COAL INDUSTRY METHANE EMISSIONS

Unlocking cost-effective methane abatement in the NSW and QLD coal industry

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common capital

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Acknowledgement of country

Common Capital recognises the First Peoples of this nation and their ongoing connection to culture and country. We acknowledge First Nations peoples as the Traditional Owners, Custodians and Lore Keepers of the world's oldest living cultures, and pay our respects to their elders – past and present.

Our Approach

The Australian, New South Wales (NSW) and Queensland (QLD) Governments have legislated long-term emissions reduction and net zero targets. We sought to investigate the potential role for state policy in NSW and QLD to complement the national climate policy landscape and unlock cost-effective abatement of emissions from coal mines.

The findings and conclusions of this report are based on:

- Extensive desktop research of academic and government literature.
- Over 80 interviews and discussions with over 10 government teams, 10 NGOs and research organisations and 30 consultants, technologists and service providers. All were based in Australia or internationally, with specific expertise in Australia.
- Stakeholder analysis of over 200 organisations and individuals involved in coal mine methane abatement and measurement.
- Emissions analysis based on publicly reported Safeguard Mechanism data to understand the reported emissions and emissions intensity at each coal mine and coal company, and the emissions impact of the Safeguard Mechanism.
- Financial analysis based on public financial reports to understand the financial impact of the Safeguard Mechanism, abatement and measurement technologies, and potential policy mechanisms.
- Cost benefit analysis of different policy measures and design options that incentivise on-site abatement of fugitive emissions from coal mines. This analysis assessed the emissions impact, the cost/benefit to industry, and the overall societal cost/benefit.

Detailed analysis of the cost, potential and readiness of abatement technologies is outlined in Appendix A. Detailed methodology of the emissions analysis, financial analysis and cost benefit analysis is outlined in Appendix B.

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Executive summary

There is a significant opportunity for state policy in NSW and QLD to complement the Safeguard Mechanism and unlock cost-effective, near-term and on-site fugitive emissions abatement from coal mines. This would materially contribute to state emissions reduction targets and benefit the overall economy at a low (or negative) cost to the mining sector.

Fugitive emissions from coal mines are currently responsible for 9.7 $MtCO_2e$ in NSW (7% of annual emissions) and 11.6 $MtCO_2e$ in QLD (8% of annual emissions). Fugitive emissions could increase significantly, by 75% in NSW (to 17 $MtCO_2e$) and by 90% in QLD (to 22 $MtCO_2e$). This is due to the potential approval of new coal mines and expansion as well as improvements to methane measurement.

We estimate that there is approximately 5.1 $MtCO_2e$ per year of abatement available in NSW and 5.5 $MtCO_2e$ per year of abatement available in QLD that is likely to be cost-effective (< \$30/tCO_2e). This abatement opportunity is from current technologies deployed at just 15 of the largest emitting, operational underground mines – nine in NSW and six in QLD. These 15 mines produce 63% of coal mine fugitive emissions for 12% of coal production. There is likely to be greater feasibility and lower marginal cost of abatement at the gassier mines.

State policy could play an important role in complementing the Safeguard Mechanism to unlock this cost-effective, near-term and on-site abatement opportunity, for two reasons. Firstly, NSW and QLD's interim emissions targets are likely to require deeper reductions than those required under the projected Safeguard trajectories. Secondly, there are significant barriers to industry investment in on-site abatement, despite often costing less than \$30/tCO_2e. These barriers incentivise coal mines to purchase Australian Carbon Credit Units (ACCUs) and Safeguard Mechanism Credits (SMCs) to meet Safeguard baselines, which may not represent emissions reductions on NSW's or QLD's inventory. This may make NSW's and QLD's emissions targets more difficult to meet in the short to medium term without additional policy measures. Coal mines are disincentivised from investing in emissions reductions due to the opportunity cost of investing in abatement compared to more profitable allocations of capital, such as coal mine expansion. Moreover, first movers within each jurisdiction and company face initial technical, cultural, core business, regulatory and cost barriers. Finally, complementary state policies can also provide a backstop to improve investor confidence and remove risks associated with potential future changes to long term national policy settings.

Through an intensive co-design process, we developed and modelled the benefits of a suite of three complementary policy measures to help industry overcome these barriers and accelerate the adoption of cost-effective, on-site abatement.

The first is a methane abatement fund in NSW, which supports early adopters of abatement technology by sharing the elevated costs facing first movers across the rest of the industry, which in turn receives the benefits of a de-risked, low cost technology. QLD has already implemented the Low Emissions Investment Partnerships (LEIP) fund to help bring forward investment in mining abatement projects. The second policy measure is a set of regulated emissions intensity thresholds that require mines to reduce emissions intensity under a certain target to drive policy certainty and unlock cost-effective abatement. The third measure is a state-wide methane measurement network to support both the continuous adoption and improvement in best practice of integrated methane measurement technologies and validate the efficacy of public and private investments under the policy framework.

We modelled the impact on emissions and the costs and benefits to the broader economy and mining sector within NSW and QLD of these three policy measures, with a range of detailed design options and sensitivities. Our analysis found that state policies that complement the Safeguard Mechanism and bring forward fugitive emissions abatement may significantly reduce emissions, benefit the economy and have limited (or negative) costs to the coal mining sector, in both NSW and QLD. In NSW, combining the most effective design options across all three policy measures may reduce emissions in 2035 by 5.4 – 6.9 MtCO_2e. This contributes $3.4 – $4.3 billion to the economy, at a net cost to the mining sector of $2.70 to $4.10 per tonne of CO_2e abated. These costs and benefits were modelled for a methane abatement fund with a total cost of $210 million, which could be raised by a levy of approximately $0.20 per tonne of raw coal for five years, and a methane measurement network with a total cost until 2050 of approximately $6 million per mine ($8 million per year for every mine in NSW and $13 million per year for every mine in QLD), or $0.03 per tonne of coal. For context, coal companies have produced a long-term average profit of $33 per tonne of coal. In QLD, the policy measures may have a smaller effect, because our modelling attributes a significant amount of potential abatement to the planned impact of the LEIP. The most effective design options across all policy measures may reduce emissions in 2035 by 0.9 – 3.1 MtCO_2e. The impact on the wider economy ranges up to a benefit of $1.8 billion at a net cost to the mining sector as low as $9.70 per tonne CO_2e abated.

For NSW, the key takeaways from the cost benefit analysis (CBA) are that many detailed design options for the policy package may result in positive outcomes for emissions and the economy, at a low (or negative) cost to the mining sector. More ambitious policies (a larger methane abatement fund and regulated emissions intensity thresholds that commence earlier) tend to result in more favourable outcomes for the economy and mining sector. For QLD, the key takeaways are that regulated emissions intensity thresholds must bring abatement forward to 2035 or earlier in order to have a significant emissions reductions impact that is additional to the LEIP and to benefit the economy at a low cost to the mining sector. In both jurisdictions, policymakers have flexibility over the design of the potential policies, particularly over the choice to prioritise deep and cost-effective reductions at the 15 largest emitting mines or incentivise moderate abatement at a larger set of coal mines.

Summary for Policymakers

This report sets out the findings of a study into the opportunity for abatement of coal mine fugitive emissions in New South Wales (NSW) and Queensland (QLD).

Part 1.1 considers the scale of fugitive emissions and the potential for these emissions to change over time. Part 1.2 considers the potential, cost and readiness of abatement and measurement technologies. Part 1.3 assesses the barriers to abatement. Part 2 quantifies the costs and benefits of different state policy mechanisms to incentivise the abatement of coal mine fugitive emissions, by considering the impact on emissions, the coal mining sector and the NSW and QLD economies.

