action Plan** (NRAP)[14] was agreed by Infrastructure and Transport Ministers in November 2019 and is led by the National Transport Commission (NTC). The Plan seeks to adopt a collaborative approach between government and industry to identify opportunities to improve the efficiency and safety of Australia's rail system by continuing to align or harmonise standards and systems in infrastructure, rollingstock, control and communication systems; and to meet the rail sector's critical skills and labour needs.

This National Rail Action Plan identified a lack of national standards as a key challenge for the Australian rail sector and the need for a harmonisation plan, and economic and financial analysis to help inform priorities. The RISSB three-year Harmonisation Plan aims to reduce inefficiencies caused by inconsistent practices around the country, increase safety and stimulate local manufacturing capabilities for railway parts needed in high volumes. A National Rollingstock Register is also being built to help reduce the administrative burden on industry, improve safety on the network and support harmonisation efforts.

The **National Rail Manufacturing Plan**[15] published in November 2023 aims to achieve a nationally coordinated approach to government procurement and investment, and to ensure a more efficient domestic supply chain selling to local and export markets. The plan seeks to promote Australia as a leader in research, design, innovation and adoption, and to ensure a highly skilled, diverse workforce. Phase 1 of the plan included the delivery of the National Rail Procurement and Manufacturing Strategy and the completion of a national scan of passenger rail procurements. Phase 2 being undertaken in 2024 focuses on identifying opportunities for Australian manufacturing in the global supply chain, with Phase 3 to develop domestic capability in priority growth areas being initiated in Q3 2024.

Commitments already delivered under Phase 1 of the National Rail Manufacturing Plan have included establishing the Office of National Rail Industry Coordination (ONRIC), and the appointment of a National Rail Manufacturing Advocate and Rail Industry Innovation Council. ONRIC worked with industry, state and territory governments, unions and the research community to develop the **National Rail Procurement and Manufacturing Strategy**[16] published in November 2023. This strategy outlines how the Australian Government will work with stakeholders to:

Develop a more collaborative approach to procuring rollingstock – locomotives, carriages, wagons, trams, light rail vehicles and their associated components and systems, and

Help grow a more globally competitive rail manufacturing sector

The National Rail Procurement and Manufacturing Strategy sets out six pillars of work:

Pillar 1 – Develop a nationally coordinated approach to rollingstock procurement
Pillar 2 – Harmonise standards for manufacturing rollingstock
Pillar 3 – Adopt a national local content approach
Pillar 4 – Maximise opportunities for freight and heavy haul manufacturing
Pillar 5 – Improve research and innovation outcomes in the rail sector
Pillar 6 – Establish the foundation for good jobs and rewarding careers in rail manufacturing

The first five-year review of the **National Freight and Supply Chain Strategy**[17] is being conducted by the Federal Government in collaboration with state and territory governments and including partnerships with industry to draw on expert knowledge. The review seeks to assess and address potential gaps in the strategy's goals to ensure it remains relevant. Decarbonisation and supply chain resilience are anticipated to be addressed in the next five-year National Action Plan. The updated strategy and next five-year National Action Plan are anticipated to be completed by mid-2024.

An independent review of the **Rail Safety National Law (RSNL)**[18] is underway with review outcomes to be presented to Australia's transport ministers in mid-2024. Although this law seeks to ensure a coordinated national approach to rail safety regulation in Australia, and all state and territory jurisdictions have adopted (or mirrored) the RSNL, several derogations remain which continue to inhibit national consistency, efficiency and efforts to reduce regulatory burden.

Other developments include:

- The Commonwealth has committed $540 million in the Federal Budget 2024-25 to improve the resilience and reliability of 8,500km of the national rail network, with an additional $500 million committed by ARTC[19].
- The establishment of the Inland Rail Project that will connect Melbourne and Brisbane, increasing rail's ability to meeting growing freight demands, whilst also removing up to 10,000 trucks off the road which will reduce emissions, improve congestion and reduce air pollution[20].
- In addition to Inland Rail, the Federal Government has committed to funding the Inland Rail Interface Improvement Project which aims to improve travel times along the route and increase axle load. It has also committed to funding business cases to consider the development plans and needs for Inland Rail-related intermodal terminals in Melbourne and Brisbane.
- BITRE is leading a review into the resilience of Australian rail and road supply chains which aims to identify and analyse Australia's critical road and rail freight routes, the risks they face, including identifying current resilience initiatives which are addressing these risks. This work will help to inform action by government on how to mitigate risks in supply chains.[21]
- Establishment of the National Freight Data Hub[22] which provides access to publicly available datasets, maps and graphs to explore trends and patterns in existing freight data. This will support evidence-based policy, improve transparency, and provide a platform for innovation.

Australian and state/territory net zero policies and initiatives with implications for rollingstock decarbonisation include:

- Net zero emissions targets, policies, strategies and funding;
- Transport decarbonisation strategies and plans;
- Electricity and renewable energy strategies;
- Hydrogen supply chain strategies and hydrogen hub plans;
- Research and development strategies and funding for low-carbon technologies.

Recent policy developments and announcements demonstrate an increased emphasis on transport sector emissions more generally and include some efforts to reduce rail emissions and promote a shift from road freight to rail (Box 3).

National and state net zero strategies and plans generally promote the use of low-emissions transport options, supported by renewable energy targets and strategies and funding for research and development. Accelerating the uptake of cleaner technologies within road transport is frequently prioritised due to the large contribution of emissions from this mode. Programs to promote the uptake of battery electric vehicles in the light vehicle fleet are a particular focus due to comparatively greater maturity and lower cost.

Electrification, battery electrification and alternative fuels including hydrogen are a focus more broadly to support economy-wide decarbonisation. Regional (place-based) strategies are increasingly being adopted to support focused planning and funding for clean technologies to support cross-sector decarbonisation (e.g. hydrogen hubs, renewable energy zones, special activation precincts). There is a growing recognition of the need for knowledge-sharing and innovation, supported by public/private partnerships and investment, to accelerate the readiness of such low-emission technologies for application in Australia.

The potential of leveraging clean technology to power rail systems is recognised in some government net zero strategies, including electrification, use of synthetic fuels and uptake of battery electric and hydrogen fuel cell technologies. Electrification of passenger rail in areas with access to suitable grid electricity transmission infrastructure is often a focus for state/territory governments and urban passenger rail operators, with the decarbonisation of the grid supporting lower scope 2 emissions from electrified rail.

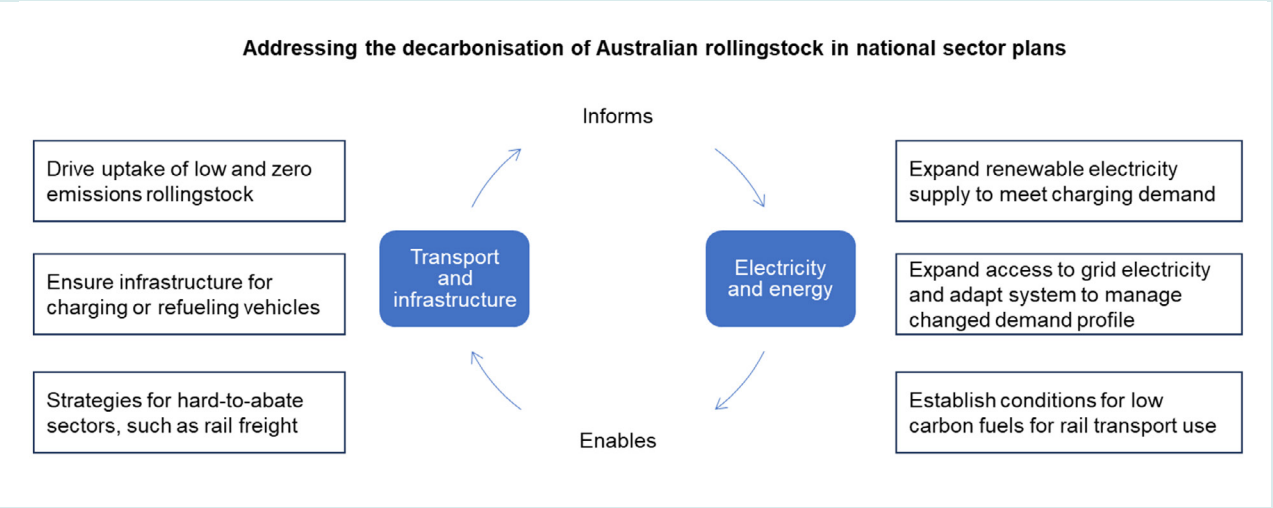
The role of rail to support the decarbonisation of the economy is generally acknowledged. Net zero and transport strategies typically include plans to increase transport interconnectivity and the share of public transport, including rail, with the benefits of shifting some road freight to rail noted in some cases. This has developed clear and consistent pathways that government and industry can plan and work together towards (see Box 4).

Box 3. Recent national and state net zero targets and policies of relevance to rail

Federal Government sectoral roadmaps and action plans

The Federal Government is developing sectoral decarbonisation plans to address major economic sectors (transport; electricity and energy; industry; resources; built environment; agriculture and land). The Department of Infrastructure, Transport, Regional Development, Communications and the Arts (DITRDCA, 'the Department of Infrastructure') is leading the development of the **Transport and Infrastructure Net Zero Roadmap and Action Plan**[77]. This roadmap, due for completion in late 2024, will examine pathways to net zero by 2050 across all transport modes (including rail), freight and supply chains and supporting infrastructure.

Also relevant for the decarbonisation of rail is the **Electricity and Energy Sector Plan** being developed by the Australian Department of Climate Change, Energy, the Environment and Water (DCCEEW). This plan will seek to enable the decarbonisation of other sectors, including rail, by setting out a credible pathway to decarbonise Australia's electricity and energy sector by 2050 while ensuring reliable, secure and affordable energy supply. The interaction between the transport and electricity and energy sector plans are illustrated below.



Adapted from DCCEEW 2024[78]

NSW Government targets and policies relevant to rail

The NSW Government legislated its state-wide net zero targets in 2023, with several transport-specific targets released within Transport for NSW's **Net Zero and Climate Change Policy**[79] including:

- 100 per cent renewable energy for operational electricity for rail, light rail and metro networks by 2025 (almost complete);
- 65 per cent reduction in TfNSW operational emissions by 2030 (compared to 2018-2019);
- Net zero TfNSW operational and fleet emissions by 2035;
- Net zero in NSW transport sector emissions by 2050;
- Net negative NSW transport sector emissions by 2060.

TfNSW's **Towards Net Zero Emissions Freight Policy**[80] announced in 2023 outlines key priorities and actions to support progress towards net zero emissions for road and rail freight transport by 2050. This policy notes that the pathway to net zero for rail freight requires coordination between governments, industry and the research community. Priorities include increasing industry engagement and communication to enable original equipment manufacturers, operators and logistic companies to share data, knowledge and lessons learned to accelerate the adoption of new and emerging technologies. Other priorities include streamlining approval processes for new locomotives, optimising the network for rail freight and increasing the attractiveness of rail for bulk and other goods to help improve regional and remote connectivity.

In early 2024, the NSW Government announced the **Freight Policy Reform Program**[81] to deliver a strategic reform agenda and action plan to optimise freight transport in NSW.

Victorian Government net zero plans related to rail

The Victorian Government's **Climate Change Strategy**[82] is supported by sector emissions and abatement pathway modelling. Transport sector emissions reductions are projected to be mainly due to reductions in light vehicle road transport emissions due to accelerated uptake of electric vehicles.

The Government's **Transport sector emissions reduction pledge**[83] includes investment in rail to improve public transport including funding for the Metro Tunnel, the Melbourne Airport Rail and the Suburban Rail Loop. It also includes a commitment that the metropolitan train and tram network will be 100 per cent powered by fully renewable electricity by 2025.

