Resources

RESOURCES

Sector summary

As the world decarbonises, Australia can continue as a world leading resource provider with a prosperous resources sector. The production of fossil fuels will decline in response to falling domestic and international demand. However, the sector can grow and diversify by expanding metals and minerals extraction and leveraging Australia's renewables comparative advantage to increase value-added processing onshore.

Australia can be a major exporter of critical minerals required for the clean energy transition. New and growing industries can create economic opportunities for affected workers and regional communities, with support from governments including for re-training and upskilling of workers and the provision of public infrastructure.

Emissions from the resources sector were 99 Mt CO_2-e in 2022, contributing to 23% of national emissions (CCA, 2024c). These were dominated by fossil fuel combustion and fugitive emissions from the mining, oil and gas subsectors. Decarbonisation of the sector requires widespread electrification, and deployment of fugitive abatement technologies in oil, gas and coal mining operations.

Electrification can play a significant role in reducing emissions from fuel combustion in the sector. Electric mining haulage and equipment is at pilot scale, with widespread adoption expected after 2030. In contrast, technologies to electrify gas and LNG operations, such as electric drives, are available now but require access to an abundant supply of firmed, cost-competitive renewable electricity through connection to the grid or off-grid generation.

Reducing fugitive emissions across oil and gas operations is also needed. This requires further development and widespread deployment of reservoir carbon capture and storage (CCS), and other abatement measures such as leak detection and repair programs and gas recovery systems. Deployment of methane mitigation technologies in underground coal mines, such as ventilation air methane (VAM) abatement technologies and gas drainage and utilisation, will be needed. Implementation of VAM abatement technologies is more nascent, with hurdles needing to be overcome before there is commercial-scale demonstration within Australia's coal mining regulatory environment.

Based on available technologies, several sources of emissions across the sector are expected to remain largely unabated while the activities continue. There are few opportunities to significantly reduce fugitive emissions from surface coal mines. For existing offshore oil and gas facilities, space constraints and difficulties accessing renewable electricity limit the opportunity to decarbonise.

Barriers to electrification and deployment of fugitive abatement measures across the sector include high upfront capital costs, integration challenges within existing facilities and the lack of access to a sufficient firmed supply of renewable electricity. Decarbonisation of the sector can be accelerated in the near to medium term with the right incentives in place to direct investment towards the long-lasting transformations required for onsite abatement, along with measures to improve emissions measurement, monitoring, reporting and verification. Timely development of shared infrastructure, such as renewable electricity generation and transmission, will be critical to this and require large-scale investment, coordination and planning.

R.1 Sector state of play

The resources sector comprises the mining, and oil and gas extraction and processing (including LNG production) subsectors. The resources sector contributes to approximately 13% of GDP (Appendix B) and accounts for more than two-thirds of Australia's total merchandise exports (DISR, 2024a). The sector employs more than 288,000 people, including 56,000 women (Appendix B).

R.1.1 Emissions profile of resources sector

In 2021-22, the resources sector was responsible for 99 Mt CO_2-e of emissions, which accounted for 23% of Australia's emissions (CCA, 2024c). As shown in Table R.1, there are five key emissions sources within the resources sector.

Table R.1: Resources sector emissions breakdown by key emissions source, 2021-22

Emissions source	Mt CO_2-e	Subsector share (%)
Fugitive emissions from coal mining	25	25
Fugitive emissions from oil and gas	20	21
Fuel combustion in mining	20	20
Fuel combustion in oil and gas	22	22
Onsite electricity generation (across all resources subsectors)	11	11
Other	1	1
Total	99	100

R.1.1.1 Fugitive emissions

Fugitive emissions are the intentional or unintentional release of greenhouse gases that occur during the extraction, processing and delivery of fossil fuels to the point of final use. Fugitive emissions from solid fuels arise from the production of coal, and emissions from decommissioned mines and coal mine waste gas flaring. Fugitive emissions from oil and gas extraction, production and transport involve venting, flaring, leakage, evaporation and storage losses (DCCEEW, 2023). Fugitive emissions account for almost half of the resources sector's emissions, with 25% from coal mining and 21% from oil and gas operations (CCA, 2024c).

Underground coal mines are responsible for 63% of coal mine fugitive emissions. Fugitive emissions from coal mining are predominantly methane emissions (95%). In oil and gas operations, 74% of fugitive emissions are carbon dioxide and 26% are methane (CCA, 2024c). For gas processing and LNG plants, the reservoir carbon dioxide that is vented after it has been removed from the gas during processing represents a large portion of reported fugitive emissions. The remaining fugitives result from flaring, venting of gas from equipment and general leaks from equipment onsite.

The reporting of fugitive emissions at the facility level has come under scrutiny in recent years due to reported discrepancies arising from comparisons with new sources of data, including from satellites. Australia's emission estimation methods, including facility-level methods under the NGER scheme, are subject to annual review and update (DCCEEW, 2024). In its 2023 Review of the National Greenhouse and Energy Reporting Legislation, the authority considered this issue and made several recommendations to improve the accuracy of fugitive methane emissions estimates in Australia through the use of higher order methods and independent verification of facility-level emissions estimates using top-down measurements (CCA, 2023).

R.1.1.2 Fuel combustion

Fuel combustion accounts for 43% of the sector's emissions, with 22% from oil and gas operations and 20% from all mining operations. The authority estimates that around 91% of these emissions are from the combustion of gaseous fuels within gas processing and LNG production facilities (CCA, 2024a), which are typically used to drive the turbines for compression or liquefaction of the gas. Within mining facilities, the authority estimates around 68% of fuel combustion emissions are from the combustion of diesel fuel (CCA, 2024a), which is used to power the mining haulage fleet and equipment.

R.1.1.3 Onsite electricity generation

The remaining 11% of the resources sector's emissions are due to the combustion of fuel to generate electricity for use onsite. The authority estimates at least 50% of Safeguard facilities within the resources sector (excluding coal mines) are not grid-connected[1] (CCA, 2024a). Many of these facilities are in remote areas including the Pilbara, central WA, northern QLD and the NT (CCA, 2024a).

1 Based on the authority's analysis of facilities under the Safeguard Mechanism.

In contrast to the rest of the sector, most coal mines are grid-connected (CCA, 2024a).

R.1.2 Decarbonisation of the resources sector is underway

The authority found various emissions reductions activities are already being implemented across the resources sector. Within the oil and gas subsector, this includes:

- energy efficiency such as more efficient turbines, waste heat recovery units, air and water chilling systems and the use of activated-methyldiethanolamine (aMDEA) for the removal of reservoir CO_2 (APPEA, 2020; Woodside, 2021; WorleyParsons & Australia Pacific LNG, 2014)
- fugitive abatement measures including replacement of existing devices with lower emitting alternatives (such as air-driven pneumatic devices), installation of new devices (such as boil-off gas compressors) and leak detection and repair programs (APPEA, 2020)
- hybrid electric-gas turbine drives or electrification of smaller compressors (APPEA, 2020; Woodside, 2021)
- sequestration of reservoir CO_2 at the Gorgon LNG facility (APPEA, 2020; Woodside, 2018, 2021)[2]

Electrification of the LNG facilities on Curtis Island near Gladstone has been investigated. A pre-feasibility study supported by the federal and Queensland governments was conducted in 2022 (Commonwealth of Australia, 2022). Santos also completed a feasibility study assessing the partial electrification of the Gladstone LNG facility and has commenced pre- front-end engineering design activities. Their project aims to replace gas-fired power generation units with grid-connected electricity and is also considering electrifying some of the gas-fired refrigerant compression (Santos, 2023a).