Fugitive emissions from coal mines are currently responsible for 9.7 $MtCO_2e$ in NSW (7% of annual emissions) and 11.6 $MtCO_2e$ in QLD (8% of annual emissions) (see Scenario 1 in Figure 1). These emissions, primarily composed of methane, occur as a by-product of coal mining.

Fugitive emissions could increase significantly, by 75% in NSW (to 17 $MtCO_2e$) and by 90% in QLD (to 22 $MtCO_2e$) (see Scenario 2 in Figure 1). There are two reasons for this:

- New coal mine projects and coal mine expansions currently awaiting approval may increase fugitive emissions by 4 $MtCO_2e$ in NSW and by 5 $MtCO_2e$ in QLD. The NSW Net Zero Commission's 2024 Annual Report highlights the significance of this pipeline of future emissions as a significant risk to NSW's emissions targets [1].
- Improvements in the accuracy of methane measurement technologies suggest that coal mine fugitive emissions may be higher than reported. As methane measurement continues to improve, the estimated coal mine fugitive emissions on the NSW and QLD inventories may increase.

Despite the potential for reported fugitive emissions to increase in the future, our analysis is based on currently reported emissions.

We estimate that there is approximately 5.1 $MtCO_2e$ per year of abatement available in NSW and 5.5 $MtCO_2e$ per year of abatement available in QLD that is likely to be cost-effective (< \$30/tCO_2e). This abatement opportunity is from current technologies deployed at just 15 of the largest emitting, operational underground mines – nine in NSW and six in QLD (see Scenario 4 in Figure 1). This abatement could contribute significantly to NSW's and QLD's interim and 2050 emissions targets.

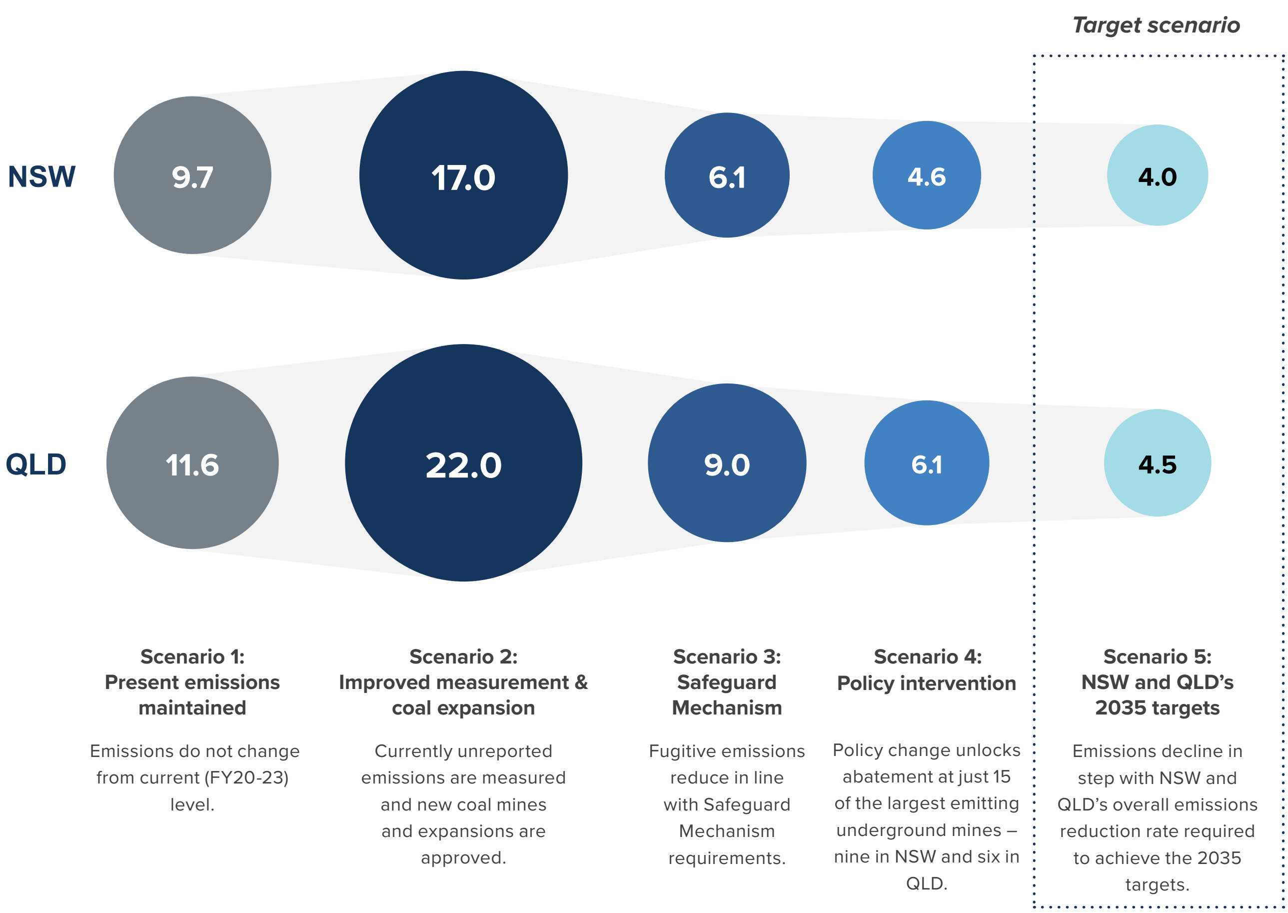
In NSW, the nine largest emitting underground mines have the greatest emissions intensity of coal production, reporting 65% of NSW's coal mine fugitive emissions while producing 11% of NSW's coal. In QLD, the six largest emitting underground mines report 60% of QLD's coal mine fugitive emissions while producing 13% of QLD's coal. Additional abatement opportunities are available at open-cut coal mines and less emissions-intensive underground coal mines.

Two main technologies – enhanced drainage and regenerative thermal oxidisers (RTOs) – are commercially ready and often cost less than \$30/tCO_2e. RTO deployment will likely be subject to an update of the mine safety framework in NSW and QLD.

Figure 1

State policy interventions can result in significant and cost-effective emissions reductions to support 2035 and 2050 targets

The potential fugitive emissions from coal mines in NSW and QLD in 2035 under five scenarios (MtCO_2e)



Dimensions are to scale. The opportunity for cost-effective, commercially ready abatement technologies at the 15 largest emitting underground mines is represented in Scenario 4. This diagram is a summary of the findings throughout Parts 1.1 and 1.2 of this report. Sources, assumptions and methodology are outlined in Part 1, Appendix A and Appendix B.

State policy could complement the Safeguard Mechanism to unlock cost-effective, near-term and on-site abatement that would support NSW's and QLD's 2030, 2035 and 2050 emissions targets. The importance of this opportunity is highlighted by the NSW Net Zero Commission's 2024 Annual Report, which states: "Unless action is accelerated, NSW may not reach net zero by 2050 and we will fail to meet out nearer term targets" [1].

State policy could play an important role in complementing the Commonwealth to achieve these targets for two reasons:

- Firstly, NSW and QLD's interim emissions targets are likely to require deeper reductions than those required under the projected Safeguard trajectories (compare Scenarios 3 and 5 in Figure 1).
- Secondly, there are significant barriers to industry investment in on-site abatement, despite often costing less than \$30/tCO_2e. These barriers incentivise coal mines to purchase ACCUs and SMCs to meet Safeguard baselines, which may not represent emissions reductions on NSW or QLD's inventory.