The **Port Rail Shuttle Network**[84] will connect the Port of Melbourne to major freight hubs using the existing rail network. Making it easier and cheaper for businesses to use rail freight is projected to reduce up to 100,000 truck trips each year.

The Victorian Department of Transport and Planning is working on a **strategy to decarbonise freight transport**[85] with recommendations due to the Victorian Government in 2024.

WA Government sectoral emissions reduction strategy

The WA Government released its **Sectoral emissions reduction strategy for Western Australia**[86] in December 2023. The pathway for transport would see transport emissions cut by about 70 per cent by 2050. Emphasis is placed on decarbonising road transport which contributes 75 per cent of transport emissions (compared to 15 per cent from rail). Investment in public rail transport to support road transport decarbonisation is a focus with new initiatives including the investment in METRONET (72km of new passenger rail with 23 new train stations).

Decarbonisation of road freight and rail are considered slower to transition due to longer distances, the need to minimise recharging/refuelling times and the weight of larger batteries. Biofuels are noted to have the potential to play a role in heavy transport, with the WA Government to identify opportunities to leverage business investment in the production of advanced biofuels (renewable diesel) and low-emission fuels for transport, mining and agriculture industries.

Box 4. International rail decarbonisation policies and plans

The **United States National Blueprint for Transport Decarbonization**[23] released in 2023 is a whole-of-government strategy that aims to reduce transport emissions, including rail, by 80 –100 per cent by 2050. The strategy considers a whole-system approach to decarbonising the rail industry with policies and strategies set out covering technology pathways, zero emission targets, encouraging mode shift, interoperability and infrastructure investments, research and development of new technology, and investments in sustainable fuel supply chains. Priority actions and levers identified in the Blueprint to decarbonise rail include: infrastructure investment; multi-stakeholder collaborations to accelerate the deployment of emission reduction technologies; and research and innovation to advance technology through pilot projects, greater infrastructure investments and continued policy and regulation support to accelerate the growth of electrification.

The **European Union's Sustainable and Smart Mobility Strategy**[24] released in 2020 aims to reduce transport emissions, including rail, by 90 per cent by 2050. This strategy aims to triple high-speed rail and double rail freight traffic by 2050 to reduce road emissions. Emphasis is placed on internalising external costs to ensure rail is on an equal footing cost-wise with road transport, investment in research and development, sustainable and circular products and services, ensuring the right vehicles and fuels are supplied by the industry, putting in place the necessary infrastructure, and incentivising demand by end-users. The strategy notes that rail transport will need to be further electrified, and wherever this is not viable, the use of hydrogen should be increased. Under related European policies, EU-wide harmonisation of vehicle approvals is seen as a key measure to reduce costs for cross-border trains. The European Green Deal calls for a substantial part of the 75 per cent of inland freight carried by road to shift to rail and inland waterways. Rail freight is considered to need 'serious boosting through increased capacity, strengthened cross-border coordination and cooperation between rail infrastructure managers, better overall management of the rail network, and the deployment of new technologies such as digital coupling and automation'.

The **United Kingdom's Decarbonising Transport**[25] plan published in 2021 aims to achieve net zero transport emissions and reduce rail emissions by 97 per cent by 2050. The plan sets an overarching target of phasing out all diesel locomotives by 2040 and subsequent policies are being developed to achieve this including mapping which technologies to deploy on each rail route which is then used to plan investments, incentives for freight operators to take up low carbon traction, rail freight growth targets, and government-funded innovation programmes to develop and demonstrate new technology.

Challenges and opportunities

A summary of challenges and barriers to decarbonisation are set out in Table 3, with some of the opportunities identified noted in Table 4. These were considered when developing priority areas and actions for the rollingstock decarbonisation critical path and supply chain capability framework.

Table 3. Challenges and barriers to decarbonisation

Challenges	Description
Regulation	Inconsistent approval processes between jurisdictions increase the cost of designing, testing and training for new locomotives, which could hinder the uptake of low and zero emission locomotives.
Industry coordination	The fragmented structure of the rail industry means the benefits and costs of a harmonised approach to decarbonisation falls unevenly across industry players. This has led to a leadership vacuum and a lack of ownership of addressing decarbonisation, which could hinder industry collaboration on this issue.
Asset investment lifecycle	Rail is characterised by a large proportion of assets with long economic lives (25-30 years) relative to other industries. This makes the business case for investing in low and zero emission locomotives more difficult, as the capital cost between existing depreciated assets is lower than new low emission technologies.
Technology readiness and availability	Low and zero emission locomotives are not yet commercially available for a full phase out of diesel locomotives and the reliability of these technologies have also not yet been demonstrated in a commercialised form in Australia.
Access to support infrastructure and renewable energy	Low and zero emission fuels such as hydrogen, renewable diesel and green ammonia will require an abundance of renewable energy infrastructure to produce. Any delay in achieving wider electricity decarbonisation targets could hinder the supply of these fuels. In addition to the supply for low carbon fuels, there are other challenges which include PPA threshold, renewable energy infrastructure ownership, access and proximity to hydrogen supply.
Procurement and local content guides	The current procurement and local content policy variations between the states will increase the cost of low and zero emission technologies as the market will be limited to individual states.
Investment	Investment can be hindered by short-termism of state government budget allocation, lack of clear strategy, individual investments in trials and a lack of government R&D investment.
Supply chain capability and skills	Freight locomotives are increasingly designed by and sourced from overseas manufacturers which could hinder the domestic supply chain's future ability to design and supply low and zero emission technologies.
Compatibility with existing infrastructure	Existing infrastructure constraints (e.g., overbridges, space limitations at depots) could increase the cost and complexity of implementing decarbonisation options.

Table 4. Opportunities and focus areas for action

Opportunities	Description
Quick wins	Implementing energy efficiency opportunities (e.g., weight reduction, CBTC) in the short term can reduce emissions from diesel fuel use and generate fuel cost savings. Other quick wins include the use of infill electrification to enable services to be electrically hauled over longer distances.
Retrofitting locomotives	Due to the long-life cycle of locomotives, retrofitting with zero emission technology represents a significant opportunity to reduce the capital costs of transitioning to net zero.
Decarbonisation of the grid	Relatively rapid decarbonisation of grid electricity in Australia enhances the overall GHG emission reductions to be achieved by grid-connected electrified rail.
Investing in renewable energy	Investing in self-generation and storage can reduce the industry's dependence on the grid, reducing exposure to risk and price volatility.
Mandatory scope 3 emissions reporting	Greater global scrutiny to report and reduce scope 3 emissions. By investing in decarbonisation, the industry can demonstrate the rail sector's green credentials.
Industry coordination	Rail industry coordination and cross-industry collaboration of trials, R&D, refuelling locations, low carbon fuels and green electricity procurement would reduce cost, increase information sharing and reduce risk.
Domestic rollingstock manufacturing	Proposed national rollingstock procurement approach presents an opportunity to boost efficiencies of the domestic supply chain, improve domestic engineering capability, and open the global market for domestic manufacturers.
Bi-mode locomotives	NSW is introducing bi-mode trains for their regional passenger fleet. These are diesel-electric hybrids able to run on overhead power when operating on electrified sections of the train network and on diesel on non-electrified sections. This brings the possibility of isolated electrified sections to reduce emissions, and the potential to transition to battery-electric hybrids.

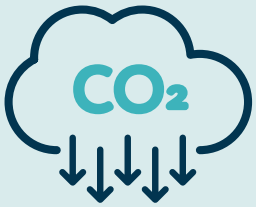
Decarbonisation technologies and pathways

Decarbonisation technologies

Achieving net zero emissions for the rollingstock in Australia will rely on the following four pillars of decarbonisation:

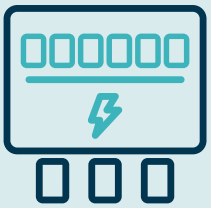
Energy efficiency and productivity measures

Efficiency improvements to existing and new equipment and infrastructure have been the focus of railway decarbonisation efforts to date and must continue to be prioritised. All efficiency improvements will reduce emissions from diesel fuel use and generate fuel cost savings.



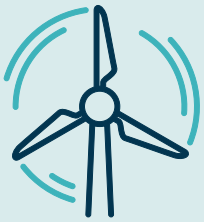
Low-carbon fuels

As railway companies increasingly focus on their efforts to decarbonise, efficiency improvements may be supplemented by the blending of renewable and low-carbon fuels.



Alternative propulsion

As the rail industry seeks to move past the limits of what low-carbon fuels and combustion engines can offer, widespread adoption of alternative propulsion technology will be required in the long term to achieve net zero emissions.



Electricity from renewable sources

Passenger railway is largely already electrified with further electrification of regional passenger rail being considered. However, the current lack of access to renewable energy is hindering further emissions reduction. The rail industry will seek to reduce emissions related to electricity use through increasing the penetration of renewable energy.

Options available under these pillars are summarised in Table 5.

Table 5. Emission reduction measures for rail

Type of measure	Technology	Description
Energy efficiency and productivity measures	Replacement of diesel/ diesel-electric line haul to Tier 4 locomotives	US EPA Tier 4 locomotives are 5% more efficient than Tier 2+ compliant locomotives.
	Improve energy efficiency of new locomotives and wagons through design	Scope includes measures to reduce weight through use of composite material and improvements to the aerodynamics of locomotives and wagons.
	Improve energy efficiency of existing locomotives (diesel and electric)	Options include software such as Driver Assistance Systems (DAS) and supported by driver training; retrofitting more efficient devices such as AC traction motors, electronically controlled pneumatic braking, and onboard or line side energy storage systems (see Box 5).
Low carbon fuels	Biodiesel	Blend of diesel with either 5% (B5) or 20% (B20) fatty acid from vegetable or animal tallow. Considered a transition fuel.
	Renewable diesel	Primarily synthesised from organic biomass (e.g., wood, straw, waste paper-pulp) and is a direct substitute for diesel.
Alternative propulsion	Battery-electric locomotive (BEL)	Electrically driven locomotive with energy derived from rechargeable batteries.
	Battery-electric locomotive (BEL) + Battery electric tender (BET)	BEL, with a BET which is a tender wagon that acts as a range extender for the BEL.
	Battery-electric locomotive (BEL) + Hydrogen electric tender (HET)	BEL with a HET as the range extender. The HET contains fuel cells, cooling systems, and high-pressure gas or liquid hydrogen tanks.
	Bi-mode locomotive	Diesel-electric hybrid that runs on overhead power on electrified network and diesel on non-electrified network. TfNSW is purchasing bi-mode trains for its regional rail network.
	Battery-electric hybrid locomotive	Electric only hybrid that runs on overhead power on electrified network and battery-electric on non-electrified network.
	Green ammonia locomotive	Electrically driven locomotive with energy derived from on-board green ammonia fuel cell. Fortescue is currently developing a green ammonia locomotive with Deutsche Bahn.
	Hydrogen-electric locomotive (HEL)	Electrically driven locomotive with energy derived from on-board green hydrogen fuel cells.
	Hydrogen-electric locomotive (HEL) + Liquid hydrogen electric tender (LHET)	HEL with a LHET as a range extender.
	Fully electric trains and locomotives	Utilises overhead electrification, a network of wires suspended above the tracks to supply electric power to trains.
Electricity from renewable sources	Grid electricity decarbonisation	The carbon intensity of grid-connected electricity is projected to reduce significantly over the next decade due to the uptake of renewable energy and storage in the major electricity markets supported by federal and state electricity strategies (see Box 6).
	On-site renewable electricity	A renewable electricity plant (e.g., solar PV array) is built on site by an operator and directly feeds into their internal network.
	Green power purchase agreement (PPA)	Operator enters into a long-term energy agreement (5-20 years) for the supply of electricity from a renewable electricity plant located on the operator's property and connected to its internal network long-term energy agreement (5-20 years) whereby the buyer agrees to purchase a project's renewable electricity for a pre-agreed price, with no physical delivery of power.
	Solar powered trains	Solar panels are directly attached to the roof of the locomotive and wagons or placed locally in the rail corridor to produce renewable electricity.