Within the mining subsector, current emissions reduction activities include:

- energy efficiency such as haul automation and mine plan optimisation (BHP, 2022; Fortescue, 2020; Rio Tinto, 2024)
- trials of battery electric and hydrogen fuel cell electric haulage trucks, trains and equipment (First Mode, 2023; Fortescue, 2024; Rio Tinto, 2022; South32, 2024)
- pre- and post-mining drainage in underground coal mines.

More broadly across the resources sector, smaller scale off-grid renewable electricity generation is beginning to come online or being actively explored (Fortescue, 2023; Rio Tinto, 2023; Whitehaven Coal, n.d.). This is not only to address emissions associated with current onsite fossil fuel-based electricity generation, but also to ensure facilities have access to sufficient electricity as they electrify.

Declining domestic production of coal and gas will contribute to a reduction in Australia's emissions. In the IEA's NZE Scenario[3], by 2030 global coal demand declines by 45%, and oil and gas demand declines by around 20%. By 2050, the share of fossil fuels in the total energy supply drops to less than 20% compared to around 80% of global total energy supply in 2022 (IEA, 2023c).

> Major changes to Australia's resources sector are expected as Australia and the world decarbonises.

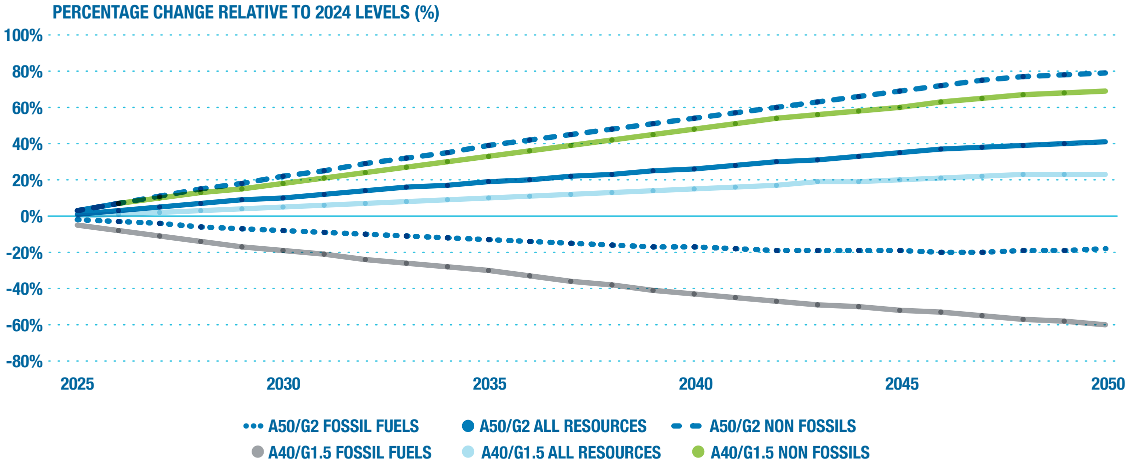
This includes:

- a reduction in production of fossil fuels as domestic and international demand declines
- ramping up of emerging industries, including the extraction and processing of critical minerals, and production of green metals such as green iron.

In modelling by CSIRO, commissioned by the authority, the output from the fossil fuels subsector declines steadily to 2050, whereas the non-fossil fuels subsector continues to grow (Figure R.1). However, global market volatility and geopolitical influences will impact the opportunity for the Australian resources sector.

2 At the time of publication Santos' Moomba CCS facility had not commenced operations, updated as of 15/07.
3 The IEA's Net Zero Emissions Scenario (NZE Scenario) shows a pathway for the global energy sector to achieve net zero emissions by 2050 (IEA, 2023a).

Figure R.1: Modelled resources sector output as a percentage change relative to 2024 levels, under A50/G2 and A40/G1.5 modelling scenarios, 2025-2050



Source: CSIRO modelling in GTEM commissioned by the Climate Change Authority

The authority also notes that various companies, such as Woodside, ExxonMobil and Santos, are investing in new carbon management services including Carbon Capture and Storage (CCS) and hydrogen production with CCS (ExxonMobil, 2024; Santos, n.d.; Woodside, 2024).

R.2 Existing and prospective technologies

The authority focused its analysis of the opportunities to achieve emissions reductions in the mining, gas extraction and processing, and LNG production subsectors, which account for around 90% of emissions from the Australian resources sector (CCA, 2024a). The authority's analysis was informed by published literature where available, and views expressed during stakeholder engagement.

R.2.1 Decarbonising onsite electricity generation

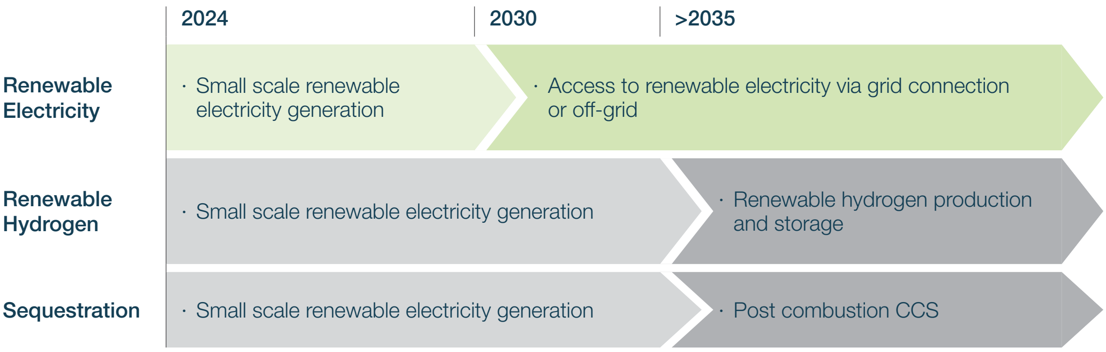
Onsite power generation from the combustion of fuels is responsible for 11% of emissions across the resources sector, predominantly at facilities that are not connected to the grid (CCA, 2024a). The oil and gas subsector (including gas processing and LNG production) accounts for 60% of the emissions from onsite electricity generation, and the mining subsector accounts for the remaining 40%.

Table R.2 outlines the key levers identified by the authority to decarbonise onsite electricity generation across the entire resources sector. Figure R.2 details the prospective decarbonisation pathways for each lever.

Table R.2: Key emissions reduction levers for reducing emissions from onsite electricity generation

Emissions reduction opportunity		Readiness	Barriers to adoption
Renewable electricity	Access to renewable electricity through grid connection or off-grid generation.	Commercial	· Lack of supporting infrastructure · High CAPEX · Obtaining land access and environmental approvals · Limited incentive under the Safeguard Mechanism
Renewable hydrogen production and storage	Access to renewable hydrogen or onsite renewable hydrogen production and storage.	R&D	· High CAPEX · Low technology maturity
Post combustion CCS	Capture and sequestration of CO^2 in the flue gas from the power generators.	R&D	· Low technology maturity · High CAPEX · Obtaining land access and environmental approvals

Figure R.2: Prospective decarbonisation pathways to reduce onsite electricity generation through renewable electricity, renewable hydrogen or sequestration



> Access to a sufficient supply of firmed renewable electricity is a key enabler to decarbonise other key sources of emissions across the Australian resources sector through electrification.