These barriers include:

Financial opportunity cost – Our analysis and interviewees suggest that coal companies are unlikely to invest their capital in on-site abatement infrastructure due to the high opportunity cost. Coal companies must decide between allocating limited capital to abatement infrastructure, coal production, or paying shareholder dividends. Our analysis suggests that coal companies in NSW and QLD would pay an average of between \$0.08 and \$0.65 for every tonne of coal produced from 2024 until 2050 to meet their Safeguard baselines with ACCUs and SMCs. In comparison, investing in on-site abatement would yield up to an additional \$2.30 per tonne of coal on average, through the generation of SMCs and the reduction of Safeguard compliance costs. Coal companies returned an average of \$33 in profit per tonne of coal from 2014 to 2021 and are likely to continue to return a similar (or greater) profit into the future. Hence, coal companies are likely to prioritise the purchase of ACCUs and SMCs over on-site abatement, choosing to allocate their limited capital to coal production and other more profitable pathways.

Core business – Coal companies, like most companies, focus their capital, resources and attention on their core capabilities. On-site abatement is not currently core business for Australian coal miners. Abatement projects face challenges of cross-organisational capability gaps and the need to direct attention away from core activities. Conversely, coal companies may purchase ACCUs or SMCs to meet Safeguard requirements, as a lower risk pathway without the need to tie up capital, resources and attention in non-core business activities.

First-of-a-kind (FOAK) – For any new technology, FOAK projects typically face higher upfront cost and regulatory challenges, often leading to a first mover disadvantage in established industries. This applies to FOAK projects for a particular company and each new jurisdiction the technology is deployed in. The first movers to invest in on-site fugitive methane abatement in NSW and QLD are likely to also face these issues. This includes the risks and costs of developing internal capabilities and helping regulators develop new rules and processes to ensure safety and effectiveness of these technologies in the regulatory contexts of NSW and QLD.

Policy uncertainty – From our interviews, we heard that within the coal industry there is perceived regulatory uncertainty related to the potential removal or softening of Safeguard obligations under a change of government, which disincentivises investment in abatement.

State policies that complement the Safeguard Mechanism and bring forward fugitive emissions abatement may significantly reduce emissions, benefit the economy and have low (or negative) costs to the coal mining sector, in both NSW and QLD. We modelled the costs and benefits of three state policy mechanisms that could be implemented in isolation or combined, to complement the Commonwealth and unlock cost-effective, near-term and on-site abatement. The costs and benefits assessed included the impact on emissions, the state economy, the mining sector and the benefit-cost ratio (BCR). The three policy measures considered were:

- A methane abatement fund in NSW to share the elevated costs facing first movers with the wider industry. QLD has already implemented the LEIP program, which achieves these outcomes.
- Regulated emissions intensity thresholds that remove regulatory uncertainty and drive the achievement of cost-effective, on-site abatement aligned with interim emissions reductions targets.
- A methane measurement network to support both the continuous adoption and improvement in best practice of integrated methane measurement technologies and validate the efficacy of public and private investments under the national and state policy frameworks.

In NSW, all policy measures that incentivised abatement resulted in significant emissions reduction, benefit to the wider state economy and low (or negative) costs to the mining sector. The scenarios that were the most ambitious in combining different policy mechanisms and bringing forward abatement to 2035 or earlier produced the most positive results. Combining the most effective design options across all three policy measures may reduce emissions in NSW in 2035 by 5.4 – 6.9 MtCO_2e. This contributes $3.4 – $4.3 billion to the economy, at a net cost to the mining sector of $2.70 – $4.10 per tonne of CO_2e abated. Even when testing extreme sensitivities, like doubling the cost of abatement, or halving the potential of abatement, the opportunity for state policy to unlock positive outcomes for NSW remained significant.

In QLD, our modelling attributed a significant amount of abatement to the LEIP. There is an opportunity for further state policy to complement the LEIP and the Safeguard Mechanism if abatement is brought forward to 2035 or earlier. The most effective design options across all three policy measures may reduce emissions in QLD in 2035 by 0.9 – 3.1 MtCO_2e. The impact on the wider economy ranges up to a benefit of $1.8 billion at a net cost to the mining sector as low as $9.70 per tonne CO_2e abated. However, policy mechanisms that do not bring abatement forward to 2035 or earlier are less likely to have a significant additional impact.

There is a significant opportunity for state policy in NSW and QLD to complement the Safeguard Mechanism and unlock cost-effective, near-term and on-site fugitive emissions abatement from coal mines. This would materially contribute to state emissions reduction targets and benefit the overall economy at a low (or negative) cost to the mining sector.

PART 1

The opportunity and barriers to cost-effective abatement

Part 1.1	Considers the scale of fugitive emissions and the potential for these emissions to change over time.
Part 1.2	Considers the potential, cost and readiness of abatement and measurement technologies.
Part 1.3	Assesses the barriers to abatement.

Key takeaways

1

Fugitive emissions from coal mines are significant and likely to rise.

Fugitive emissions are currently responsible for 9.7 $MtCO_2e$ in NSW (7% of annual emissions) and 11.6 $MtCO_2e$ in QLD (8% of annual emissions). Fugitive emissions could increase by 75% in NSW (to 17 $MtCO_2e$) and by 90% in QLD (to 22 $MtCO_2e$) due to improvements in measurement methods and the approval of new coal mines and expansion projects.

2

There is a significant opportunity for emissions reductions through deployment of commercially ready technologies.

We estimate that there is approximately 5.1 $MtCO_2e$ per year of abatement available in NSW and 5.5 $MtCO_2e$ per year of abatement available in QLD that is likely to be cost-effective (< \$30/tCO_2e).

3

Prioritising nine mines in NSW that produce 65% of emissions and six mines in QLD that produce 60% of emissions is an opportunity for low cost, quick wins.

Emissions intensity varies significantly between mines. By focusing on a small number of sites – responsible for 65% of emissions and 11% of coal production in NSW, and 60% of emissions and 13% of coal production in QLD – substantial abatement can be achieved efficiently and cost-effectively.

4

State policy could play an important role in complementing the Safeguard Mechanism to unlock this abatement.

There are two reasons why complementary state policy may unlock low cost abatement: firstly, NSW and QLD's interim emissions targets are likely to require deeper reductions than those projected under Safeguard trajectories; secondly, there are significant barriers to industry investment in on-site abatement, including opportunity cost, core business, first-of-a-kind and policy uncertainty barriers.

1.1

NSW and QLD coal mine methane emissions are significant and likely to rise

Fugitive emissions from coal mines account for 7% of NSW's emissions and 8% of QLD's emissions

In NSW, fugitive emissions from coal mines account for 9.7 $MtCO_2e$ every year, equivalent to 7% of annual NSW emissions. In QLD, fugitive emissions from coal mines account for 11.6 $MtCO_2e$ every year, equivalent to 8% of annual QLD emissions.[1,2,3] These estimates only account for coal mines that report to the Safeguard Mechanism – inclusion of fugitive emissions from smaller coal mines would increase the total estimate of fugitive emissions.

Fugitive emissions occur as a by-product of coal mining; they are waste emissions. They occur as methane (and to a lesser extent carbon dioxide) is released from coal seams into the atmosphere during the process of coal mining. In this report we do not include or consider emissions from abandoned or closed coal mines (approximately 3 – 5% of Australia's coal mine methane emissions [2]).[4]

The majority of reported fugitive emissions come from underground mines. In NSW, 82% of coal mine fugitive emissions are from underground mines, while the remaining 18% are from open-cut mines. In QLD, 72% of coal mine fugitive emissions are from underground mines, while the remaining 28% are from open-cut mines. Fugitive emissions from coal mining are 95% methane [3]. Breakout Box 1 outlines how the global warming potential (GWP) of methane compares to carbon dioxide and how methane has a greater impact on short-term warming than is valued by the GWP_{100} metric.