Box 5. Energy efficiency improvements of locomotives

Aurizon[26] is developing energy efficiency projects to increase its ability to reduce idling by focusing on increasing starting reliability and or Auto Engine Start Stop (AESS) technology. The company is also undertaking energy efficiency driving methodologies and adopting Train Energy Management solutions to improve consistency and reduce emissions.

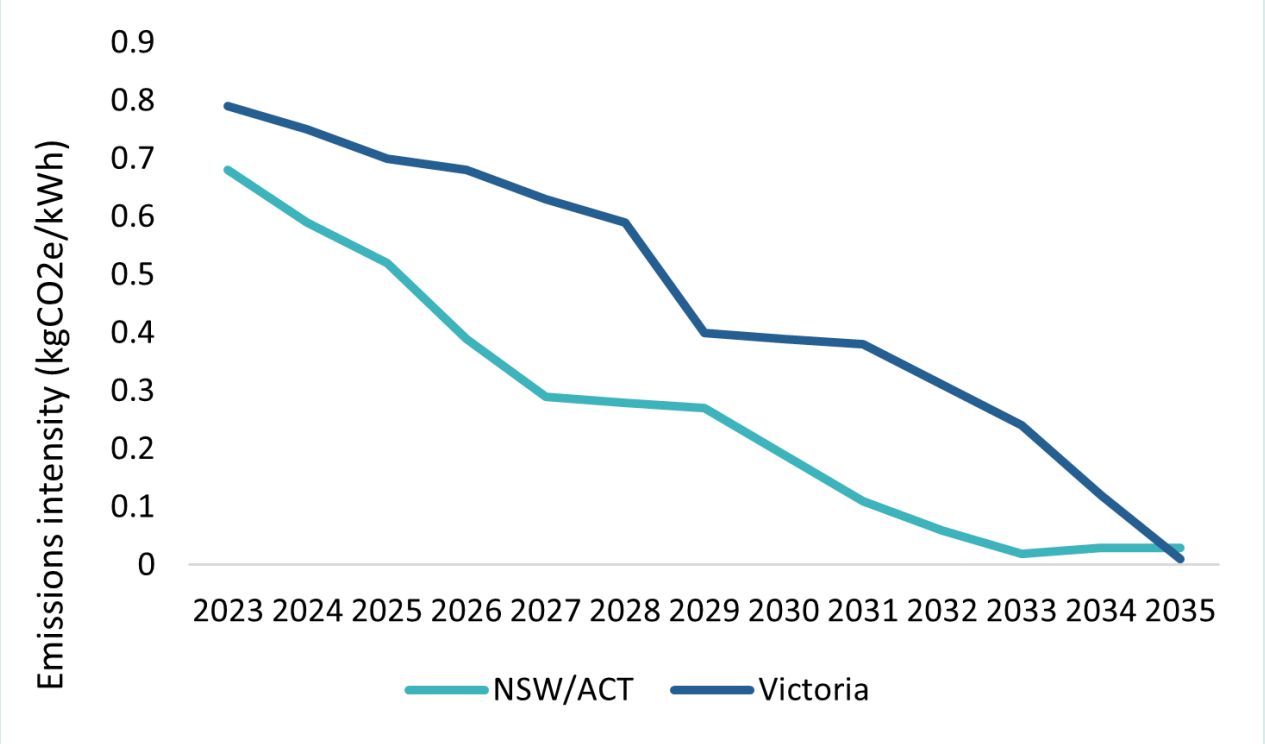
Pacific National[27] is implementing a series of optimisation projects that are focused on reducing the fuel consumption of their operations. This includes:

- A Loco-Offlining program where train dynamics allow locomotive horsepower to be turned off when operating in appropriate circumstances (e.g., empty journeys), reducing fuel consumption while in transit and turning the locomotive back on when additional energy is required.
- In-line fuelling modifications to improve transit time and service running, which will enable additional capacity on services by reducing the number of fuel wagons.
- Double stacking program to increase volumes hauled.
- Train length improvements to improve fuel efficiency and reduce carbon emissions intensity. Improvements have been focused on customers in Victoria so far, with an increase in standard 40 wagon train length to 50 wagons with a 25 per cent payload improvement.

Box 6. Grid electricity decarbonisation case studies

The **NSW Electricity Infrastructure Roadmap**[9] outlines a roadmap and policies designed to support the NSW Government's ambition to deliver at least 12 GW of new renewable electricity generation by 2030 and reduce electricity emissions by 90 MtCO2-e by 2030. Under the stated aims of the roadmap, the emissions intensity of the electricity grid in 2035 in NSW is expected to be 96 per cent lower than 2023 levels.

The **Victorian State Government**[9] has a state target to reach 65 per cent renewable electricity penetration by 2030 and 95 per cent by 2035, with a key pillar of their goal to install up to 4 GW of offshore wind power by 2033. The State aims to support this renewable electricity generation by targeting to install 6.3 GW of renewable energy storage capacity by 2035. If these targets are achieved, the emissions intensity of the electricity grid in 2035 in Victoria is expected to be 99 per cent lower than 2023 levels**.**



Rollingstock decarbonisation trials and research

Real-world case studies are an essential step in the transition from theoretical assumptions of potential applications towards widespread replacement of diesel-powered freight and heavy-haul locomotives.

A market scan of rollingstock decarbonisation trials demonstrated that domestic trials are mostly focused on the emissions reduction capability of battery-electric locomotives (BELs) (Table 6). These trials are being undertaken by mining companies operating in Western Australia (Roy Hill, BHP, Fortescue, Rio Tinto) and by Aurizon in Queensland (refer to Box 6 for further details). These trials will provide critical learning opportunities for the wider heavy haul and freight industry.

Several of the cases identified involved purchasing new BELs from American companies (Wabtec, Progress Rail) who are designing and manufacturing the BELs outside of Australia, with trials expected to commence in 2024. An exception is Aurizon's development of the first BEL to be constructed in Australia for trialling in late 2025, and its plans to build a battery electric tender (BET) locally for trialling in early 2026.

In some cases, BELs are planned to be run in conjunction with diesel-electric locomotives. This phased approach has been adopted due to concerns about the range of battery-electric trains, particularly without existing charging infrastructure along the heavy haul routes. Exceptions include Fortescue's plans for its 'Infinity Train' and Aurizon's plans to build and operate a BEL + BET.

Other technologies include Fortescue's development of a dual-fuel ammonia-powered locomotive prototype with mainline trials planned to be undertaken in 2024 at its Solomon mine in WA in 2024, and Wilmar Sugar and Renewable's trials involving renewable diesel from hydrogenated vegetable oil (HVO).

The Fortescue ammonia, Wilmar renewable diesel, and Aurizon BET trials are of note due to these solutions involving retrofits to existing locomotives.

Table 6. Summary of domestic rollingstock decarbonisation trials

Entities	Rail Operation	Location	Technology	Date	Trial/Implement
Aurizon Progress Rail[28]	Freight	Redbank, QLD	Battery electric locomotive	Trials expected mid 2025	Trial (Demonstration)
Aurizon Alta Battery Technology[29]	Freight	Redbank, QLD	Battery electric tender	Trials expected early 2026	Trial (Demonstration)
BHP Wabtec Progress Rail[30]	Heavy Haul	Pilbara region, WA	Progress Rail EMD® Joule, 14.5 MWh battery Wabtec FLXdrive 7 MWh battery	Delivery expected late 2023	Implement
Rio Tinto Wabtec[31]	Heavy Haul	Pilbara region, WA	FLXdrive 7 MWh battery	Trials expected early 2024	Trial (In commercial operation)
Hancock Prospecting – Roy Hill Mine Wabtec[32]	Heavy Haul	Pilbara region, WA	FLXdrive 7 MWh battery	Delivery expected early 2024	Implement
Wilmar Sugar and Renewables Australia[33]	Freight	Herbert region, QLD	Renewable diesel using recycled vegetable oil	Late 2023, early 2024	Trial (Demonstration)
Fortescue Deutsche Bahn[34][35]	Heavy Haul	Solomon Mine Site, Mount Sheila region, WA	Dual-fuel ammonia-powered locomotive prototype (retrofit)	Mainline trials at Solomon planned for 2024	Trial (Demonstration)
Fortescue Willams Advanced Engineering[36] [37]	Heavy Haul	WA	Battery electric locomotives, including the "Infinity Train" solution	Trials planned for 2024.	Trial (Demonstration)

Box 7. Rollingstock decarbonisation trials in Australia

Aurizon collaborated with the University of Queensland to undertake a detailed analysis of the electricity power requirements for each of their key freight routes based on trip distance and matched these with the expected power capacities of low and zero emission technologies in 2030[38] [39]. On this basis, Aurizon concluded that 30 per cent of its freight haul routes could be suitable for BELs, with a BEL coupled with a BET covering an additional 50 per cent of routes. The remaining 20 per cent of freight haul routes, with the highest energy demand, could be met with the combination of a BEL with a HET. Further information on Aurizon's decarbonisation approach is given in Box 8.

In May 2023, **Aurizon** commenced work on the first BEL to be constructed in Australia, with the prototype expected to start on-track trials in late 2025[40]. This technology is expected to support freight hauls of up to 400km. In March 2024, Aurizon secured a $9.4 million grant from the Australian Renewable Energy Agency (ARENA) to develop, test and trial a battery electric tender (BET) to be used in conjunction with a modified locomotive. The ARENA grant represents half of the required funding for the 'Battery Powered Tender for Heavy Haul Fleet Decarbonisation' project, with Aurizon to fund the balance. The BET and modified locomotive project will be built by Aurizon and technology project partner, Alta Battery Technology at a facility in Australia, with design and technology inputs from Alta. Trials involving the BET are expected to start in early 2026. When coupled with the BEL, the BET aims to extend the range for freight hauls up to 850km[41].

Ministerial support for Aurizon's Battery Powered Tender for Heavy Haul Fleet Decarbonisation project to be co-funded by ARENA[42]

Federal Minister for Infrastructure, Transport, Regional Development and Local Government Catherine King:

"Most of the emissions from railway freight come from the consumption of diesel, so this trial is an important first step to decarbonise our freight rail system and shows the importance of government and industry working together to find the best ways to meet our net zero target."

Federal Minister for Climate Change and Energy Chris Bowen:

"Through ARENA's support, the government is pulling out all stops to decarbonise heavy industry and helping seize the opportunity for cleaner, cheaper to operate transport.

"Aurizon's innovative technology is an exciting step in the future of electrification for the transport sector, particularly in the regions."

BHP has invested in battery-electric locomotives to trial on its Western Australia iron ore rail network, with two locomotives supplied by Progress Rail and two coming from Wabtec. BHP developed operating prototypes with Wabtec in 2021 and Progress Rail in 2022, with an operating trial of both technologies planned for 2024. The company is targeting the deployment of their rail solutions from 2029 onwards, upon successful completion of trials[43].

Hancock Prospecting's Roy Hill operation in the Pilbara placed an order for BELs in 2021. In November 2023, Roy Hill Mine took delivery of a 7 MWh FLXdrive battery heavy-haul locomotive for mainline service from Wabtec[44]. This locomotive is to be delivered to the Pilbara in 2024 to start operations. It will reportedly be deployed together with the existing Wabtec diesel-electric locomotives to transport iron ore. By using regenerative braking, the locomotive will charge its battery on the 344km downhill run from the mine to the port facility, with the stored energy being used to return to the mine. Roy Hill's Energy of the Future Program aims to optimise diesel consumptions and transition through alternative energy sources.