Facilities across the sector are already accessing smaller scale renewable electricity through onsite generation or power purchase agreements (PPAs) with independent power producers (IPPs) (Fortescue, 2023; Rio Tinto, 2023; Whitehaven Coal, n.d.). Future larger scale renewable electricity generation will be realised through similar approaches or by connecting to the grid.

The authority heard from industry of several key challenges in switching from onsite electricity generation using fuel combustion to renewable electricity, as described below.

Accessing a firmed supply of electricity

Most facilities require a reliable source of electricity to run their operations day and night. Options for firming include gas back-up or energy storage technologies such as batteries. Batteries with the required energy storage to provide the firming capability do exist, but the authority heard that they are typically cost prohibitive.

Accessing a sufficient and flexible supply of electricity

Significantly higher electricity demand and increased variability of demand loads are expected as facilities electrify. Industry has identified the ability to provide sufficient power to support the electrification of the sector as a key concern.

'…increasing the supply of low emission, affordable and reliable electricity is critical for decarbonisation of the resources sector. Many members advise that facility decarbonisation pathways to the mid-2030's predominantly involve process electrification, which is reflected in the significant increase in forecast industry electricity demand over the next decade. CME recommends that increasing low emission generation capacity should be prioritised, with improved co-ordination across Australia required to accelerate the transition.'

The Chamber of Minerals and Energy of Western Australia submission, 2024

Some grid-connected mines are establishing additional onsite electricity generation capability to ensure sufficient electricity supply due to concerns regarding the capacity of the grid. The authority is of the view that the expected electricity demand from the sector as it decarbonises and how this will be met is a notable current information gap, also noted in Minerals Council of Australia's submission to the authority's 2024 Issues paper.

'Delivery of renewable energy projects and transmission infrastructure within a limited timeframe is a critical enabler…..

There is little information available on additional electricity demand estimates coming from electrification of mining fleets, and potential additional electricity demand from an expansion in critical minerals processing.'

Minerals Council of Australia submission, 2024

Limited incentives under the Safeguard Mechanism

The authority heard from industry that there are limited incentives to replace electricity generated onsite through combustion of fuels with imported renewable electricity (either from the grid or off-grid but not co-located within the facility). As only scope 1 emissions generated within a facility boundary are included within the baseline, importing renewable electricity would result in a facility's gross emissions and baseline both reducing. Woodside Energy's submission to the authority's 2024 Issues paper identified this as a disincentive towards importing lower carbon electricity from a separate facility (not sited within facility boundaries as defined for reporting under the National Greenhouse and Energy Reporting (NGER) framework).

'The current Safeguard Mechanism (SGM) production variables disincentivise opportunities to drive emissions reductions through import of renewable or lower-carbon electricity from a separate facility. This disincentive occurs because these opportunities reduce emissions as well as the facility's baseline, due to a reduction in electricity production at the facility.'

Woodside submission, 2024

Cost of connection to the grid or local networks, and/or required upgrades to electricity infrastructure can be inefficient for some facilities.

Many of the facilities across the resources sector are not connected to the grid and are located in remote areas making connection to the grid prohibitively expensive. Additionally, upgrades to electricity infrastructure necessary to supply increased power demands can also be prohibitively expensive.

R.2.2 Decarbonising mining

Key subsectors within mining include coal mining, iron ore mining, and all other metals and minerals mining. In addition to the emissions from onsite electricity generation, the main sources of emissions across mining are fugitive emissions from coal mining and the combustion of diesel from mining haulage and equipment.

R.2.2.1 Emissions reduction levers for fugitive emissions from coal mining

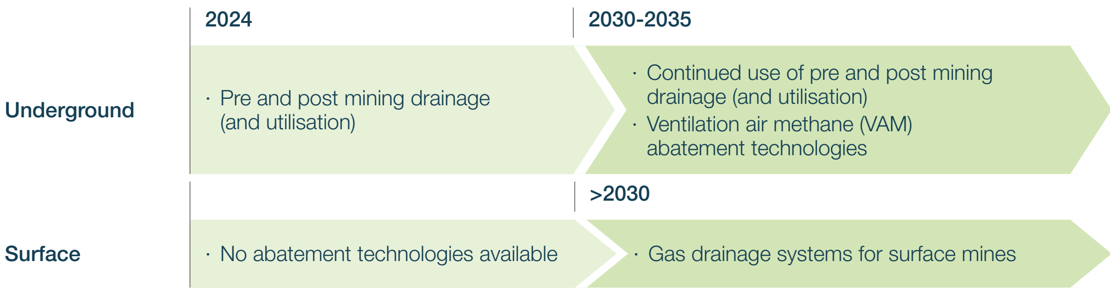
Fugitive emissions from surface and underground coal mines account for 25% of emissions from Australia's resources sector, and account for the majority 74% of emissions from Australia's coal mines (CCA, 2024c). These emissions are the result of the fracturing of gas-bearing strata when coal is extracted (Clean Energy Regulator, 2023). The amount of gas released varies considerably across different sites due to variations in the gas content and composition across coal basins.

The key levers identified by the authority for reducing these emissions are outlined in Table R.3. The technologies applicable to a particular mine depend on its characteristics, including whether it is a surface or underground mine, the gassiness of the mine and the gas composition of the fugitive emissions (e.g. methane or carbon dioxide). Figure R.3 outlines the prospective decarbonisation pathways for underground and surface mines.

Table R.3: Key emissions reduction levers for fugitive emissions from coal mining

Emissions reduction levers		Readiness	Barriers to adoption
Ventilation air methane (VAM) abatement technologies	Destruction or utilisation of the captured ventilation air methane from underground mines through thermal or catalytic oxidation, or concentration.	R&D to Commercial	· Low technology maturity · Safety risk · Safety regulation and approvals process · Difficulty integrating within existing facility
Gas drainage systems (and utilisation) for surface mines	Capture of gas from the coal seam, through bore holes into a pipeline collection system, and utilisation (such as electricity generation, pipeline injection or flaring).	R&D	· Low technology maturity · Lack of enabling regulatory environment · Lead time required to drain gas ahead of mining operations
Gas drainage systems (and utilisation) for underground mines	Capture of gas from the coal seam, through bore holes into a pipeline collection system, and utilisation (such as electricity generation, pipeline injection or flaring).	Commercial	· Cost to purify gas for utilisation · Lack of supporting infrastructure for utilisation

Figure R.3: Prospective decarbonisation pathways for fugitive emissions from underground and surface coal mines



In addition to the above key levers in Table R.3, the authority also heard of the potential use of CCS to abate fugitive emissions from coal mines.