Our analysis distinguishes between underground and open-cut coal mines because they face distinct issues and have a different set of technological solutions.

[1] NSW's fugitive emissions of 9.7 $MtCO_2e$ and QLD's fugitive emissions of 11.6 $MtCO_2e$ represent the average reported emissions from coal mines under the Safeguard Mechanism from FY20 to FY23. An average over four years was taken to minimise the impact of year-by-year fluctuations in coal production, which could skew emissions estimates for individual years. In NSW, an estimate of 9.7 $MtCO_2e$ is generally consistent with the emissions estimates in the Australian National Greenhouse Accounts, which suggest annual fugitive emissions of 9.6 $MtCO_2e$ from NSW coal mines [56]. The NSW Net Zero Emissions Dashboard suggests that fugitive emissions from 2019 to 2022 have been an annual average of 12.1 $MtCO_2e$ [58]. In QLD, an estimate of 11.6 $MtCO_2e$ is generally consistent with the emissions estimates in the Australian National Greenhouse Accounts, which suggest annual fugitive emissions of 10.9 $MtCO_2e$ from QLD coal mines [56].

[2] In 2023, the Climate Change Authority determined that the average ratio of fugitive emissions to total scope 1 emissions was 0.95 for underground mines and 0.41 for open-cut mines [5] – these factors have been used throughout our analysis to convert Safeguard-reported scope 1 emissions to fugitive emissions. Therefore, the reported Safeguard emissions from NSW and QLD coal mines from FY20 to FY23 were 12.9 and 18.0 $MtCO_2e$ of scope 1 emissions, respectively, of which 9.7 and 11.6 $MtCO_2e$ are estimated to be fugitive emissions.

[3] Fugitive emissions of 9.7 $MtCO_2e$ represent 7% of total NSW emissions in 2019, 2020 and 2021 - as per total emissions reported by the NSW Net Zero Emissions Dashboard [58]. Emissions from 2022 have not yet been reported. Fugitive emissions of 11.6 $MtCO_2e$ represent 8% of QLD emissions (excluding the LULUCF sector) in 2019, 2020, 2021 and 2022 - as per total emissions reported by the Australian National Greenhouse Accounts [56].

[4] Emissions from abandoned and closed mines are likely to increase as more coal mine close.

BREAKOUT BOX 1

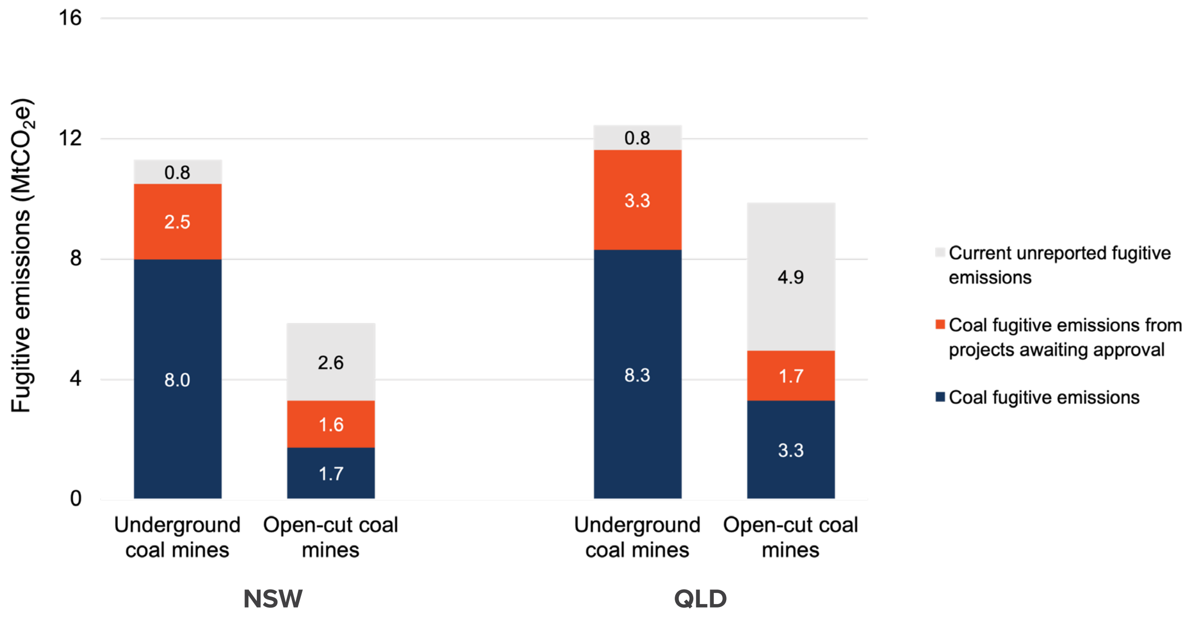
The global warming potential of methane depends on the timeframe used

GWP is a measure of the amount of heat trapped in the Earth's atmosphere by a tonne of greenhouse gas, relative to a tonne of carbon dioxide. Over a 100-year timeframe, methane has a GWP 28 times that of carbon dioxide. International and national emissions accounting frameworks use a 100 year timeframe when considering GWP (GWP_{100}), and therefore this analysis uses GWP_{100} as well. However, methane has a very short atmospheric lifetime, which means its greenhouse effect is concentrated in the short-term. When comparing the greenhouse effect of methane and carbon dioxide over a 20-year timeframe (GWP_{20}), methane is 82 times more effective at trapping heat than carbon dioxide. This means that using a GWP_{100}, like in this report, under-values the short-term warming impact of methane. Methane has a greater impact on 'peak warming' and potential climate tipping points than is represented by using a GWP_{100}.

Figure 2

Reported fugitive emissions from coal mines could increase due to approved coal mine projects and improved measurement

Current and potential fugitive emissions from coal mines in NSW and QLD



Current coal fugitive emissions (solid blue) are calculated by averaging reported emissions from Safeguard mines from FY20-23 (see the first subsection in Part 1.1 and 'Current and future coal production, fugitive emissions and emissions intensity' in Appendix B). Coal fugitive emissions from projects awaiting approval (solid orange) are calculated by proponent-led projections of fugitive emissions [4] (see the subsection on new coal mines below and 'Current and future coal production, fugitive emissions and emissions intensity' in Appendix B). Current unreported fugitive emissions (solid grey) represent a single, conservative scenario that is significantly lower than many independent estimates (see the subsection on improved measurement, directly below). This scenario is designed to represent the order-of-magnitude impact of improved measurement, rather than a precise estimate of actual emissions.

Reported fugitive emissions from coal mining could increase by 75% in NSW and by 90% in QLD

Reported methane emissions from coal mines are unlikely to decline in the coming years without policy change. Conversely, the approval of new coal mines and expansion projects, and emerging improvements in methane measurement accuracy may result in the reported fugitive methane emissions increasing, as shown in Figure 2. In NSW, fugitive emissions may increase by 75%, to 17 $MtCO_2e$. In QLD, fugitive emissions may increase by 90% to 22 $MtCO_2e$. Despite the potential for reported fugitive emissions to increase in the future, our analysis throughout Part 1 and Part 2 is based on currently reported emissions.