Fortescue is aiming to decarbonise their rail operations to achieve a zero operational emissions rail solution by 2030, with battery electric locomotives and green ammonia use in retrofit locomotives having been identified and progressed as potential solutions[45]. The company's investment in battery electric solutions includes the purchase of battery electric locomotives and the development of a regenerating battery electric iron ore train, called the Infinity Train. To date, Fortescue has purchased two battery electric locomotives, progressed research into the development of the Infinity Train, and developed and delivered a dual-fuel ammonia-powered locomotive prototype for deployment at the Solomon mine site. Studies underway on the Infinity Train include gravitational energy recharging battery electric systems without any additional charging requirements. In 2024 Fortescue plan to do mainline trials of the dual-fuelled prototype ammonia-powered locomotive at Solomon and to continue Infinity Train studies. According to Renew Economy (2024), Fortescue estimates that electrifying its 16-train fleet could save up to 82 million litres of diesel a year[46].

Wilmar Sugar and Renewables is currently running trials involving renewable diesel from hydrogenated vegetable oil (HVO) for a locomotive transporting sugar between the company's Victoria Mill and the Lucinda Bulk Sugar Terminal (44km round trip)[47]. The trial is anticipated to be completed in 2024 with Wilmar doing diagnostics and analysis to estimate the emission reduction achieved.

Rio Tinto aims to halve its scope 1 and 2 emissions in the Pilbara by 2030 and is targeting net zero emissions from operations by 2050. Noting that achieving its 2030 target will require technology breakthroughs, Rio Tinto is investing in electrification including battery electric locomotives and haul trucks and electric boilers. The company is reported to have purchased four 7 MWh FLXdrive battery-electric locomotives from Wabtec, with production of these locomotives being undertaken in the US. Based on reports from 2022, these locomotives are to be trialled in 2024[48]. These trials are however not called out in the actions to be undertaken in 2024 within Rio Tinto's 2023 Climate Change Report, despite reference being made to the commencement of battery electric haul truck trials. Emission reductions from battery locomotives are forecast to displace mobile diesel usage in the medium to long term, with biofuels and the use of battery and electric mining equipment projected to displace more usage in the short to medium term[49].

Limited local trials were identified involving renewable fuels, with no planned trials involving hydrogen-electric locomotives (HELs) noted. A key barrier to developing and deploying these technologies is the lack of developed domestic hydrogen and renewable fuels markets, with rail also expected to be in competition with other sectors seeking to secure supply. Other challenges that may limit the uptake of hydrogen and renewable fuels as solutions to decarbonise rail in Australia were identified as follows:

Hydrogen challenges:

- **Total cost of hydrogen** – Notwithstanding the uncertainty around the cost of hydrogen fuel, the cost of delivering and storing hydrogen is also expected to be very expensive.
- **Storage and transport safety concerns** – The high flammability and low density of hydrogen means additional measures will be required to ensure the safe transportation and storage of hydrogen.
- **Performance constraints** – The energy density of compressed hydrogen makes it unsuitable for longer distances due to its lack of power and higher storage requirements.
- **Infrastructure concerns** – There are concerns on the distribution of supply locations and competition of those facilities with other industries e.g., road transport.

Renewable fuels challenges:

- **Sustainability credibility** – There are concerns of the limited emissions reduction potential of renewable fuels once life-cycle emissions are considered.
- **Uncertainty on impacts to assets** – Although renewable fuels are seen as a drop-in fuel, there is uncertainty what impacts they will have on assets e.g., reduced asset life.
- **Total cost of renewable fuels** – The cost to produce and store renewable fuels is expected to be much higher than diesel.

In contrast to the domestic trials, many current international trials are noted to focus on the use of hydrogen electric locomotives (HELs) for passenger rail, with some planned for freight rail. The HEL trials appear to be along the non-electrified portion of the networks and the HELs are typically not coupled with diesel-electric locomotives. Examples of overseas rollingstock decarbonisation trials involving use of bi-mode locomotives and hydrogen and battery-electric technologies are given in Box 8.

Box 8. Examples of overseas rollingstock decarbonisation trials

Reseau Charlevoix and Alstom (Quebec, Canada) – Hydrogen-electric locomotive[50]
A three-month pilot demonstration project was undertaken where Alstom's Coradia iLint **hydrogen passenger train** was run along a passenger line between Montmorency Falls and Baie-Saint-Paul. The train transported 10,000 passengers during the trial phase and saved approximately 8,400 litres of diesel and averted 22 tons of CO_2 emissions during this pilot. A final report was issued in early 2024 to analyse the results of the trial and will be used to chart the next steps to develop hydrogen propulsion technology and foster the adoption of green transportation in North America.

Nestlé Waters, Alstom, ENGIE (Vosges, France) – Hydrogen fuel cell generator wagon with electric locomotive[51]
Nestlé Waters plan to use a hydrogen fuel cell solution for rail freight, including renewable hydrogen supply. The solution was developed by Alstom and ENGIE under a partnership announced in April 2022. The high-powered hydrogen fuel cell system developed by Alstom aims to replace the diesel-powered locomotives currently used on most lines in France and most European countries. In non-electrified areas, the system will power electric locomotives making it possible to carry out freight journeys with the same electric locomotive, powered by the catenary on electrified lines and by the hydrogen generator wagon in non-electrified areas. ENGIE will supply the renewable hydrogen for the solution. The Nestlé Waters trial and subsequent commercial operation is planned to commence in 2025.

SNCF and Alstom (Toulouse, France) – Bi-mode locomotive[52]
SNCF and Alstom partnered in 2018 to replace half of the diesel engines of the Regiolis trainsets with energy storage systems consisting of lithium-ion batteries. The bi-mode locomotives have been tested on real line profiles and in real conditions, with the initial results demonstrating braking energy recovery rate being over 90 per cent, resulting in energy savings up to 20 per cent. The start of the experimental commercial service was scheduled for the end of 2023 in Occitanie, particularly on the Mazamet – Toulouse and Rodez – Toulouse regional passenger lines.

Vale, Progress Rail, and CRRC (Tubarão and Sao Luis, Brazil) – Battery-electric locomotive[53]
Vale, in partnership with Progress Rail, developed a new, 100 per cent electric, battery-powered switchyard locomotive, with the pilot-phase for the EMD Joule locomotive was launched in the second half of 2020. This locomotive can operate for up to 24 hours without recharging and is capable of pulling 9,000 ton-trains three to five times a day. In 2022, Vale expanded their test of 100 per cent electric locomotives by purchasing a 1000kWh battery-electric locomotive from CRRC for the Ponta da Madeira Terminal switchyard. The locomotive can operate up to 10 hours without stops for recharging.

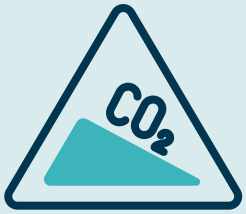
Domestically, rollingstock decarbonisation related research is being undertaken by universities, CRCs and through government funding mechanisms such as ARENA focusing on aspects of new rail technologies. An example of collaborative research to address rollingstock decarbonisation policies is a collaboration between the NSW Government, Swinburne University of Technology, and the University of Queensland through iMOVE. This study involves developing and modelling the impact of various policy levers on carbon emissions from road and rail freight and identifying the economic benefits (including value of GHG emissions reductions and public health effects) that will result from decarbonising the freight sector in NSW[54]. The recent collaboration between Aurizon and the University of Queensland informed the selection of technologies for the Aurizon fleet[55], with ARENA funding secured by Aurizon in early 2024 to progress the design and development of a BET in collaboration with Alta Battery Technology[56].

The **Australian Railway Research and Innovation Network, AusRRIN** was launched in November 2023[57]. This collaborative research initiative comprises a network of five Australian universities working together with five railway industry entities to identify and deliver critical railway research and innovation necessary for the future of Australia's railways. Their aim is to also advance an associated rail manufacturing sector in support of the Federal Government's National Rail Manufacturing Plan.

Internationally, research is being undertaken by governments, universities, and industry with a trend towards collaborative and co-funded research applying more holistic approaches that aim to address the rail ecosystem innovations needed to support rollingstock decarbonisation. Investment in research and innovation represents a key component of the rail decarbonisation strategies in the US and EU (refer Box 2). By example, Europe's Rail **FP4-Rail4EARTH (95.1m euro, 4 year) project[58]** addresses rollingstock, infrastructure, stations and their sub-systems and addresses decarbonisation, noise, vibration, energy savings, circular economy, resource consumption, climate resilience and end user experience. In the United States, the Federal Railroad Administration (FRA) **Railroad Research and Development program** addresses safety, infrastructure, innovation, regulatory reform, energy efficiency and clean technologies using an integrated approach[59].

Plausible technology pathway to decarbonise rollingstock

Achieving interim emission reduction targets will require an operationally optimised mix of early emission reduction solutions (improved energy efficiency and transitional solutions such as biofuels). As the rail industry seeks to achieve net zero emissions, it will have to move past the limits of what low-carbon fuels and combustion engines can offer, and implement the widespread adoption of alternative propulsion technology such as:

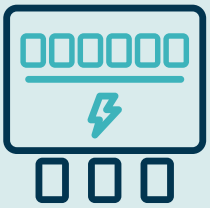


Improved energy efficiency and productivity solutions

Energy efficiency and productivity improvements remain instrumental in contributing to emissions reductions in the near term and will continue to be important to ensure the efficiency and cost-effectiveness of rail.

Transitional solutions

Biofuels, renewable diesel and the use of bi-mode locomotives represent transitional solutions that can be increasingly deployed. This includes diesel-electric or battery-electric hybrid locomotives able to run on overhead power on electrified networks where available.



Alternative propulsion solutions

Electrification, along with battery, hydrogen and other zero emission alternative propulsion technologies, are emerging as a focus and long-term solution within rollingstock decarbonisation plans, both internationally and within Australia.

Table 7 presents a plausible technology pathway, developed based on a market scan of findings from the analysis of emissions reduction measures and decarbonisation trials, as well as industry's current understanding of the likely suitability and commercial availability of low and zero emission technologies.

Table 7 demonstrates that whilst there is a plausible pathway for the decarbonisation of rollingstock in Australia, **most zero emission solutions are not yet commercially available for a full phase out of diesel locomotives**. This means that decarbonising rollingstock will require a **phased, long-term approach**.

Operators will likely focus on implementing efficiency improvements and transitional solutions to achieve emissions reductions in the near to medium term. Deep emission reductions from switching to alternative propulsion technologies will likely occur in the medium to long term as these technologies become commercially available and viable.

Alternative propulsion technologies (including renewable fuels) are longer-term solutions due to their current immaturity. Table 8 outlines key challenges that must be addressed in the short term to enable these solutions to be implemented within the timeframes suggested in Table 7.