Underground coal mines

Both gas drainage systems and VAM abatement technologies can be applied to underground mines. Gas drainage systems are already implemented at underground coal mines. Safety regulations across Australian jurisdictions require the methane concentration within the ventilated air of an underground coal mine to remain below a safe operating limit (NSW Government, 2014; Queensland Government, 2022). The introduction of gas drainage techniques in Australian gassy mines was necessary to complement ventilation systems to satisfy these requirements (KPMG, 2021). The cost of drilling additional bore holes and longer lead times ahead of mining are the barriers to further uptake of gas drainage systems in underground mines. Barriers to further utilisation of the drained gas through electricity generation or pipeline injection include cost, low or fluctuating methane concentrations and access to pipeline infrastructure.

In contrast, the implementation of VAM abatement technologies in Australia is more nascent and has significant uncertainties around its effectiveness, cost, commercial readiness, and deployment timeframes. While commercial-scale deployment of this technology has been demonstrated with multiple commercial VAM projects currently in operation, mostly in China and the US (CSIRO & Global Methane Initiative, 2018; U.S. Environmental Protection Agency, 2018), the authority heard that safety considerations remain a significant barrier to deployment within the Australian coal mining regulatory environment.

> *'The only currently available technologies to abate VAM involve a high-temperature, regenerative thermal oxidisation (RTO) system (~1000C). This is yet to be widely implemented due to concerns with meeting Australian mine safety requirements.'*
>
> Mineral Council of Australia submission, 2024

It is important to note that the regulatory environments in which these systems have been deployed overseas are very different to that of Australia, but the authority observed a knowledge gap of how these systems could be safely deployed domestically.

The authority also notes that deployment of these systems at even only a small portion of coal mines could result in meaningful emissions reduction. Approximately 60% of the fugitive methane emissions from underground coal mines are from ventilation air methane systems (EY Port Jackson Partners (internal assessment, unpublished), 2024). Anglo American have recently undertaken initial concept studies and are working to progress from a pre-feasibility to feasibility stage in VAM abatement with the design and construction of an industrial unit at its Moranbah North mine in Queensland (AngloAmerican, 2023).

Surface coal mines

There are limited opportunities to reduce fugitive emissions from surface coal mines due to their diffuse nature. It is possible to apply gas drainage techniques to surface mines, but few commercially viable applications have been reported globally (United Nations Economic Commission for Europe, 2021). The authority heard from mining companies that technical challenges remain. These include lower gas concentrations, draining multiple seams and longer drainage times required ahead of mining compared with underground coal mines. The authority observed that there is limited understanding of the potential application of gas drainage systems to surface coal mines in Australia, including the efficacy, cost, and realistic timeline of implementing such systems.

> *'While methane drainage is a mature technology for underground mining, it is novel for open-cut mining. This is especially the case at established mines where the integration of gas drainage and handling is likely to lead to mine planning and other operational challenges. These interactions need to be better understood, as do the geological conditions that are favourable (or otherwise) for effective gas drainage in this new and untested open-cut mining context.'*
>
> BHP submission, 2024

R.2.2.2 Emissions reduction levers for mining haulage and equipment

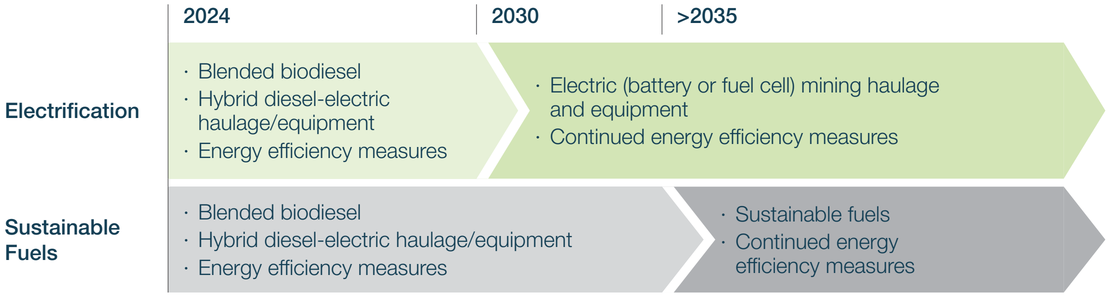
Combustion of diesel fuel to power the mining haulage fleet and equipment (e.g. dump trucks, diggers, loaders, excavators, drills and shovels) is responsible for around 14% of the resources sector's emissions (CCA, 2024a). The key levers for decarbonising mining haulage and equipment identified by the authority are outlined in Table R.4. Figure R.4 outlines the prospective decarbonisation pathways for mining haulage.

Table R.4: Key emissions reduction levers for reducing emissions from mining haulage and equipment

Emissions reduction levers		Readiness	Barriers to adoption
Electrification of haulage and equipment	Battery and tethered electric trucks and mining equipment. Trolley assist systems where haul trucks are connected to an overhead cable to power the electric drive.	Demonstration	· Low technology maturity · High CAPEX · Integration of the required supporting infrastructure to existing mines · Lack of supply of electric haulage and equipment · Lack of supply of firmed renewable electricity
Fuel cell electric trucks	Hydrogen fuel cell-powered haulage trucks and mining equipment.	Demonstration	· Low technology maturity · High CAPEX · Lack of supply of renewable hydrogen
Sustainable fuels	Fuel switching to more lower carbon fuels such as biodiesel or renewable diesel.	Commercial	· High OPEX · Lack of supply of sustainable fuels

In addition to the above key levers in Table R.4, the authority also heard the potential to use in pit crushing and conveying to reduce emissions from mining haulage and equipment.

Figure R.4: Prospective decarbonisation pathways for battery and fuel-cell electric mining haulage and equipment and sustainable fuels



Nearer term opportunities expected to be deployed ahead of the key abatement levers include continued energy efficiency improvement (such as haul automation and mine plan optimisation), the use of blended biodiesel as a drop-in fuel and hybrid diesel-electric haulage and equipment (Clean Energy Finance Corporation & Minerals Research Institute of Western Australia, 2022).

While the authority heard that battery-electric or tethered-electric haulage and equipment is the technology pathway most companies anticipate following, hydrogen fuel cell electric haulage is still being actively pursued by some. Both these technologies are at the R&D or demonstration phase, with various trials underway or announced (BHP, 2023). Partnerships and initiatives between industry and the original equipment manufacturers (OEMs) have been identified as an essential driver to accelerate technology development (BHP, 2023; ICMM, 2022). Widespread electrification of mining haulage is not expected to begin until 2030-2035 (BHP, 2023; KPMG, 2023), with the larger mining companies being the likely first adopters. It is also expected that underground mines will electrify first due to the enabling regulatory environment, co-benefits of switching from diesel to electric equipment in terms of noise and emissions reduction, and the commercial availability of electric equipment for underground operations.

A key prerequisite for mine site electrification is access to a sufficient supply of flexible but firmed electricity. Significantly higher electricity demand and increased variability of demand loads are expected as mines electrify. The ability to provide sufficient electricity, either from onsite generation or the grid, to support the electrification of mines has been identified as a key concern by industry. Electrification of a mine site also requires significant enabling infrastructure, including: charging stations, transmission lines and overhead power lines for trolley assist systems. The dynamic nature of some mining operations presents a challenge for the installation of such semi-permanent infrastructure due to continually evolving mine plans.