Improvements in methane measurement may increase reported fugitive emissions

Methane measurement technologies have advanced significantly in recent years as summarised in subsection 'Coal mine methane measurement technologies are rapidly developing' within Part 1.2 and Appendix A. The development of these new methane measurement technologies has shown that open-cut coal mine fugitive emissions may be higher than currently reported [5] [6] [7] [8] [9] [10] [11] [12].[5] Independent estimates of Australia's coal mine methane emissions suggests that the actual emissions from the sector may be between 65% and 172% greater than reported [6] [7] [8] [9] [13]. While there is significant uncertainty, in Figure 2 we present a conservative scenario where Australian coal mine emissions are 43% greater than reported. Specifically, emissions from open-cut mines are 150% greater than reported and emissions from underground mines are 10% greater than reported.[6,7] This is the scenario that we use to estimate that fugitive emissions in NSW and QLD may increase by 75% and 90%, respectively. Using this scenario, fugitive emissions from NSW may increase by 3.4 $MtCO_2e$ (35%) and fugitive emissions from QLD may increase by 5.8 $MtCO_2e$ (50%). This conservative scenario is presented to represent the potential scale of impact of more accurate measurement technologies, rather than to represent the actual emissions from coal mines. However, for the rest of our analysis in Part 1 and Part 2, we use the reported fugitive emissions rather than an assumption that emissions are higher than reported.

[5] This was also acknowledged repeatedly in confidential interviews with academics, industry, NGOs and other current state and national practitioners.

[6] We include mines that employ both underground and open-cut operations within the 'underground' category.

[7] Underground coal mines are generally considered to measure emissions with reasonable accuracy [5]. However, accuracy of underground coal mine methane measurement could be increased by requiring mines to measure their emissions continuously. Currently, mines may measure periodically, which may under-estimate the actual emissions if the emissions monitors are not turned on during particularly emissions-intensive days of the coal mining process.

Open-cut coal mines in Australia report their fugitive emissions through a choice of methods in the National Greenhouse Energy and Reporting (NGER) scheme. In December 2023, the Climate Change Authority (CCA) released a review of the NGER scheme. They found that the methods used to estimate methane from open-cut mines (Methods 1 and 2) could be updated to improve their accuracy [5]. In August 2024, The Commonwealth Government announced that Method 1 would be phased out by FY27, and that Method 2 would be "reviewed" [14]. Breakout Box 2 outlines Methods 1 and 2 and their areas for improvement.

There are two key implications from this analysis:

- It increases the importance of action to reduce coal mine methane.
- It shows that accurate measurement of coal mine methane is important to understand the actual magnitude of emissions, verify abatement support the Safeguard Mechanism and other policies that require an accurate quantification of emissions. Accurate, facility-specific measurement is also likely to even the playing field between open-cut and underground mines.[8]

New coal mines and expansion projects could increase fugitive emissions in NSW and QLD by 40%

There are at least 17 new coal mines and coal mine expansion projects in NSW awaiting Federal approval, and at least 18 in QLD. The NSW Net Zero Commission's 2024 Annual Report states that there are a total of 33 planning applications for coal operations [1]. Some of these mines have recently received Federal approval in 2024 [4] [1].[9] Estimates from the coal mine proponents in NSW suggest that collectively, these new projects could produce 4 $MtCO_2e$ every year in fugitive emissions (an increase of 41%). The NSW Net Zero Commission highlights this pipeline of emissions as a key risk to NSW's 2030, 2035 and 2050 emissions targets, writing: "The Commission is concerned about the risks to state's targets from increased emissions in the resources sector" [1]. In QLD, the proponents of the coal mine projects estimate collectively that new projects could increase annual fugitive emissions by 5 $MtCO_2e$ (an increase of 43%). It should be noted that actual emissions from these coal mines may also end up being greater than projected. Conversely, coal mines are likely to produce less than their maximum mining limit, which would reduce projected emissions.

[8] The Safeguard Mechanism determines baselines (emission limits) for coal mines based on an average emissions intensity across all mines. Because open-cut mines are more likely to have emissions that are not currently measured, it skews the industry average emissions intensity. Underground mines are therefore required to reduce emissions rapidly, while open-cut mines have very relaxed requirements. For some open-cut mines, their projected 2030 and 2040 baselines are above their current annual emissions [55].

[9] Only considering projects currently awaiting Commonwealth EPBC approval. More projects may be awaiting approval by the NSW Government.

BREAKOUT BOX 2

NGER Methods 1 and 2 for open-cut coal mines depends on the timeframe used

Methods 1 and 2 are used by open-cut coal mines in Australia to estimate their annual emissions. This breakout box outlines how they work, and their limitations.

Method 1 uses a state-based emissions factor, multiplied by total coal production to estimate emissions. The Commonwealth is phasing out Method 1 by FY27 [14].

Insights from interviewees supported findings from other studies that the primary limitation of Method 1 is that different coal mines have large variances in 'gassiness'. Using a state average under-estimates the emissions from particularly gassy coal mines. A well-known example of this is Hail Creek coal mine in QLD. Independent estimates suggest that its reported emissions (using Method 1)[10] might under-estimate the actual emissions by over 10 times [5] [10] [11] [12]. While Method 1 is also likely over-estimating emissions from less gassy coal mines, these mines may instead report with Method 2. One study has found that every mine that has transitioned from Method 1 to Method 2 has reduced its estimated emissions [15].

Method 2 involves sampling and modelling of the gas content within the coal seam (similar to the processes used to estimate a coal seam gas resource).

Stakeholder concerns raised in interviews for this research, which could be considered in Australian Government's planned review of Method 2, include:

1. Additional sources of methane outside of the scope of the sampling and modelling methodology. Methane from other coal seams is likely to leak in and escape into the atmosphere. Method 2 requires that the methane content up to 20 metres below the coal seam is estimated and assumed to be released. However, our interviewees and research suggest that methane may leak from up to 100 metres below the seam, 200 metres above and many hundreds of metres horizontally [16].

2. The sampling process may produce an unrepresentative estimate of the methane volumes. A minimum of three samples are required and companies do not need to disclose their process to calculate their total gas resource. Our interviewees suggested that this could lead to an estimate of the methane resource that was not representative of the total resource. The CCA's 2023 review of the NGER scheme reached the same conclusion [5].

For example, one report that analyses Method 2 has shown that the Carmichael mine in QLD estimates fugitive emissions through Method 2, at a rate that is 135 times lower than the state average emissions per tonne of coal [15]. In NSW, the Hunter Valley Operations coal complex reduced its annual reported emissions by 600,000 tCO_2e in 2016 by shifting from Method 1 to Method 2 [15].

Therefore, there is a risk that the fugitive emissions from open-cut coal mines are greater than currently reported, increasing the importance of coal mine methane measurement and abatement.

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[10] Mines do not have to publicly disclose which method they report with. However, our estimates of Hail Creek's emissions using the Method 1 QLD emissions factor are very close to their reported emissions. This strongly suggests that Hail Creek uses Method 1.

Fugitive emissions from coal mines could make 2030 and 2035 state targets harder to meet

NSW

Current fugitive emissions from NSW coal mines are reported as 9.7 MtCO_2e. This could increase to approximately 18 MtCO_2e annually from improvements to measurement and the approval of new coal mines and expansion projects.