Table 7 Initial technology pathway setting out the low and zero emission technologies, timeframes, and abatement potential of technologies with relevance to the Australian rail industry

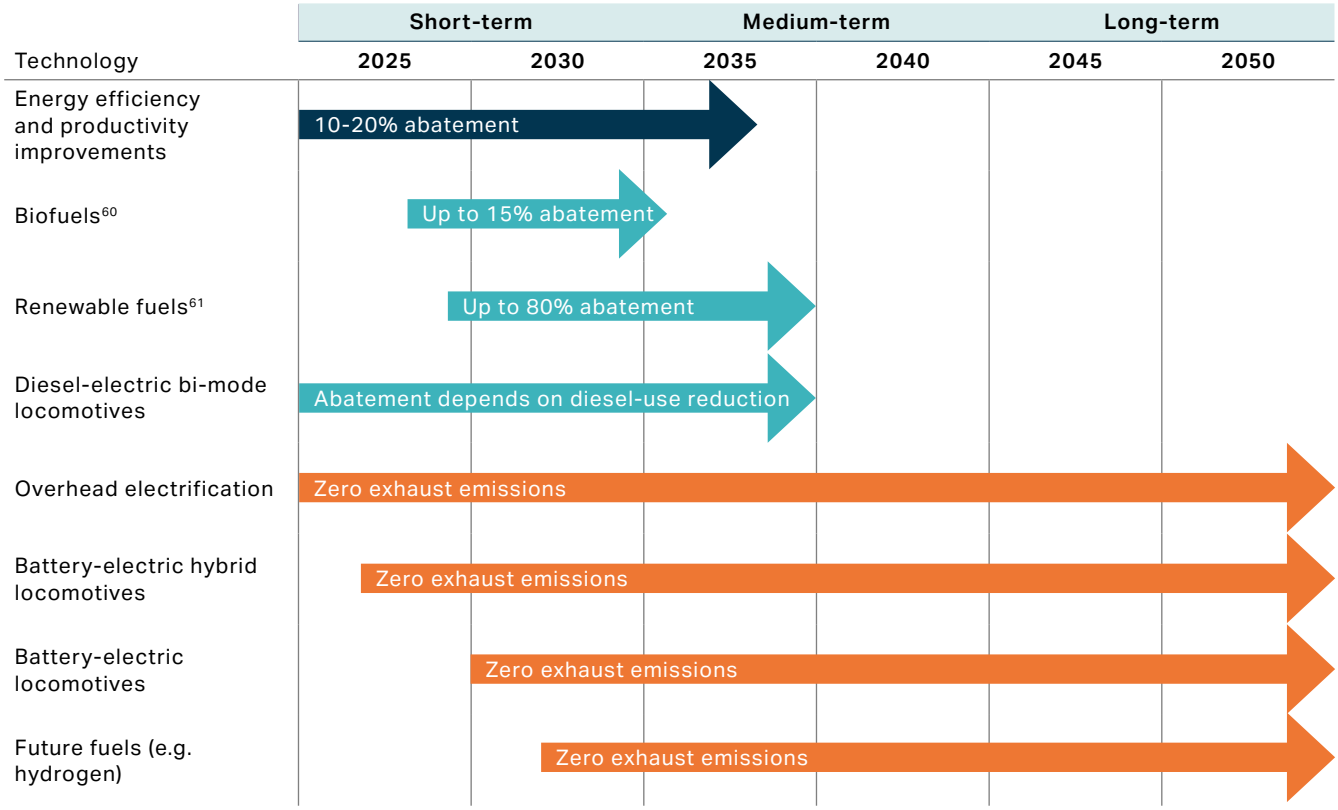


Table 8 Key challenges for the main low and zero emission technologies to be implemented within the suggested timeframes

Technology	Key challenges
Renewable fuels	• Absence of domestic renewable fuels supply chain • Competition to secure sufficient renewable fuels with other industries • Higher fuel cost of renewable fuels compared to diesel • Absence of trials of renewable fuels in Australia
Battery-electric locomotives	• Higher capital cost compared to diesel locomotives • Lack of enabling charging infrastructure • Obtaining safety approvals for new technology from RIMs • Lack of battery supply chain (e.g., sustainable sourcing, maintenance equipment, responsible and viable disposal) • Operational constraints related to range and capacity for use in freight and heavy haul operations • Need for revised operational practices (e.g., driver training, maintenance requirements)
Future fuels (e.g. hydrogen)	• Absence of domestic future fuels supply that meet power and storage requirements for longer routes • Absence of coordinated planning of future fuels supply locations and rail refuelling infrastructure • Total cost of future fuel (inc. fuel, transport, and storage costs) is higher than diesel • Absence of trials and demonstrations of future fuel locomotives in Australia

Australian context demands tailored pathways

Table 7 outlined one plausible technology pathway for the decarbonisation of rollingstock in Australia. However, due to the variation in gauges, operating conditions, and regulations, there is **no one size fits all approach to decarbonise the rollingstock in Australia**. The feasibility of decarbonisation technologies will depend on the specific use case and rail operators will need to assess the specific performance requirements of their own operations to understand which technologies will be most relevant to them. The common factors to be considered include:

- Operational requirements of the rail tasks, i.e. the ability to match the performance of diesel for each rail task (e.g., range, power capacity, refuelling time and refuelling frequency).
- Additional considerations such as the infrastructure already in place and available (e.g., overhead electric lines available, refuelling hub on route) and engineering constraints of the rail infrastructure (e.g., weight limits).
- Costs to develop, test, gain approval, implement and operate the technology, including costs for supporting infrastructure.
- Fuel costs and security of supply.

This is demonstrated by the differences by the Aurizon and Deutsche Bahn decarbonisation case studies (refer to Box 8 and Box 9 respectively).

The nature and timing of low and zero emission technologies likely to support rollingstock decarbonisation in Australia have implications for the regulatory frameworks, financing mechanisms, supporting infrastructure and supply chain capabilities that will be required. Therefore, a **network specific decarbonisation strategy** would be useful to guide the optimum technologies to deploy on the unelectrified parts of the Australian rail network, and support coordinated planning and investment. Based on local circumstances and considering lessons from the UK's experience (refer Box 10), to be successful such a strategy would need to be co-developed by governments and industry, consider both track and locomotives and be sufficiently flexible to respond to emerging technologies.

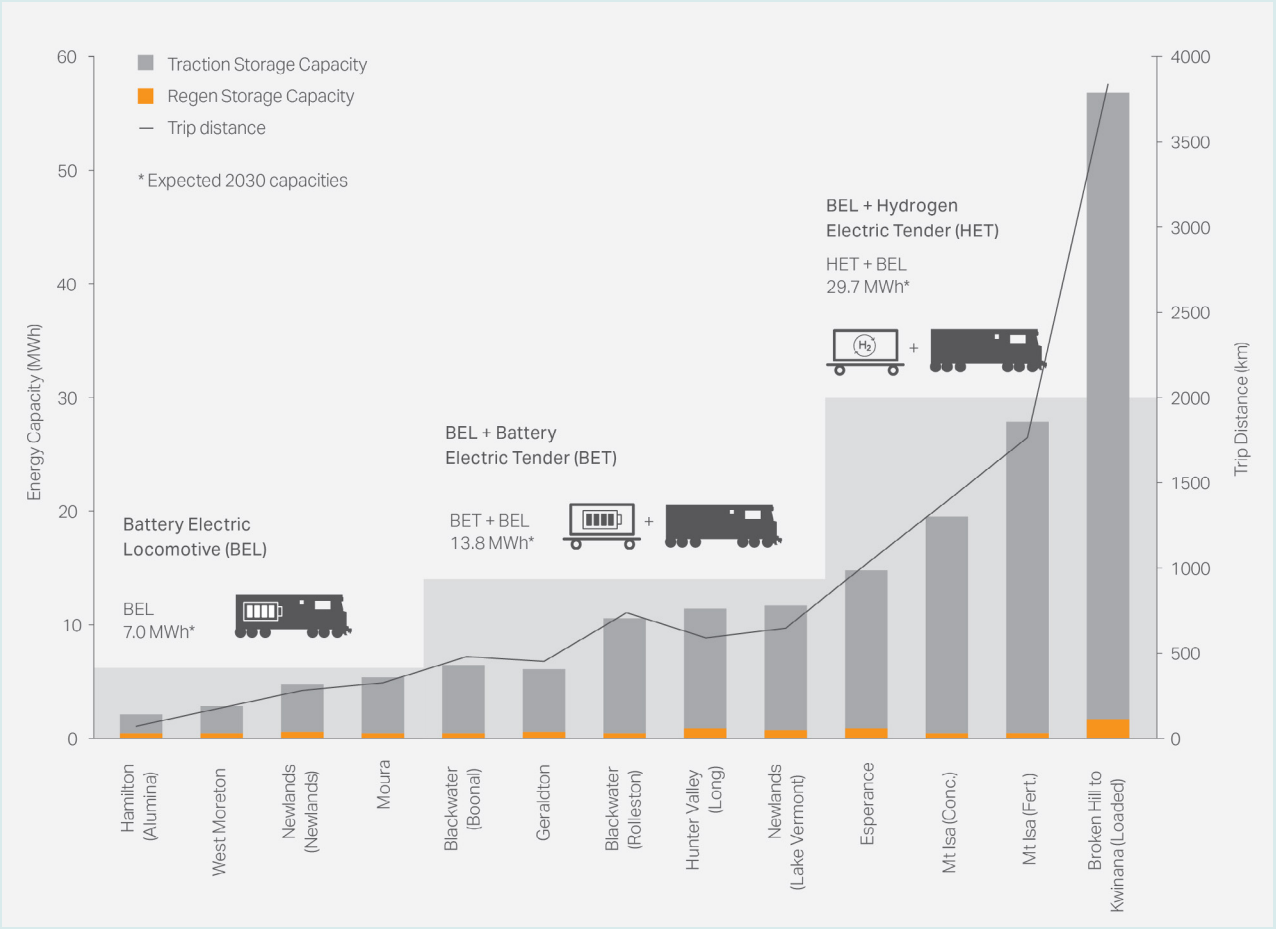
Box 9. Domestic case study: Aurizon fleet decarbonisation roadmap[87]

Aurizon is prioritising energy efficiency improvements (idling reduction, train energy management) and the use of zero carbon drop-in fuels (renewable diesel, synthetic diesel) to reduce emissions by 20-25 per cent in the short term. In the long term, Aurizon plans to phase in low and zero emission locomotives which are centred around three platforms:

- BELs with a pantograph charging system for short haul routes (<500km)
- BELs with a BET to extend to mid-range haulage tasks (500-1000km)
- BELS with a HET to extend the range to the longest haulage tasks with the highest energy demands (>1000km)

These platforms were selected based on a techno-economic analysis of the future capacities and cost of different technologies and the energy storage requirement of Aurizon's rail routes. HELs were discounted for the longer freight routes because there is insufficient space within the locomotives to house the necessary infrastructure (fuel cells, batteries, cooling systems, and hydrogen tanks). Therefore, BEL + HET were selected as the preferred technology option for Aurizon's longer freight routes.

Aurizon is aiming to develop, build and trial prototypes of these three technologies to ensure they are tailored for their specific use cases. They are also partnering with Progress Rail to retrofit an existing 4000-class diesel locomotive with battery technology, with the aim to expand this to Aurizon's full fleet of 120 4000-class locomotives.



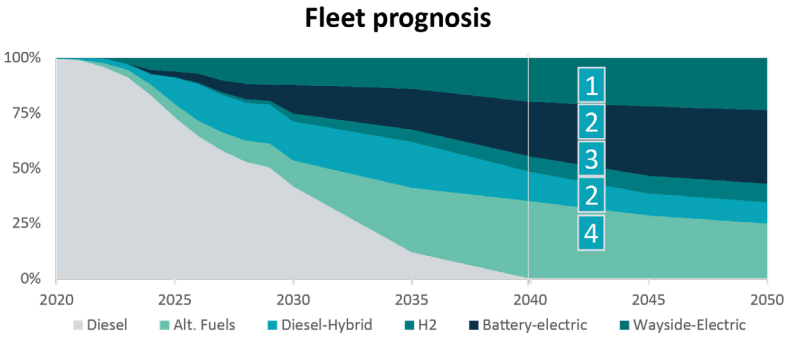
Box 10. International case study: Deutsche Bahn global decarbonisation strategy for rail[62]

Deutsche Bahn (DB) currently has about 3000 diesel rail vehicles with operations focused in Germany, and aims to be climate neutral by 2040. This will require the replacement of the diesel rail fleet with alternative propulsion alternatives.

DB projects that about **50 per cent** of the diesel rail fleet can be converted to e-traction or battery-electric traction by 2040, with other propulsion technologies to address the balance to include alternative fuels (renewable diesel), diesel-hybrids and hydrogen fuel cell alternatives to diesel. The first trains and locomotives with batteries have been ordered and are being put into service. This includes hybrid shunting locomotives and regional rail locomotives.

Further BEMU and HEMU trials and testing are being conducted in regular service, with DB's strategy being the gradual replacement of vehicles at end of life. Alternative fuels have been trialled on the advanced TrainLab, and are being introduced within long-distance, cargo and regional rail businesses, with the intent that the current fleet can be approved to use renewable diesel.