Various mining companies have proposed the use of sustainable fuels as a long-term decarbonisation strategy due to their benefits as drop-in fuels and the operational flexibility they offer. However limited supply of sustainable fuels (and no current domestic supply chain) and expected competition from other sectors with limited alternatives, such as aviation, introduce uncertainty around the viability of this pathway to decarbonise mining haulage.

> *'We would also observe that some existing solutions such as biofuels are currently cost prohibitive, are supply constrained and have a range of issues in relation to ethical providence which may make them unsuited for large scale deployment and use.'*
>
> Glencore submission, 2024

The authority observed there is an information gap relating to the future production, use and import of biofuels in Australia.

R.2.2.3 Emissions pathways for the mining subsector

Based on the analysis of the key levers to decarbonise mining discussed in the previous sections, the authority has developed the following possible emissions pathways for the coal mining, iron ore mining and all other mining subsectors that could be achieved through implementation of particular decarbonisation levers (CCA, 2024b). This ground up analysis considered several factors including estimated timing of implementation, barriers to implementation and emissions reduction potential for each decarbonisation lever.

Table R.5: Possible decarbonisation pathway for the coal mining subsector, showing the relevant emissions reduction levers and corresponding reduction in emissions

	Emissions reduction opportunity (as % of total subsector emissions)	Estimated start of implementation
Battery or tethered electric ancillary fleet	10	2025
Battery electric haul trucks	13	2030
VAM and gas drainage	29	2030
Open cut drainage	5	2035

Table R.6: Possible decarbonisation pathway for all other mining, showing the relevant emissions reduction levers and corresponding reduction in emissions

	Emissions reduction opportunity (as % of total subsector emissions)	Estimated start of implementation
Battery or tethered electric ancillary fleet	23	2025
Source renewable energy via Independent Power Provider	26	2028
Battery electric haul trucks	31	2030
Not considered	12	N/A

The emission sources from all other mining that the authority did not consider in this analysis largely relate to the processing and refining of metals and minerals within the mine sites.

R.2.3 Decarbonising gas processing and LNG

The key sources of emissions for gas processing and LNG production (in addition to the emissions from onsite electricity generation) are from the compression and liquefaction of gas, vented reservoir CO_2, and all other fugitive emissions from flaring, venting from other equipment and general leaks.

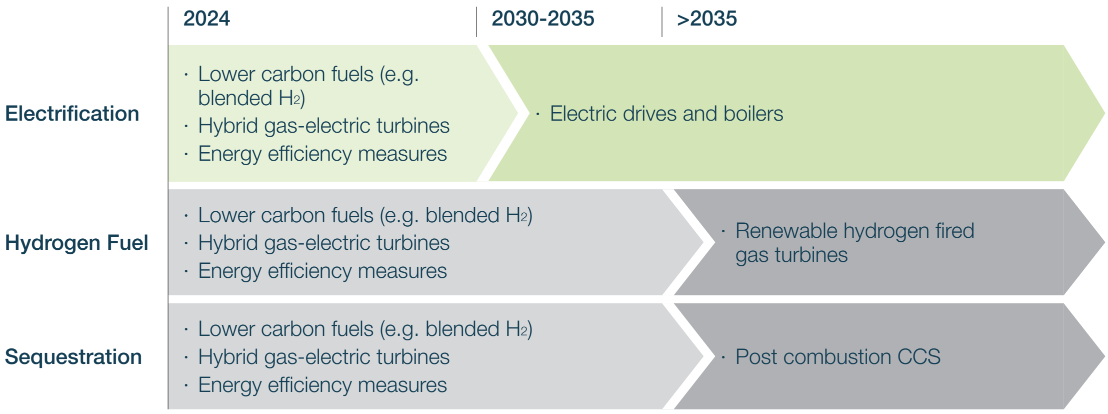
R.2.3.1 Emissions reduction levers for the compression and liquefaction of natural gas in gas and LNG production

Combustion of gaseous fuels, predominantly consumed to drive turbines for the compression and liquefaction of natural gas, is responsible for around 20% of emissions from the Australian resources sector (Advisian, 2022; CCA, 2024a). Table R.7 outlines the key levers identified by the authority to decarbonise this process. Figure R.5 outlines the prospective decarbonisation pathways for each key lever.

Table R.7: Key emissions reduction levers for decarbonising the compression and liquefaction of natural gas

Emissions reduction opportunity		Readiness	Barriers to adoption
Electrification	Installation of electric drives or boilers.	Commercial	· High CAPEX · Difficulty integrating within existing facilities · Lack of supply of firmed renewable electricity · Production downtime
Hydrogen fired gas turbines	Replacement of natural gas with hydrogen to fuel the turbines.	R&D	· Low technology maturity · Lack of supply of renewable hydrogen
Post combustion CCS	Capture and sequestration of CO^2 in the flue gas from gas-fired turbines.	R&D	· Low technology maturity · High CAPEX · Obtaining land access and environmental approvals · Difficulty integrating within existing facilities · Lack of supporting infrastructure

Figure R.5: Prospective decarbonisation pathways for decarbonising the compression and liquefaction of natural gas through electrification, hydrogen fuel and sequestration



Near term opportunities include energy efficiency (such as more efficient gas turbines), use of lower carbon alternative fuels such as blended hydrogen, and hybrid electric-gas turbine drives (APPEA, 2020; Woodside, 2021).

Electric drives and boilers are already commercially available. However, retrofitting such equipment within an existing facility is challenging. This is due to the large land requirements to build electric equipment alongside existing assets, or the long periods of shutdown to replace existing equipment with the associated cost of production downtime being a barrier to uptake. Operators would also need to consider alternative uses for the end flash gas following electrification of the assets. Additionally, if a facility does not have access to a firmed supply of renewable electricity, there can be limited emissions reductions when electrifying these processes. This is due to the electricity being otherwise generated onsite through fuel combustion. An Advisian study examining opportunities for reducing fuel combustion emissions in the mining and energy sector forecast zero uptake for electrification of refrigerant compressors and boilers at LNG facilities under a BAU scenario. Under a more optimistic 'high technology scenario', the study forecast that electrification of refrigerant compressors may be implemented at Curtis Island LNG plants.

The use of hydrogen fuel for gas turbines is a less proven technology. However, the authority heard from several major industry companies of their intended use of hydrogen as a key lever to decarbonise their operations.

Post-combustion CCS is a demonstrated technology. However, it is yet to be deployed at a commercial scale for natural gas processing[4]. Integration challenges within existing facilities are expected to be the main barriers to deployment.

The authority heard there are very limited opportunities to electrify or deploy post combustion CCS at offshore facilities due to the difficulty in accessing renewable electricity and space constraints.

R.2.3.2 Emissions reduction levers for reservoir CO_2 in gas and LNG production

Carbon dioxide that is removed from gas during processing (known as reservoir CO_2) and then vented to the atmosphere often contributes to a large portion of fugitive emissions for gas processing and LNG production facilities (Chevron, 2024b; Shell, 2020; Woodside, 2021). Capture and sequestration of the reservoir CO_2, known as reservoir CCS, is the only available technology to abate these emissions (see in Table R.8). It is important to note that reservoir CCS is a different approach to post-combustion CCS (which instead is targeting the CO_2 from a flue gas stream). Reservoir CCS is used to abate the reservoir CO_2 emissions that would otherwise be vented to the atmosphere and has significant cost advantages (Wood Mackenzie, 2021).