These new and increased emissions sources may make the legislated state emissions reduction targets (50% of 2005 levels by 2030, 70% by 2035 and net zero by 2050 [17]) harder to meet. Currently, NSW's total emissions must decline by 59% from 2022 to 2035, to meet the legislated 2035 target. If coal mine methane were not addressed with state policy, the 2035 target would require an emissions reduction of 64% from all other sectors from 2022 levels. If emissions that are not currently measured and coal mine expansions were included, the required reduction rate could reach up to 71%, increasing the requirement for emissions reductions on other sectors. This further highlights the importance of action to unlock coal fugitive abatement and measurement opportunities.

The subsection titled 'Interim state targets' in Appendix B outlines the methodology used to calculate the emissions reduction rates above.

QLD

Current fugitive emissions from QLD coal mines are reported as 11.6 MtCO_2e. This could increase to approximately 23 MtCO_2e annually from improvements to measurement and the approval of new coal mines and expansion projects.

These new and increased emissions sources may make the legislated state emissions reduction targets (75% of 2005 levels by 2035 and net zero by 2050 [18]) harder to meet. Currently, QLD's total emissions must decline by 61% from 2022 to 2035, to meet the legislated 2035 target. If coal mine methane were not addressed with state policy, the 2035 target would require an emissions reduction of 68% from all other sectors from 2022 levels. If emissions that are not currently measured and coal mine expansions were included, the required reduction rate could reach up to 77%, increasing the requirement of emissions reductions on other sectors. This further highlights the importance of action to unlock coal fugitive abatement and measurement opportunities.

The subsection titled 'Interim state targets' in Appendix B outlines the methodology used to calculate the emissions reduction rates above.

1.2 Existing abatement technologies could deliver deep, low cost emissions cuts

Overview

Our analysis suggests there is an opportunity in NSW and QLD to reduce coal mine methane emissions by approximately 50% through cost-effective (< $30/tCO$_2$e) and commercially ready fugitive emissions abatement. This can be realised through the deployment abatement technology at the nine gassiest mines in NSW and the six gassiest mines in QLD.

- Implementing abatement at nine coal mines in NSW and six coal mines in QLD can target the majority of coal mine emissions, while having negligible impact on coal production. This is due to the significant variance in gassiness of mines. In NSW, nine coal mines produce 65% of the state's fugitive emissions for only 11% of the state's coal. In QLD, six coal mines produce 60% of the state's fugitive emissions for only 13% of the state's coal.
- Abatement technologies now exist that are cost-effective and commercially ready. These technologies could abate approximately 50% of both NSW and QLD's fugitive methane emissions in the near-term by deployment at the largest emitting underground mines (nine in NSW, six in QLD).
- Top-down measurement technologies now exist to support abatement and compliance. Further research and development are required to develop a network of different measurement approaches that most accurately measures facility-specific coal fugitive emissions.

Prioritising the 15 most emissions-intensive is an opportunity to deliver low cost quick wins

Nine mines in NSW report 65% of NSW's coal mine methane emissions for 11% of the state's coal production. Six mines in QLD report 60% of QLD's coal mine methane emissions for 13% of the state's coal production.[11,12] Figure 3 shows the emissions intensity of these nine mines in NSW and Figure 4 shows the emissions intensity of these six mines in QLD. Throughout this report, these 15 mines will be known as the 'largest emitting underground mines'. The 15 largest emitting underground mines all produce more than double the federally legislated 'industry-average' emissions per tonne of raw coal. This is due to the huge variation in gassiness between coal mines. Different coal seams vary in the quantity of gas they contain, and the composition of the gases. Abatement at these nine mines in NSW and six mines in QLD is both more cost-effective and technologically feasible, due to the high methane content. The largest emitting underground mines provide an opportunity to target 65% of NSW coal mine emissions and 60% of QLD coal mine emissions in the near-term, at low cost.[13] The approximately 80 remaining operating mines (30 in NSW, 50 in QLD) that are not the largest emitting underground mines (which we have labelled as open-cut mines and 'other underground mines') represent further opportunities for abatement, depending on the feasibility and cost at each mine.

[11] This is based on Safeguard-reported emissions. If methane measurement improves, the nine mines in NSW and the six mines in QLD are likely to report a smaller fraction of each state's coal mine emissions.

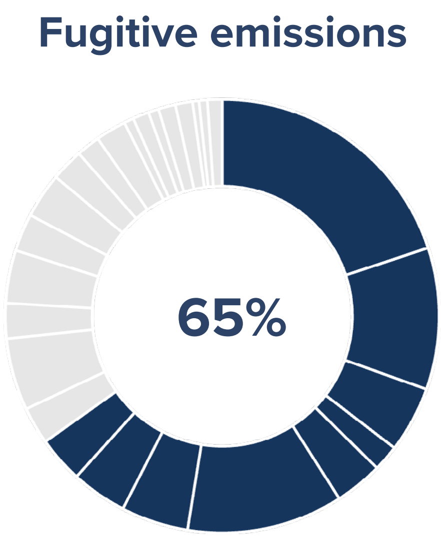
[12] The emissions and coal production are both expressed as a percentage of the emissions and coal production from all Safeguard coal mines in the state. The nine gassiest mines in NSW produce 9% of all state coal, when considered as a fraction of all NSW mines. The six gassiest mines in QLD produce 11% of all state coal, when considered as a fraction of all QLD mines.

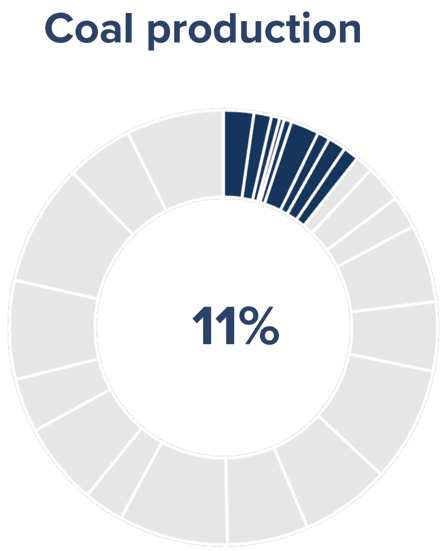
[13] One of the nine largest emitting underground mines in NSW (Russell Vale Colliery) was closed in 2024. We have included its emissions in our analysis of the abatement opportunity in Part 1, as there is a strong push to keep the mine open under different ownership [60]. In QLD, one of the six largest emitting underground mines (Grosvenor) has ceased production, but it appears likely that mining may continue when safe [63]. Two of the nine largest emitting underground mines in NSW and two of the six largest emitting underground mines in QLD may need to extend their mining licences to continue mining past 2032. This may reduce the incentive for mines to invest in abatement infrastructure, but many of the estimates of RTO costs in Appendix A amortise capital costs over 7 – 10 years. Therefore, abatement is still likely to be cheaper than purchasing ACCUs for mines that do not have the certainty of continued operations beyond 2035.