Hydrogen combustion is seen as the possible solution for **heavy haul rail.** Green hydrogen will be produced using 100 per cent renewable energy generated by DB via electrolysis. Feasibility studies on hydrogen and ammonia engines have found no insurmountable obstacles, with piloting of these engines underway (ammonia more progressed).



Technological alternatives to Diesel

1. Wayside-Electric
2. Battery: Batterie-electric
3. Hydrogen:H2 Fuel Cell
2. Battery: Diesel-Hybrid
4. Alt. Fuels

Box 11. Network-wide decarbonisation strategy case study: UK Traction Decarbonisation Network Strategy[63]

The UK Traction Decarbonisation Network Strategy (TDNS) was developed by Network Rail in 2020 to help identify the optimum deployment of electrification, battery and hydrogen technologies on the unelectrified UK rail network. The purpose of the strategy was to inform government decisions regarding the capital works required to support such technologies displacing diesel trains on the network to contribute to achieving the UK's net-zero legislative targets. The UK Decarbonising Transport plan published in 2021 included a commitment to use this strategy to guide work with partners across the rail sector to deliver an affordable, deliverable program to fully decarbonise railways[64].

Although the TDNS is reportedly being used by the UK Government as a guide for decision making, in March 2024 the UK Minister of State (Department of Transport) highlighted the role of alternative technologies such as battery and bi-mode trains, and indicated the government is progressing work on a whole systems approach by ensuring both track and train are considered.[65]

Critical path priorities and actions

Emerging low and zero emission technologies have been identified which offer plausible pathways for rollingstock decarbonisation to support national net zero emission objectives.

In Australia, rollingstock is not anticipated to transition at the same pace as some other sectors of the economy due to the maturity of technology and the challenges to be overcome to facilitate implementation. Early and coordinated action by industry and government will be needed to support the transition and capture the emissions reductions and other benefits rail can provide.

Based on challenges, opportunities and insights informed by the industry and the review of international best practice approaches, several priorities have been identified to help accelerate the journey towards rollingstock decarbonisation. Considering plausible technology pathways and strategic, policy, process, coordination and investment required to support the transition, the following Critical Path (CP) priorities are recommended:

1) **Shared vision and long-term plan:** Establish a shared vision across government and industry regarding the nature and pace of rollingstock decarbonisation in Australia, and set out a long-term plan for the transition;
2) **Fit for purpose regulatory frameworks:** Ensure policy and regulatory frameworks are fit for purpose to support the transition;
3) **Financing the transition:** Secure and coordinate public and private sector investment to finance the transition;
4) **Early emission reductions using available technologies:** Leveraging available technologies to achieve early emission reductions to support the decarbonisation journey and contribute to interim net zero targets;
5) **Research, trials and demonstrations**: Collaboratively research, develop, trial and demonstrate low and zero emission technologies for rail operations in Australia;
6) **Enabling infrastructure:** Take action to assess, develop and ensure access to appropriate rail and energy infrastructure to support the implementation of low and zero emission technologies;
7) **Education and information sharing:** Support education and awareness through information sharing and access to resources to support technology assessments and decision making;
8) **Performance measurement**: Establish evidence-based performance measurement to track progress being made and support forward planning.

The specific actions recommended to be taken by industry and government to address these priorities are set out in the following sections.

A number of actions seek to leverage the **Memorandum of Cooperation** (MoC) concluded in December 2022 which commits rail operators, builders, manufacturers and transport ministers to work together to make rail more interoperable, particularly for any future major rail investments. MoC participants committed to share the long-term vision that passengers and freight will move seamlessly and safely between major cities and regions on a modern and productive national rail network. Notwithstanding the in-principle support of an interoperable rail network, financial decisions, funding and implementation solutions were agreed to remain the responsibility of the relevant jurisdictions and investors.

CP Priority 1 – Establish a shared vision and long-term plan

The absence of a shared vision for the transition to decarbonised rollingstock across industry and national and state/territory governments is a major barrier to progressing the transition in a coordinated, orderly and efficient manner. Actions are needed to avoid the potential misalignment of national and state/territory policies and uncoordinated action by government and industry on transport infrastructure and ecosystems. A shared vision will support the availability, uptake and successful implementation of low and zero emission technologies. Actions set out below are intended to address this and lay the foundation for greater investment certainty and early, collaborative action.

Federal Government | State governments | Industry | \ Engagement | / Lead

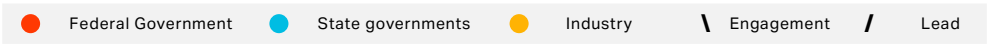
	CP Priority 1: Shared vision and long-term plan	Timing	Responsible
1.1	**Develop a national Network Specific Decarbonisation Strategy (NSDS) to support a long-term plan and suitable targets for the transition of the rail industry and provide policy and investment certainty. The strategy should be developed by a newly created Rail Industry Decarbonisation Taskforce and include clear roles and responsibilities, for the decarbonisation of the Australian rollingstock.** A shared vision is needed to establish and communicate specific roles and responsibilities to support rollingstock decarbonisation. The development of an NSDS for the unelectrified parts of the Australian rail network will support this shared national vision. It is recommended the development of the strategy is led by a newly created Rail Industry Decarbonisation Taskforce, as part of the existing ITMM decarbonisation workstream. It is recommended the strategy be delivered as part of the Transport and Infrastructure Decarbonisation Roadmap and Action Plan. This strategy should seek to: • assess rail networks, tasks and rollingstock to inform expended access to electricity infrastructure and identify suitable locations for charging/refuelling facilities. • utilise the findings from this assessment to identify the preferred combinations of decarbonisation traction options across the network to achieve the most cost-effective emissions reduction. • consider both the preferred long-term solution and the most effective transitional arrangements (e.g., early introduction of bi-mode locomotives) before transitioning to battery electric hybrid locomotives in the longer term. • It is recommended that the taskforce use the findings from the NSDS to consider and agree suitable targets aligned with the long-term plan and the anticipated contribution of rail to Australia's net zero objectives. Other performance indicators to enable the tracking of progress are addressed under CP action 8.2.	2024-25	/ ● ●
1.2	**Seek and secure shareholder support for rollingstock decarbonisation efforts.** The decarbonisation of the rail industry will require public and private sector investment, particularly given the potential costs associated with the transition of assets with long operational lives. Securing shareholder support for transition efforts will be pivotal to ensure private sector commitment and investment.	2024-25	/
1.3	**Ensure government sector decarbonisation plans address the priority actions needed and the financial instruments to support it, including incentives and technology support programs.** Governments' focus on sectors with higher emissions and near-term emissions reduction opportunities means sector plans may not make adequate provisions for the early action required to reduce rail emissions by 2050. Policy, planning and investment support to ensure rail's access to low carbon fuels, low/zero emission technologies and enabling infrastructure must be coherently addressed within state/territory and national sector plans, including the Federal Government's Transport and Infrastructure and Electricity and Energy sector plans (refer Box 3).	2025-26	/ ●
1.4	**Review and revise the long-term plan for rollingstock decarbonisation.** Informed by progress being made to support the transition of rail, including supply chain capability, the taskforce should review and adjust the long-term plan every three to five years to address gaps and ensure new and emerging opportunities are being leveraged. This review should be conducted by 2030, with reviews to continue at regular intervals beyond this.	By 2030	/ ● ●

CP Priority 2 – Fit for purpose regulatory frameworks

The rail and net zero policy and regulatory context within Australia is relatively complicated, being characterised by inter-jurisdictional differences and co-regulatory approaches. Australia's co-regulatory framework allows rail operators to adopt and administer their own standards, according to their safety management system and risk assessments. This results in rail operators adopting and implementing different standards. Inconsistent safety standards, operating rules, processes and regulation across rail infrastructure managers adversely affects industry productivity and represents a challenge to the transition of the industry. Within this regulatory context, technology suppliers navigate multiple standards and approval processes, slowing the time to market for new technologies.

The decarbonisation of rollingstock to support Australia's net zero objectives will require fit for purpose regulatory frameworks able to support the transition.

ACRI (2023) recommended the promotion of operational harmonisation through centralised guidance (including mandatory standards), overseen by a regulator responsible for achieving both enhanced productivity and safety outcomes. Such an approach would clearly also have benefits in terms of more efficiently addressing barriers to new low and zero emissions technologies. While acknowledging the benefits of this approach, actions recommended below largely leverage existing regulatory review processes. Due to the co-regulatory context, responsibilities span both tiers of government and industry.



	CP Priority 2: Regulatory frameworks	Timing	Responsible
2.1	**RISSB to address rollingstock decarbonisation when harmonising existing standards for rollingstock manufacturing.** Poor harmonisation of standards, operating rules, processes and regulation could impede the transition of the rail sector. RISSB should consider how their work to harmonise standards for manufacturing rollingstock in *the Harmonisation Plan* can support improved productivity, early access to low/zero emission technologies, and the capability of the local manufacturing industry in relation to such technologies.	2024-25	
2.2	**RISSB to proactively develop national standards for new technologies and enabling infrastructure.** Whereas there is currently a focus on harmonising standards, action is needed by RISSB to proactively develop new standardised standards for new low and zero emission technologies and enabling infrastructure (e.g. charging/refuelling infrastructure). This will ensure a nationally consistent, harmonised approach to decarbonised rollingstock from the outset.	2025-26	
2.3	**Review and revise government procurement processes to ensure early and ongoing access to low/zero emission technologies.** The absence of a national approach to rollingstock procurement is a barrier to the efficiency and growth of Australia's rail manufacturing sector. State government procurement policies often specify a minimum level of local content required which may inhibit manufacturing scale and timely access to new technologies. Efforts are underway as part of the National Rail Procurement and Manufacturing Strategy to develop a nationally coordinated approach to rollingstock procurement (Pillar 1). During this process, consideration must be given to ensuring both early and ongoing access to low and zero emission technologies. In the near term this may require helping to foster international partnerships to uplift local manufacturing and maintenance services.	2025-26	
2.4	**Review the impact of Safeguard Mechanism reforms on rollingstock operators' decarbonisation plans.** Under the Safeguard Mechanism reforms, facilities must achieve a 43% reduction in emissions by 2030. However, near-term investment by rollingstock operators may only support meaningful emissions reduction post 2030 due to long asset life. The unique constraints of rollingstock operators should be considered during the *2026-2027 Review* of the Safeguard Mechanism reforms.	2026-27	
2.5	**Streamline rollingstock approvals to encourage easier adoption of new rollingstock.** Approval processes for new locomotives have been identified as a key barrier to investments in low and zero emission locomotives, with red tape considered to have time and cost implications. Efforts underway by NTC to streamline the approvals process under the *National Rail Action Plan* should include a focus on addressing barriers to low and zero emission technologies, including retrofit and new alternative propulsion technologies.	By 2030	
2.6	**Conduct a review to determine whether further regulatory reform is required to accelerate the transition.** Informed by progress being made, the taskforce should review the extent to which further regulatory reform is necessary to accelerate the transition aligned with net zero objectives, and promote additional reforms as required.	By 2030	

CP Priority 3 – Financing the transition

Public and private sector investment will be needed, and potentially new business and finance models established, to support the transition to alternative propulsion technologies at the scale and within the timeframe required. Governments should seek to create an enabling environment for private investment and ensure Australian entities can access capital to pursue credible opportunities to support the transition. Access to government support, sustainable finance and carbon markets will likely be needed to help mitigate risks and improve financial viability.