4 Based on a review of Global CCS Institute's Facilities database for 'Commercial CCS facilities' in 'operation', as at 15/06/2024

Table R.8: Key emissions reduction lever to abate reservoir CO² emissions

Emissions reduction opportunity		Readiness	Barriers to adoption
Reservoir CCS	Capture and sequestration of the CO_2 that is removed during the processing of the natural gas.	Commercial	· High CAPEX · Obtaining land access and environmental approvals · Difficulty integrating within existing facilities · Lack of supporting infrastructure

This technology has been in use at Chevron's Gorgon facility since 2019 (Chevron, 2024a) but has experienced technical challenges since commencement (CSIRO, 2023). Under the terms of the environmental approval from the WA government, Chevron is required to sequester 80% of the CO_2 emissions extracted from the Gorgon reservoir (WA Government, 2009). This CCS facility was designed to capture and inject 4 Mt of CO_2 each year (Chevron, 2021). Chevron reported that in the 2022-2023 financial year, 5.0 Mt CO_2-e of reservoir CO_2 was removed from the incoming natural gas stream, and 1.7 Mt CO_2-e of the reservoir CO_2 was injected. Chevron cites the key reason for the shortfall between the volume of reservoir CO_2 extracted and injected is the management of injection rates to ensure reservoir pressure remains within an acceptable range (Chevron, 2023).

Santos' reservoir CCS project at the Moomba gas processing facility is expected to commence in 2024 (Santos, 2023b). Inpex's Ichthys LNG facility was designed to be able to retrofit the facility with CCS capability in the future (APPEA, 2020). Inpex was awarded the greenhouse gas assessment permit in the offshore Petrel sub-basin in 2022 and is exploring the development of a large-scale CCS facility (Inpex, n.d.).

In relation to the deployment of reservoir CCS in Australia, the authority heard from industry that:

- Deployment is more likely at onshore gas and LNG processing facilities that are extracting gas from reservoirs with higher CO_2 concentration (due to the space constraints at offshore gas and LNG processing facilities and low CO_2 concentration reservoirs being less suitable due to the increased cost associated with concentration and compression of the gas).
- Cost and approvals processes are significant barriers.
- Purchasing offsets may be more cost effective in the longer term for facilities with shorter lifespans if abatement using reservoir CCS is not available in the near term.

R.2.3.3 Emissions reduction levers for all other fugitive emissions in gas and LNG production

All other fugitive emissions in the gas and LNG subsectors result from flaring, venting from other equipment and general leaks. There are a range of measures and technologies currently available to reduce these fugitive emissions shown in Table R.9.

Table R.9: Key emissions reduction levers to reduce fugitive emissions in gas and LNG subsectors

Emissions reduction opportunity		Readiness	Barriers to adoption
Fugitive abatement measures	Range of measures including: · replacing existing devices with lower-emitting versions, · installing new devices that can reduce or avoid vented emissions, · leak detection and repair programs, · more stringent regulations around non-emergency venting and flaring, and · equipment standards.	Commercial	· High CAPEX · Difficulty integrating within existing facilities

There are a range of measures and technologies commercially available to reduce fugitive emissions within oil and gas operations. Replacement of existing devices with lower-emitting versions include replacing pneumatic pumps with air instruments or electric pumps, replacing fuel motors with electric motors and converting wet seals to dry seals. Installation of new devices that can avoid or reduce emissions include boil off gas compressors and flare gas recovery systems. Leak detection and repair programs aid in the location and repair of fugitive leaks and can be applied across the supply chain. In addition to these technologies, other abatement measures include regulation of non-emergency venting and flaring, and equipment standards (APPEA, 2020; IEA, 2023b; Rystad Energy, 2023). The IEA estimates that many of these measures could be deployed in Australia at no net cost (IEA, 2024).

R.2.3.4 Emissions pathways for the gas processing and LNG subsectors

Based on the analysis of the key decarbonisation levers in the previous sections, the authority has developed the following possible emissions reduction pathways for gas processing and LNG subsectors that could be achieved through implementation of particular decarbonisation levers (CCA, 2024b). This ground up analysis considered factors including estimated timing of implementation, barriers to implementation and emissions reduction potential for each decarbonisation lever.

Table R.10: Possible decarbonisation pathway for the onshore gas processing and LNG subsectors, showing the relevant emissions reduction levers and corresponding reduction in emissions

	Emissions reduction opportunity (as % of total subsector emissions)	Estimated commencement
Leak detection and repair	2	2025
Flare and boil off gas recovery	7	2028
Connect to grid for auxiliary power	14	2030
Compressor electrification	48	2030-2035
CCS of reservoir CO_2	26	2030

R.3 Barriers, opportunities and enablers

R.3.1 Think global, act local

With significant reserves of critical metals and minerals required for the global energy transition, Australia is well placed to seize the opportunities, and leverage its competitive strengths, to grow and diversify metals and minerals extraction and increase value added processing onshore. This will help Australia improve resilience of supply chains while increasing sovereign critical minerals processing capacity.

R.3.2 Technical constraints

Some technologies to decarbonise the sector are not yet mature. Trials of electric mining haulage are currently being conducted, with widespread deployment not expected until after 2030. Drainage systems for surface coal mines and VAM abatement technologies for underground coal mines have not been widely demonstrated within Australia with technical hurdles still to be overcome.

The ability to retrofit or integrate new assets or infrastructure within an existing facility is a significant barrier for the deployment of technologies including electric drives or CCS within gas and LNG facilities, or the supporting infrastructure required to electrify a mine site. The associated production downtime to integrate new assets or equipment into an existing facility can also be a significant barrier to deployment.

R.3.3 Green premiums

The high cost of implementing most emissions reduction levers is a significant barrier across the resources sector. These technology deployment opportunities are typically capital intensive, and for some technologies that are more nascent there is also significant uncertainty around the cost of deployment.

The limited remaining lifespan of facilities reduces the incentive to invest in decarbonisation technologies, with viable business cases being difficult to develop when the payback period exceeds the life of the facility.

Allocating public capital expenditure committed to developing common infrastructure in parallel with significant development planning can act as a key enabler to kickstart the private finance necessary to build out the sector.

> The high cost of implementing most emissions reduction levers is a significant barrier across the resources sector.

Accelerated innovation and RD&D for nascent and less mature technologies through partnerships between industry, manufacturers and researchers, and access to funding mechanisms such as grants and concessional loans.

Accelerated uptake of reservoir CCS through the development of common use CCS infrastructure, including pipelines and storage, signalling from government on the role of CCS to decarbonise the sector, and improved regulation for the sequestration of reservoir CO^2.

Alternate business models which shift the investment towards OPEX costs rather than CAPEX costs where there is limited appetite for high upfront investment (such as facilities with limited lifespan or independent contractors who are responsible for the operation of the emissions intensive equipment).