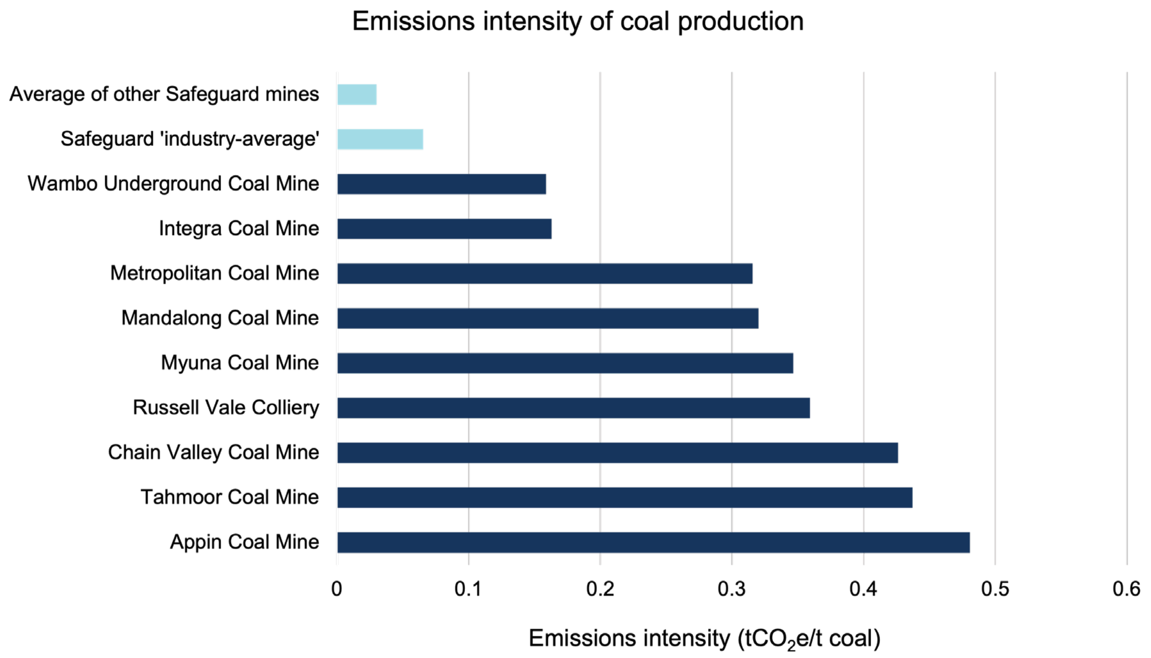
Figure 3

Nine mines produce 65% of NSW's fugitive emissions and 11% of NSW's coal

Emissions intensity of the nine largest emitting underground mines in NSW from 2020 to 2023





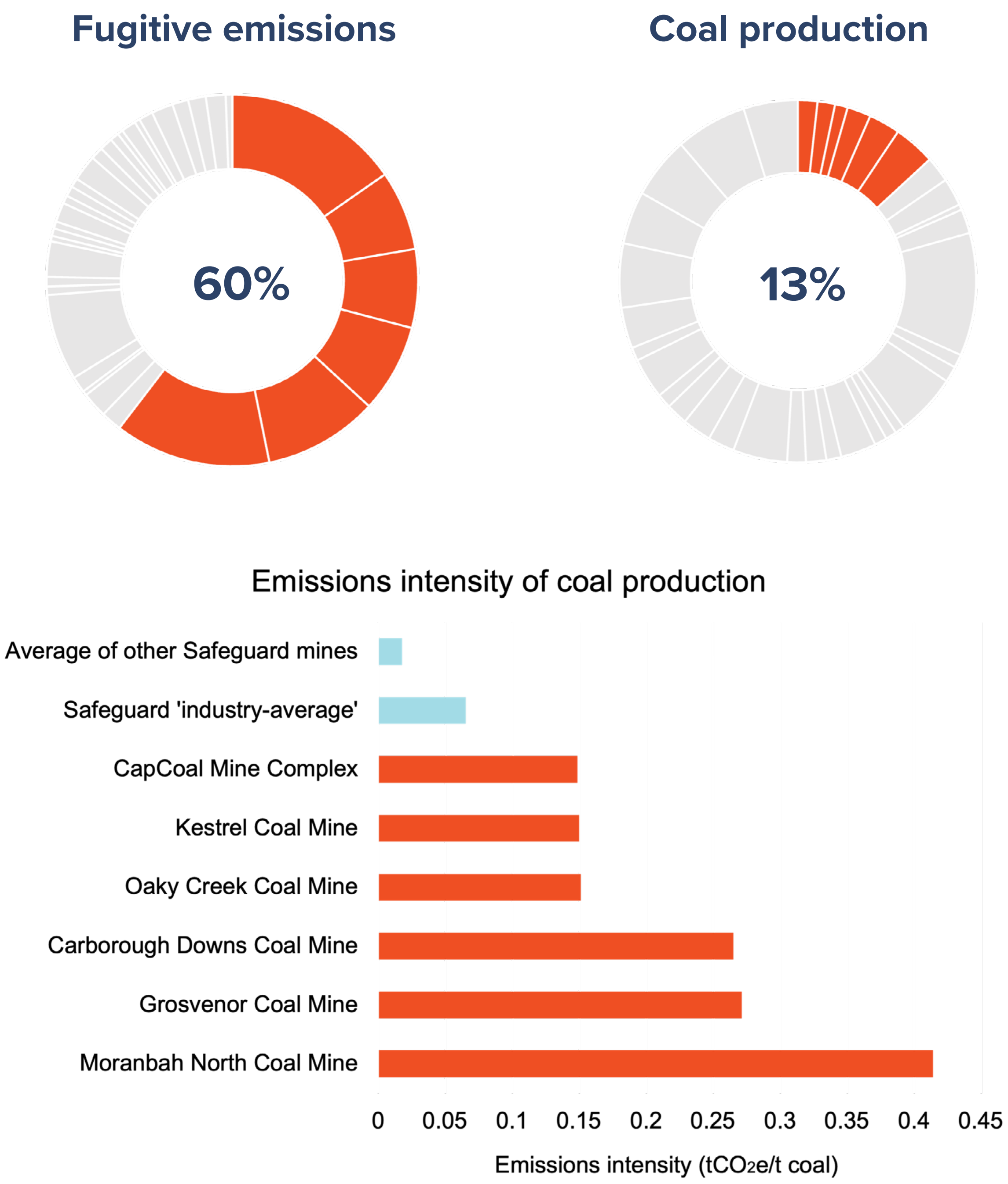


The donut charts represent fugitive emissions and coal production from Safeguard-reporting NSW mines, with the largest emitting underground mines highlighted in dark blue. The bar chart compares the emissions intensity of the nine mines with an average emissions intensity of other Safeguard mines, and the legislated 'industry-average' emissions intensity [19]. Methodology outlined in 'Current and future coal production, fugitive emissions and emissions intensity' in Appendix B.

Figure 4

Six mines produce 60% of QLD’s fugitive emissions and 13% of QLD’s coal

Emissions intensity of the six largest emitting underground mines in QLD from 2020 to 2023



Emissions intensity of the six largest emitting underground mines in QLD from 2020 to 2023. The donut charts represent fugitive emissions and coal production from Safeguard-reporting QLD mines, with the largest emitting underground mines highlighted in orange. The bar chart compares the emissions intensity of the six mines with an average emissions intensity of other Safeguard mines, and the legislated ‘industry-average’ emissions intensity [19]. Methodology outlined in ‘Current and future coal production, fugitive emissions and emissions intensity’ in Appendix B.

Commercially ready technologies could reduce roughly half of NSW and QLD coal mine methane emissions for under $30/tCO_2e

Commercially ready abatement technologies for fugitive methane from underground mines include enhanced drainage and RTOs [20] [21] [9] [22]. For open-cut mines, the technology at the highest readiness level to abate fugitive methane is drainage, which is currently at the demonstration stage [22] [2] [23]. We have analysed the abatement potential, cost and readiness across three different mine types: the 15 largest emitting underground mines (nine in NSW, six in QLD), other less emissions-intensive underground mines and open-cut mines [22] [2] [23]. These results are summarised in Table 1.