Federal Government | State governments | Industry | \ Engagement | / Lead

	CP Priority 3: Financing the transition	Timing	Responsible
3.1	**Government sector decarbonisation plans should address the priority actions needed and the financial instruments to support it, including incentives and technology support programs (refer CP Action 1.4).** Ensure that the economic, social and environmental benefits of rollingstock emission reduction measures are adequately addressed in cost benefit analyses and investment decisions when developing such programs.	2024-25	/ \
3.2	**Rail operators should investigate business strategies, carbon markets and cost-recovery opportunities to improve the financial feasibility of low emission technologies.** Strategies may include: • Accounting for the value of carbon benefits within business cases for low and zero emission technologies; • Investigating alternative business models, e.g. 'build to lease' where appropriate; • Accessing carbon markets, such as generating Australian Carbon Credit Units (ACCUs) under the Transport Method for projects that reduce emissions by improving fuel efficiency and changing energy sources; and • Identifying customer demand and cost recovery opportunities for low emission transport services.	2024-25	/
3.3	**Targeted funding for research to accelerate the technology and commercial readiness of low and zero emission rollingstock and assess their system-level impacts.** Table 7 demonstrates that low and zero emission locomotives are not yet commercially available for a full phase out of diesel locomotives. Government funding should be provided for: • R&D to accelerate the technology and commercial readiness of low and zero emission technologies through existing funding streams (e.g., ARENA); and • System-level research on the impact of these technologies on energy and rail infrastructure through existing research bodies (e.g., AusRRIN).	2025-26	/ \
3.4	**Targeted funding for improving the scalability and implementation of low and zero emission rollingstock.** Techno-economic studies by rollingstock operators demonstrate that the abatement cost of decarbonisation options is prohibitive. Government should ensure that low and zero emissions rollingstock are eligible under CEFC and NRF financing focus areas so that operators can access cheaper capital and reduce the abatement cost of these options.	2025-26	/ \
3.5	**Existing government investments in electricity and rail infrastructure should be informed by the Network Specific Decarbonisation Strategy (NSDS) and seek co-investment opportunities to fill funding gaps.** Align existing government investment in energy infrastructure, including power network growth and upgrades, with the findings from the NSDS on the rail sector's need for access to energy infrastructure for charging and refuelling networks. Where recommendations from the NSDS cannot be met with existing investment, then the government should seek opportunities for leveraging additional capital through existing or new sustainability bond programs or similar mechanisms to co-fund additional improvements. This should be promoted only where this can be supported commercially or by a broader cost benefit analysis including the monetisation of other benefits (e.g., emissions reduction, air pollution reduction).		/ \
3.6	**Commission an independent review to assess the efficiency, equity and cost-effectiveness of mechanisms being used to finance and incentivise the transition.** To inform the five-yearly review of the long-term rollingstock decarbonisation plan, the taskforce should commission a review of the adequacy, effectiveness, equity and cost-effectiveness of measures used to finance and incentivise the transition and action recommended improvements.		/ \

CP Priority 4 – Early efforts using available technologies

Alongside the electrification of rail infrastructure, the two main technologies anticipated to make a significant decarbonisation impact are battery-electric and hydrogen powered locomotives. While these technologies mature and challenges related to power output, performance and cost are addressed, there is value in pursuing available and nearer-term technologies to realise emissions reductions able to contribute to interim net zero emission targets. Such technologies include the potential use of biofuels and renewable fuels and bi-mode locomotives. Energy efficiency and productivity improvements are available measures which will continue to have a role despite transitions in the motive power of locomotives.

Federal Government · State governments · Industry · \ Engagement · / Lead

	CP Priority 4: Early efforts using available technologies	Timing	
4.1	**Continue to improve productivity and energy efficiency of existing locomotives and benchmark against best practice.** Rollingstock operators should seek further opportunities to implement productivity and energy efficiency measures to reduce emissions and realise fuel cost savings. Operators could assess their emissions intensities by referencing the international best practice benchmark emissions intensities for bulk freight on dedicated and non-dedicated lines, rail transport of non-bulk freight and rail passenger transport being developed under the Safeguard Mechanism.	2024-25	Industry /
4.2	**Review government service level agreements to optimise freight productivity.** Transport for NSW is in the process of reviewing service level agreements with rail managers to identify how freight productivity may be improved, such as through two-way loading[66]. Similar reviews by other jurisdictions, supported by national coordination and industry (above and below rail) engagement, should be undertaken to support the optimisation of freight productivity nationally.	2025-26	State governments /
4.3	**Consider available technologies such as bi-mode locomotives and retrofit opportunities to support early progress.** Bi-mode trains could be used while electrification is extended, with subsequent conversion to either fully overhead electric or battery-electric hybrid. Given long asset lifetimes, retrofitting locomotives with zero emission technology represents a significant opportunity to reduce the capital costs of transitioning to net zero.	2026-27	State governments / Industry /

CP Priority 5 – Research, trials and demonstrations

The National Rail Manufacturing Plan seeks to promote Australia as a leader in research, design, innovation and adoption, with efforts to improve research and innovation outcomes in the rail sector to be addressed under Pillar 5 of the plan. The Australian Railway Research and Innovation Network (AusRRIN) comprises five Australian universities working together with five railway industry entities to identify and deliver critical railway research and innovation necessary for the future of Australia's railways. Due to the National Rail Manufacturing Plan being published and AusRRIN being launched in November 2023, the extent to which the research and innovation will address low and zero emission technologies for rollingstock and associated infrastructure is not yet apparent.

A holistic approach to rollingstock decarbonisation research and innovation is required with a systemic analysis of technologies and measures to determine their suitability for real world applications in Australia. Research is needed that spans the ecosystem of new rollingstock technologies, including supporting infrastructure, energy sources and digital technologies. Research into operational emissions reduction capabilities of technologies must also address embodied carbon emissions, operational constraints (e.g., weight increase, additional storage requirements) and broader benefits and costs. This research should be periodically reviewed and research priorities adjusted and ensure targeted funding for trials to address critical knowledge gaps and emerging opportunities.

Engineers Australia (2022) has advocated for the development of a national rail test facility similar to those in the US and UK. It has recommended that such a facility undertake static and dynamic testing to investigate, research and evaluate concepts, components and integration of systems to evaluate performance, develop nationally consistent type approvals and reduce the time-to-market cycle in the Australian environment. By linking such a facility with TAFE and university partners, Engineers Australia argue it would also assist in addressing skills development, maintenance and retention in the rail workforce and help reduce the shortfall in engineers, scientists and other skilled workers needed to deliver the pipeline of new infrastructure required[67].

Rollingstock decarbonisation trials in Australia are currently being primarily undertaken by companies in the Pilbara and by Aurizon in Queensland. Opportunities exist for greater government and industry co-investment and collaboration to trial and demonstrate low and zero emission technologies in Australia.

Federal Government · State governments · Industry · \ Engagement · / Lead

	CP Priority 5: Research, trials, and demonstrations	Timing	Responsible
5.1	**Partner with the research sector to deliver system-wide solutions to decarbonising rollingstock to determine their suitability for real world applications in Australia.** Research is underway on different factors to support rollingstock decarbonisation (e.g., charging infrastructure, low carbon fuels, rollingstock technology). However, achieving suitable decarbonisation of rollingstock requires a whole-system approach. There is currently a research gap on developing integrated solutions to decarbonising rollingstock which account for direct emissions reduction as well as: • renewable energy supply • charging infrastructure • lifecycle carbon impacts and circular economy principles • operational constraints • health and safety Government and the rail industry should partner with the research sector, potentially leveraging the AusRRIN network, to set out a clear research plan aligned with the long-term plan for decarbonising rollingstock, with investment targeted to support this critical research.	2025-26	\ \ /

CP Priority 6 – Access to enabling infrastructure

Coordinated action will be needed to assess, develop and ensure access to appropriate rail and energy infrastructure to support the implementation of low and zero emission technologies. The development of a national Network Specific Decarbonisation Strategy under Priority 1 will be instrumental in supporting the coordinated action and targeted investment that will be required for the transition and eventual decarbonisation of rollingstock.

Actions to support expanded access to electricity (catenary systems) and development and access to charging/refuelling infrastructure are addressed below, with actions to support access to low carbon fuels addressed within the Supply Chain Capability Framework.

Federal Government · State governments · Industry · \ Engagement · / Lead

	CP Priority 6: Access to enabling infrastructure	Timing	Responsible
6.1	**Investigate and invest in self-generation and storage to reduce dependence on grid electricity, reducing exposure to risk and price volatility.** Microgrids comprising on-site renewable energy generation and battery energy storage, and in some cases the recovery of trains' braking energy, are being considered to increase the resilience of some rail applications[68] [69] [70]. Such systems are already being deployed in WA to supply the energy for an off-grid construction of the state's largest rail infrastructure project, the Metronet Morley-Ellenbrook Line[71].	2025-26	/
6.2	**Develop a national approach for cross-border trials and joint investments in charging or refuelling infrastructure across the rail freight network.** Leveraging the NSDS in CP action 1.1, the taskforce should oversee the development of a national approach to support cross-border trials and joint investments in charging or refuelling infrastructure across the rail freight network.	To 2030	/ · ·
6.3	**Assess and support rail track upgrades that may be required to improve rail productivity and support new technologies.** State/territory governments planning track upgrades should consider improvements to support rail productivity measures and new rollingstock technologies, e.g. supporting increased loads.	By 2030	/ \
6.4	**Expand access to electricity infrastructure to support rail decarbonisation.** Informed by the NSDS in CP action 1.1, state governments should engage with rail infrastructure managers and rail operators to identify opportunities to expand electrification/partial electrification of intensively used lines used for regional passenger and freight rail.	By 2030	/ \

CP Priority 7 – Education and information sharing

Government and industry have roles to play to help address knowledge gaps and increase awareness of rail decarbonisation technologies and market trends. Experience being gained by rail operators conducting trials of new fuels and propulsion technologies can help to identify real-world challenges, inform the selection of solutions and reduce uncertainties related to rollingstock decarbonisation.

Federal Government · State governments · Industry · \ Engagement · / Lead

	CP Priority 7: Education and information sharing	Timing	Responsible
7.1	**Share information on proof of concept trials and results of research into rollingstock decarbonisation technologies and measures.** Rail operators are gaining practical experience and insight by developing prototypes and undertaking trials. Sharing such information can help to reduce uncertainties and accelerate more widespread uptake of technologies, with potential 'economy of scale' benefits to the rail industry. Government has a role to play in providing credible information on clean technologies and their feasibility. Learnings from local and international studies could be used to develop information resources to support knowledge dissemination through online platforms, guides, webinars (etc).	2024-25	· · /

CP Priority 8 – Data-driven decarbonisation planning and performance tracking

Data gaps are currently impeding a robust understanding of diesel-powered rollingstock and the national freight task. Rail freight statistics are collected by both rail operators and rail infrastructure providers but are not typically publicly available. Rail data previously collected and reported in aggregate by BITRE relied on the cooperation of individual companies supplying the information, with complete data generally being unavailable since 2017. The coordinated and efficient decarbonisation of rollingstock will require data-driven planning, decision making and performance tracking. Actions to support data sharing and performance monitoring arrangements are detailed below.