R.3.4 Supply chain constraints

The lack of access to a sufficient supply of firmed low emissions electricity is currently a key barrier to the electrification of the resources sector. The authority heard that it is difficult for industry to create a business case to electrify their operations without a reliable source of firmed low emissions electricity. This challenge arises due to the remote locations of many resource projects.

There are uncertainties in the supply and availability of key decarbonisation levers including electric mining haulage and equipment and alternative fuels.

> *'There are also likely to be supply chain pressures when electrified fleets become widely available for deployment, so it will not be feasible to replace all global mining equipment fleets simultaneously.'*
>
> Glencore submission, 2024

Government actions could accelerate access to firmed renewable electricity by developing common use infrastructure, renewable energy hubs and incentivising all Safeguard facilities to switch to renewable electricity.

R.3.5 Planning, approvals and coordination

A number of submissions to the authority's 2024 Issues paper highlighted that approval processes for decarbonisation activities can be long, inefficient and duplicative between state and federal jurisdictions.

> *'A crucial consideration for AIGN members revolves around the approvals processes for developing new projects which could contribute to Australia's decarbonisation pathway. In short, Australia's approvals policy framework is no longer fit for purpose'.*
>
> Australian Industry Greenhouse Network submission, 2024

> *'One key issue we believe is important in enabling deployment of emission abatement or reduction technologies, is the streamlining of regulatory approvals and removal of duplication in policy across federal and state jurisdictions. This is a major area of concern to Glencore.'*
>
> Glencore submission, 2024

> *'Improving legislation to ensure approvals are provided in a timely manner and with certainty is a key enabler of Australia's energy transition, by providing a framework to streamline the approvals process required for renewable energy projects, the transmission network, and the energy and critical minerals sectors.'*
>
> Woodside submission, 2024

R.3.6 Regulatory inconsistency and gaps

Improved regulation within oil and gas operations for non-emergency venting and flaring, and equipment standards, could accelerate adoption. This should be done in conjunction with measures to improve measurement, monitoring, reporting and verification of fugitive methane emissions under the NGER scheme, as highlighted in the authority's 2023 Review of the National Greenhouse and Energy Reporting Legislation (CCA, 2023).

R.3.7 Workforce and skills shortages

The transition will require complex and digital skills from the resources workforce. The government's Critical Minerals Strategy aims for greater onshore refining (DISR, 2023). Processing capabilities represent a new driver for skilled roles that do not exist within the mining workforce (DISR, 2023). The use of automated and digital technologies in mining is giving rise to higher paying jobs and opportunities for remote and flexible work (AUSMASA, 2023).

The growth of remote operations centres is seeing an increase in workers being able to support mining operations from metropolitan rather than remote locations, providing an opportunity to expand workforce diversity (Australia Resources and Energy Group, 2018). These jobs will require higher digital skills and many need specialised job qualifications (AUSMASA, 2023).

The electrification of the mining industry will also see a need for upskilling (AUSMASA, 2023). Electrification will involve an ongoing transition of mobile plant and light vehicles away from diesel and on to battery-electric systems which will require workers on mine sites to be upskilled to support both diesel and electric plant vehicles (AUSMASA, 2023).

> *'…shortages of necessary skillsets risks delaying the transition. In an increasingly automated and decarbonised world, Australia's mining and energy sectors will need new skillsets and capabilities to prosper. Decarbonisation will radically increase the demand for electrical and trade skills and implementing more technology in the continued shift towards automation will require higher order capabilities across analytics and data science.'*
>
> BHP submission, 2024

The resources sector has an ageing workforce which could exacerbate pre-existing shortages. The number of young people choosing to work in the mining sector is being outstripped by those approaching retirement (AUSMASA, 2023).

A barrier to attracting younger workers to the sector is a negative perception of the mining industry and a lack of understanding of its role in the net zero transition. Research conducted by Year 13 noted that almost three quarters of respondents felt the mining industry did more harm than good and only 27% knew that the industry mined lithium, a necessary critical mineral for transition technologies (AUSMASA, 2023; Year 13, 2023). The same research also noted that career advice in relation to the mining industry is lacking.

Critical minerals mining may offer opportunities for coal mining workforces to be retrained and re-engaged. Analysis by the International Energy Agency (2021) found that reaching the goals of the Paris Agreement (climate stabilising at 'well below 2°C global temperature rise') would require a quadrupling of mineral requirements for clean energy technologies by 2040. Australia has some of the world's largest recoverable resources of critical minerals (Geoscience Australia, 2022) and could build a new critical minerals industry. These jobs could see regional workers moving to a different jurisdiction or to metropolitan hubs from which fly-in, fly-out operations are staged (AUSMASA, 2023).

As bioenergy industries develop, workers in petroleum refining are likely to experience demand for their skills in biofuels (JSA, 2023). Increasing global and domestic use of batteries to store renewable energy may increase demand for mining workers for lithium, graphite, nickel, cobalt and aluminium (JSA, 2023).

To attract younger workers, government and industry could communicate career opportunities and advise how the sector is addressing social and environmental issues. This includes the role the resource sector plays in providing the raw materials required for renewable technologies that will help Australia reach net zero.

Strong investment in VET across Australia could ensure the resources workforce has the skills needed for the transition. Investment in regions undergoing major workforce transitions (such as coal mining regions) is critical. Access to adequate training, facilities and educators must be available to not only meet the labour demands of the transition but to allow regions to benefit by producing local professionals.

R.3.8 Benefit sharing

> Decarbonising and diversifying the mining industry could unlock a new generation of high-wage, high-skilled, high-tech jobs in metals and minerals extraction and processing. This will help support Australia's regions by providing new employment opportunities while sustaining secure jobs for local businesses.

The growth of the critical minerals sector could provide opportunities to create intergenerational social and economic benefits for First Nations people. There will also be significant challenges involved in finding new work opportunities for First Nations people currently employed in emissions-intensive areas of the resources sector, including in low-skilled roles at risk of becoming redundant through automation.

Box R.1: First Nations opportunities in critical minerals growth

Growth of the critical mineral industry, being supported by more than $7 billion in federal funding (DISR, 2024b), can improve outcomes for First Nations people if combined with investments to reform engagement, negotiation, and delivery of projects.

Over the past few decades, progress has been made in increasing First Nations employment within the mining industry (Parmenter & Barnes, 2021). Many mining companies have entered into land use agreements which guarantee ongoing employment and training to First Nations communities (Commonwealth of Australia, 2016). Despite this progress, significant variability exists in employment and economic outcomes between communities (Taylor, 2018). As mining activities ramp-up to meet demand for critical minerals required to support renewables, regional planning is necessary to ensure that First Nations communities can share in associated benefits (Owen et al., 2022).

First Nations will have a crucial role to play in the growing critical minerals industry given the significant overlap between mineral reserves and the First Nations Estate[5] (Burton et al., 2024b). First Nations communities located alongside existing critical minerals projects have not always shared equitably in socio-economic benefits (Burton et al., 2024a). In communities which already host, or are likely to host future critical minerals projects, First Nations households can earn as little as 12% as much as non-Indigenous households, on a per capita basis (Burton et al., 2024a). Increasing automation of mines and the use of 'fly-in fly-out' workers may also limit opportunities for local workers, especially for First Nations people who are typically employed in lower skill roles (Holcombe & Kemp, 2019; Paredes & Fleming-Muñoz, 2021; Storey, 2010). Given these existing barriers to benefit sharing with First Nations, it must not be assumed that government investment in the critical minerals industry will result in better outcomes.