Federal Government · State governments · Industry · \ Engagement · / Lead

	CP Priority 8: Performance tracking	Timing	Responsible
8.1	**Establish sharing and publication of freight task and rollingstock data to support data-driven decarbonisation planning and performance tracking.** Rail infrastructure managers should commit to regularly providing BITRE with rail freight data sets including freight volumes, types and origin and destination. Rail operators should provide regular information on the type, motive power, energy/fuel use and ages of rollingstock. BITRE should aggregate and de-identify this data and publish it within the National Freight Data Hub so that it can be used for decarbonisation planning, emissions modelling and performance tracking.	2025-26	/\ ● ●
8.2	**Establish key performance indicators (KPIs) and track progress being made to transition the rail industry.** Rail operators and rail infrastructure owners and managers should work with BITRE to confirm a preferred suite of KPIs to track progress being made to reduce traction energy emissions and replace diesel-powered locomotives with alternative propulsion technologies. Indicators are likely to include: number of diesel-powered locomotives; diesel consumption; uptake of low and zero emission technologies; access to electricity and charging/refuelling infrastructure; availability and use of low carbon fuels; rail mode share; investment in research, trials, enabling infrastructure and low and zero emission propulsion technology uptake; rail emissions and outlook. BITRE should aggregate and publish de-identified data for each KPI on the National Freight Data Hub. This KPI trend data should be used to inform the Rail Industry Decarbonisation Taskforce's review and revision of the long-term plan for rollingstock decarbonisation (see CP action 1.4).	2026-27	/\ ● ●
8.3	**Review suitability of data and key performance indicators (KPIs) used to track progress being made to transition the rail industry.** As part of the five-yearly review of the long-term rollingstock decarbonisation plan (see CP action 1.4), the taskforce should commission a review of the completeness, correctness, clarity and relevance of the data and KPIs used to track and assess the progress of the transition and action recommended changes.	By 2030	/\ ● ●

Supply chain capability framework

The efficient and timely decarbonisation of rollingstock will be substantially dependent on supply chain capability and available workforce and skills. Innovation, manufacturing, maintenance, skills or workforce constraints could negatively impact the availability and successful implementation of low and zero emission technologies by the rail industry. This is also likely to result in a failure to capitalise on the opportunity to improve Australian rollingstock supply chain competitiveness in the global market.

Early and coordinated action by industry and government will be needed to ensure there is domestic capability to support the transition to emerging low and zero emission technologies and improve the competitiveness of the Australian rollingstock supply chain. The following supply chain (SC) capability priorities have been identified to support the critical path for rollingstock decarbonisation in Australia:

1) **Supply chain capability assessment and planning:** Understanding the current capability of the supply chain to support the development and access to low and zero emission technologies.
2) **Low carbon fuels:** Actions to develop and support the domestic markets for low carbon fuels.
3) **Procurement mapping and coordination:** Greater coordination of public and private sector procurement to reduce costs of low and zero emission technologies and foster market for local manufacturing
4) **Early access to alternative propulsion technologies**: Collaboration with domestic and international partners to uplift local capability to design and manufacture low and zero emission technologies.
5) **Enhance the capability and competitiveness of Australian rollingstock manufacturers and maintenance sectors:** Assess opportunities and develop actions to capitalise on opportunities in the transition to improve the capability and competitiveness of the Australian rollingstock manufacturers and maintenance sectors.
6) **Skills development and workforce training:** Supporting training and skills development to develop future workforce required for the transition to low and zero emission technologies.

SC Priority 1 – Supply chain capability assessment and planning

The absence of a robust understanding of the capability of the Australian supply chain to meet future demand for emerging low and zero emission technologies could lead to missed opportunities and demand being met by international suppliers. The action set out below is intended to address this by mapping the current capability of the supply chain, understanding the gaps in capability, and planning to support the development of the domestic supply chain to provide low and zero emission technologies in line with the envisioned pace and nature of the transition.

Federal Government State governments Industry \ Engagement / Lead

	SC Priority 1: Capability assessment and planning	Timing	Responsible
1.1	**Conduct a supply chain capability gap analysis and develop a plan to uplift capabilities focusing on low and zero emission technology ecosystems.** Leveraging insight gathered to date, identify the gaps in the capability of the supply chain to support low and zero emission technology ecosystems in line with the shared vision for rollingstock decarbonisation. The findings from this analysis should be used to develop a plan to uplift the capability of the supply chain to meet the needs of the shared vision.	2024-25	

SC Priority 2 - Low carbon fuels

Low carbon fuels were identified as potentially plausible solutions for the transition to the decarbonisation of rollingstock in the technology pathway. However, the lack of developed domestic markets are constraining the feasibility and uptake of these fuels as solutions to decarbonise rollingstock in Australia. The actions set out below are intended to address this by demonstrating the viability of these fuels and laying the foundation for greater investment in the domestic fuel markets.

Federal Government · State governments · Industry · \ Engagement · / Lead

	SC Priority 2: Low carbon fuels	Timing	Responsible
2.1	**Develop pilot projects to produce low and zero emission fuels for use in rollingstock operations.** Develop and undertake pilot projects to demonstrate the viability of producing low and zero emission fuels in Australia suitable for use in rollingstock operations. This will provide confidence for investment in establishing domestic low carbon fuel markets.	2024-25	
2.2	**Support industry to accelerate the commercial feasibility and support supply chains for low carbon fuels to address short-term decarbonisation efforts.** The shared vision for the decarbonisation of rollingstock should establish the role of low carbon fuels to support short-term decarbonisation efforts. For industry to achieve near-term emission reduction objectives, policy (e.g., biofuels mandate) must be tied with funding support (e.g., incentives) to ensure rail can remain cost competitive with other transport modes.	2025-26	
2.3	**Work to secure supporting low-carbon and renewable fuel supply, e.g. biofuels, renewable diesel.** The expected supply of renewable fuels is expected to be constrained and subject to increased demand from hard to abate sectors. Ongoing cross-sector coordination is required to secure annual supply of these fuels for access by rail operators.	2025-26	
2.4	**Facilitate cross-sector coordination of hydrogen demand and supply.** Concerns were identified about the distribution of potential supply locations of hydrogen and competition with other hard to abate sectors for access to supply. Cross-sector coordination by government can establish requisite domestic demand for suppliers and coordinate the location of hydrogen supply hubs to meet the needs of the rail industry as well as other sectors.	By 2030	

SC Priority 3 - Procurement mapping and coordination

The lack of a unified approach in procurement policies between the states and industry investment could increase the costs of low and zero emission technologies and thus hinder and delay the transition to net zero rollingstock emissions. Actions set out below are intended to address this by advocating for the development of a coordinated approach which can increase economies of scale and reduce costs of low and zero emission technologies.

Federal Government · State governments · Industry · \ Engagement · / Lead

	SC Priority 3: Procurement mapping and coordination	Timing	Responsible
3.1	**Coordinate government procurement processes across states to provide scale for growing local manufacturing for alternative power drives and fuels.** Efforts underway to develop a nationally coordinated approach to government procurement in the National Rail Procurement and Manufacturing Strategy should focus on providing economies of scale for local manufacturing that reduces inefficiencies, costs, increases investment and open the global market for domestic manufacturers.	2025-26	
3.2	**Establish industry solutions and coordinate to ensure access to cost-effective low and zero emission technologies.** To support local supply chain capability to provide low and zero emission technologies, industry should map their decarbonisation strategies to provide clarity on the solutions they are looking for. It should be coordination between industry to reduce the number of solutions so economies of scale can be achieved, and costs reduced.	By 2030	

SC Priority 4 - Early access to alternative propulsion technologies

The commercial manufacturing of low and zero emission rollingstock is more advanced internationally than in Australia. There is a risk that Australian rollingstock manufacturers could fall behind these competitors in accessing the alternative propulsion technologies (e.g., batteries) that power these new rollingstock, affecting their ability to support the transition. Actions set out below address this through collaboration with domestic and international partners to uplift local capability to design and manufacture low and zero emission technologies.

Federal Government · State governments · Industry · \ Engagement · / Lead

	SC Priority 4: Early access to alternative propulsion technologies	Timing	Responsible
4.1	**Collaborate with local rollingstock decarbonisation manufacturers to develop low and zero emission technologies.** Engaging technology proponents and collaborating with industry clusters and research institutions to solve technical challenges with respect to developing low and zero emission technologies and integrating them into industry operations.	2025-26	Federal Government / Lead, State governments \ Engagement, Industry \ Engagement
4.2	**Partner with international technology providers for early access to technologies.** The purpose of this partnership will be to secure early access to alternative propulsion technologies from overseas OEMs to establish domestic manufacturing for low and zero emission technologies.	By 2030	Federal Government / Lead, State governments \ Engagement, Industry / Lead

SC Priority 5 - Capability and competitiveness of Australian manufacturers and maintenance providers

The decarbonisation of rollingstock will require the development of new rollingstock and related components. This presents a significant opportunity to uplift the capability and competitiveness of Australian rollingstock manufacturing compared to overseas suppliers. There is a risk that failure to uplift the capability of local industry will negatively impact the availability and uptake of low and zero emission technologies. Actions set out below are intended to enhance the capacity of local manufacturers to support low and zero emission technologies into the future.

Federal Government · State governments · Industry · \ Engagement · / Lead

	SC Priority 5: Capability and competitiveness of Australian manufacturers and maintenance providers	Timing	Responsible
5.1	**Provide greater certainty on future demand for specific low emission technologies.** The shared vision for the decarbonisation of rollingstock should establish the future demand of low and zero emission technologies. This should be communicated by rollingstock operators to their value chain to provide greater certainty and allow for future planning to meet this demand.	2025-26	State governments / Lead, Industry / Lead
5.2	**Define the scope of influence within the domestic supply chain.** Establishing supply chain network visibility allows industry to understand its scope of influence and identify actions to accelerate decarbonisation.	2025-26	Industry / Lead
5.3	**Identify key opportunities for Australian rail manufacturing in the global supply chain.** The results from the supply chain capability gap analysis under SC action 1.1 should be mapped against the shared vision for decarbonisation to identify opportunities for Australian rail manufacturing as part of Pillar 4 of the *National Rail Procurement and Manufacturing Strategy*.	2026-27	Federal Government / Lead, State governments \ Engagement, Industry \ Engagement
5.4	**Develop domestic manufacturing and OEM ecosystems for alternative power drives and fuels.** High import costs for alternative power drives and fuels can be addressed by establishing a domestic OEM presence and developing part of the value chain. This will require strong collaboration and engagement between government and industry to identify gaps and opportunities to develop the OEM ecosystem. This action should be aligned with Pillar 4 of the *National Rail Procurement and Manufacturing Strategy*.	2026-27	Federal Government / Lead, State governments \ Engagement, Industry \ Engagement
5.5	**Facilitate financing and investment in local rollingstock manufacturing R&D.** The lack of investment in R&D from local rollingstock manufacturing can be understood in part by the loss of industrial scale required to support robust innovation and supply chain expansion. R&D can lead to innovations through new products, improved processes, and lower costs. Financing for R&D should be facilitated across the industry (e.g., grants, incentives) to spur investment to improve the competitiveness of local rollingstock manufacturing.	2026-27	Federal Government / Lead, State governments \ Engagement, Industry \ Engagement

SC Priority 6 - Skills development and workforce training

Low and zero emission technologies will drive demand for new or expanded skills in the rail industry and this process will accelerate in coming years. As Australia undergoes whole of economy decarbonisation, the rail industry will face strong competition for technical skills which could hinder the transition of rollingstock. Actions set out below are intended to identify future skills gaps, measures to develop the workforce to meet these gaps and strategies to attract and retain these skills.

Federal Government · State governments · Industry · \ Engagement · / Lead

	SC Priority 6: Skills development and workforce training	Timing	Responsible
6.1	**Collaborate to identify and address skill and workforce gaps.** Identify future critical skills gaps for the transition to low and zero emission technologies and develop specific recommendations to address such gaps. The availability of skilled labour and development of requisite training could be through industry initiatives, education and training reforms, immigration reform, and cross-sector (industry, government, education bodies) partnerships.	2025-26	/● ● ●
6.2	**Develop programs to establish, retain and attract workforce.** The rail industry is already experiencing a skills shortage, which is expected to worsen with the increased demand of specialised skills for the net zero transition across the economy. Therefore, it is crucial for industry to implement programs to retain current workforce and attract new entrants and skilled workers from other sectors. This could be through internal education training, supporting external training through institutions such as the T&L Industry Skills Hub, and reward programs.	2025-26	/ ●
6.3	**Provide funding to strengthen training and education programs to close skill and workforce gaps.** The purpose of the National Skills Agreement (NSA) is to deliver skills for critical and emerging industries, with a key priority being "clean energy and net zero transformation of the economy". The funding set aside as part of the NSA should be utilised to address future skills and workforce gaps identified in SC action 6.1.	2026-27	/● ●

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