If barriers to benefit sharing with First Nations are to be overcome, representative bodies require equal access to information and expertise so that they can secure ongoing workforce and equity partnerships (Clean Energy Council and KPMG, 2024).

5 Also known as Australia's Indigenous land and forest estate

During consultation, the authority heard that whilst First Nations representatives have an intimate understanding of their Country, they often lack the technical expertise required to assess the impacts of developments on future generations (CCA First Nations Roundtable, 2024). Existing governance frameworks for the mining industry are generally reliant on 'negotiated agreements' which are determined on a project-by-project basis (Kung et al., 2022). First Nations require clear, accessible and accurate information and appropriate education to understand impacts to community, so that they can negotiate from a position of strength (Tomlinson, 2019). Both government and industry have a role to play in supporting this capacity uplift (Clean Energy Council and KPMG, 2024).

An independent inquiry into the destruction of ancient rockshelters in Western Australia's Juukan Gorge found that, without clear, enforceable standards for what constitutes 'informed' consent, past industry conduct has caused significant harm to First Nations Cultural Heritage (Joint Standing Committee on Northern Australia, 2021). The inadequacy of historical policy settings for protecting First Nations values from the impacts of mining has been detailed in academic analysis (Annandale et al., 2021; Burton et al., 2024a; Graetz, 2015; Kemp et al., 2023) and previous submissions from First Nations stakeholders, which detail lasting deleterious impacts to Community, Culture and Country (Janke et al., 2021).

Changes to legislative frameworks to ensure Free, Prior and Informed Consent (FPIC) in the expansion of critical mineral mining could reduce the risk of future harm to First Nations communities and values. The government's Critical Minerals Strategy commits to 'genuine engagement and collaboration with First Nations communities that promotes benefit sharing and respects the land and water rights and interests of First Nations people and communities' (DISR, 2023). The authority also welcomes the federal government's acceptance of a recommendation from the Juukan Gorge inquiry that '*the Australian Government legislate a new framework for cultural heritage protection at the national level… [which]… should set out the minimum standards for state and territory heritage protections consistent with relevant international law (including the United Nations Declaration on the Rights of Indigenous People UNDRIP)…*' (DCCEEW, 2022). Implementation of these cultural heritage reforms is an important pre-requisite to ensuring socially responsible expansion of critical minerals mining and refinement in Australia.

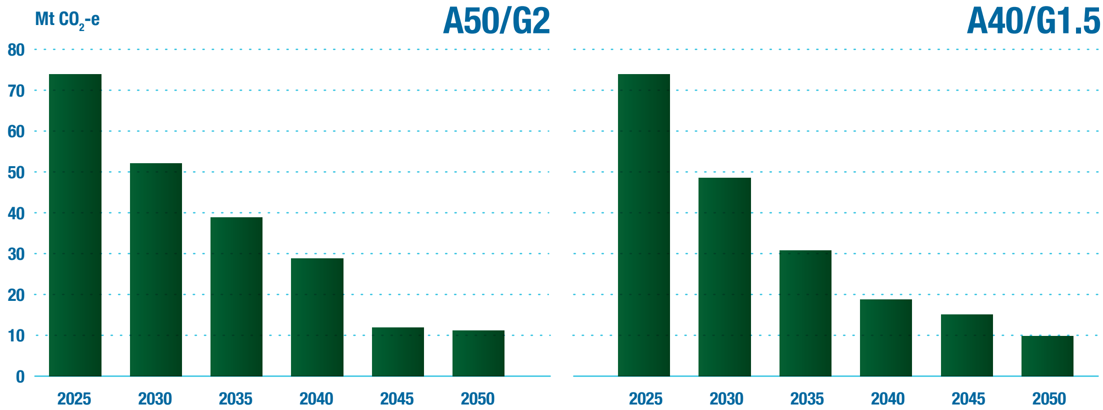
R.3.8 Information and data gaps

There is room to improve understanding of the application and safe deployment of gas drainage systems for surface coal mines and VAM abatement technologies.

R.4 Emissions pathways

In addition to the ground up analysis, the authority also commissioned modelling (conducted by CSIRO) of emissions from the resources subsector from 2025 to 2050 under various scenarios. The results for the A50/G2 and A40/G1.5 scenarios are shown in Figure R.6.

Figure R.6: Modelled emissions for the resources subsector, under A50/G2 and A40/G1.5 scenarios, 2025-2050



Source: CSIRO modelling in AusTIMES commissioned by the Climate Change Authority

Modelled emissions under both scenarios show significant reductions for the resources sector out to 2050. These reductions in emissions are driven by:

- Emissions from combustion reducing across the mining sector, partly due to fuel switching. Final energy use shows a sharp decline in diesel, which is predominantly replaced by electricity and, to a lesser extent, hydrogen.
- Emissions from fuel combustion declining within gas extraction, partly due to fuel switching from natural gas to electricity.
- Fugitive emissions decreasing across the coal mining, and oil and gas subsectors (due in part to the reduction in fossil fuel production as shown in Figure R.1).

A comparison between the authority's estimates of emissions from the Resources sector in 2050 from the ground up analysis and modelling are presented in Table R.11 (CCA, 2024b). It is important to note the emissions estimate from the ground up analysis does not take into account any change in production levels for any subsector. Estimates from the modelling scenarios incorporate projected changes in production (shown in Figure R.1) but do not explicitly account for efficiency gains through improved recycling.

Table R.11: Projections of emissions reductions to 2050 using estimates from AusTIMES modelling and ground-up analysis

Reference: emissions in 2022 were 99 Mt CO_2-e Subsector	Projected emissions reductions to 2050 (Mt CO_2-e)[6]		
	Modelling Scenario A50/G2	Modelling Scenario A40/G1.5	Ground-up
Coal mining	20	23	12
All other mining	11	11	14
Oil and gas extraction and processing (including LNG production)	30	28	28
Total	60	62	54

Projected emissions reductions were calculated as the difference between base year emissions and the projected 2050 emissions from each model. In AusTIMES the base year for the abatement calculation was 2025 and in ground-up estimates the base year for estimates was 2022.

R.4.1 Residual emissions

The modelling results indicate there could be 10-11 Mt CO_2-e of remaining emissions in the resources sector by 2050.

For some sources of emissions, there are limited opportunities for direct abatement in the near term due to lack of mature technologies. This includes decarbonising mining haulage and equipment, and abating fugitive emissions from underground and open cut coal mines.

In the longer term, the authority identified several sources of emissions which are currently expected to largely remain unabated out to 2050 due to the limited opportunities to decarbonise. These include emissions from offshore oil and gas facilities (due to space constraints and restricted access to renewable electricity) and fugitive emissions from open cut coal mines (due to unknown technical feasibility of open cut gas drainage systems).

6 Emissions estimates from the modelling scenarios take into account modelled changes in production (shown in Figure R.1), whereas the ground up analysis estimates assume constant production levels between 2022 to 2050 for all subsectors.

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