There are two sources of coal mine methane emissions that are manageable with commercially ready abatement technologies, represented in Figure 5. The first source, ventilation air methane (VAM), is methane from underground mines that has been diluted to safe levels and is released into the atmosphere from the mine's vent shafts. VAM is low in concentration, but accounts for a majority (60% - 80%) of coal mine methane emissions from underground mines [22][2]. VAM can be destroyed by RTOs, which are large combustion chambers that are hot enough to oxidise the low concentration VAM. RTOs are designed to oxidise VAM between specific concentrations ranges, typically reported as 0.2% - 1.2% [22] [16] [21]. RTOs may not be applicable at all underground mines, particularly if the VAM concentration is likely to be lower than 0.2% - 0.3%.

The second source, drained methane, is directly extracted through vacuum pressure from coal seams and recovered in much higher concentrations than VAM. Drained methane can be captured and used for power generation, flared, or released directly into the atmosphere (venting). Both using the drained gas for power generation and flaring the drained gas oxidises the methane into CO_2. While methane has often been drained from underground mines for safety purposes, more extensive drainage could be deployed at both underground and open-cut mines to capture and oxidise a greater percentage of the methane in the coal seams. This is known as enhanced drainage throughout the report. The percentage of potential coal mine methane emissions that can be abated through enhanced drainage and oxidation depends on individual mine characteristics and whether it is underground or open-cut. At underground mines, we estimate that between 30% and 55% of coal mine methane can be oxidised. At open-cut mines (where methane drainage is a less mature technology), we estimate that between 10% and 20% of coal mine methane can be oxidised. See Appendix A for assumptions and sources behind these estimates.

The third source of coal mine methane, diffuse emissions, are not manageable with existing abatement technologies. These emissions occur to a large extent at open-cut mines, where mining of the coal seams leads to the diffuse release of methane into the atmosphere. Diffuse emissions also occur to a much lesser extent in underground mines, as methane leaks through the cracks and seams to escape into the atmosphere. There are no commercially ready technologies for capturing or abating methane from diffuse sources.

Table 1

Fugitive methane abatement technologies could reduce fugitive emissions at the largest emitting underground mines by 80% for less than $30/tCO_2e$

The potential and cost of fugitive methane abatement technologies

Mine type	Technology type	Abatement potential			Cost ($/ tCO_2e)
		$MtCO_2e$ in NSW	$MtCO_2e$ in QLD	Percentage of emissions from mines	
Largest emitting underground mines	RTO	~3.5	~3.8	~55%	$6 - 30
	Enhanced drainage & abatement	~1.6	~1.7	~25%	-$17 - 28
Other underground mines	RTO	Unknown	Unknown	Unknown	Unknown
	Enhanced drainage & abatement	~0.6	~0.5	~35%	-$17 - 28
Open cut mines	Drainage & abatement	~0.2	~0.3	~10%	$16 - 200

Abatement potential and cost of technologies to reduce coal mine fugitive emissions in NSW and QLD. Mines are classified into 'largest emitting underground mines' which represents nine mines in NSW and six mines in QLD, 'other underground mines' and 'open-cut mines'. Abatement potential as a percentage represents the average across all mines in NSW and QLD. Cost is represented as a range, with the value used for cost benefit modelling in Part 2 in brackets. All data are estimates. Open-cut mine abatement potential and cost has particularly high levels of uncertainty. Calculations, sources, evidence and assumptions and sources are outlined in Appendix A. Abatement potential of open-cut drainage and abatement may increase significantly if open-cut methane emissions are greater than reported.

Abatement at underground mines

Underground mines employ two primary abatement solutions:

1. drainage of coal mine methane, either through surface-to-inseam or underground-to-inseam drilling. This can occur either prior to or during mining.
2. RTO systems. These are high-temperature combustion chambers that can oxidise methane vented continuously out of underground mines at a low concentration, known as VAM.

These technologies are both cost-effective and commercially ready. In Table 1, we synthesise these results to show their potential in the NSW and QLD context. Below, we also outline each technology in brief, along with key considerations. Appendix A details the potential, cost, readiness and limitations of these technologies.

RTO deployment at underground mines

Our analysis suggests RTOs are technically and commercially ready to cost-effectively reduce a significant fraction of emissions.

Abatement potential: We estimate that RTOs can reduce fugitive emissions at the largest emitting underground mines in NSW and QLD by 55%. We estimate that RTOs cannot be deployed widely at other underground mines, although the exact extent of their deployment potential is unknown. As explained in Appendix A, our estimates of abatement potential are formed from the product of three factors: the percentage of total underground fugitive emissions that are from ventilation air, the percentage of total VAM that could be abated by RTOs, and the efficiency of RTO abatement.

We estimate that approximately 60% of total fugitive emissions are from VAM. This is at the lower end of the range estimated by other analyses and our interviewees. CSIRO calculate 78% [21], Rystad calculated 62% [2] and our interviewees suggested a range of 60 – 80%. We have selected a number at the lower end of this range to reflect that these RTO systems may be deployed in conjunction with enhanced drainage, which may reduce the methane content in the ventilation air.

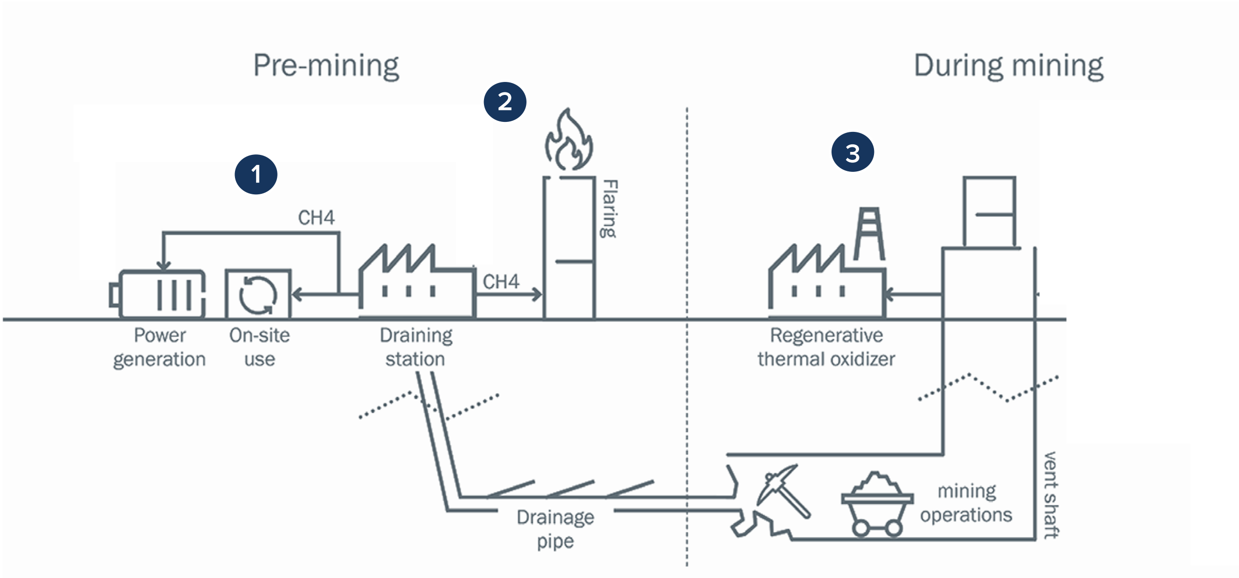
We estimate that the VAM produced at the largest emitting underground mines is available to RTO deployment, while the VAM produced at other underground mines is not. The primary determinant for whether an RTO can be deployed at a mine is the concentration of methane in the ventilation air: it must be between 0.2% and 1.2% [22] [16] [21]. In practice, questions remain around the feasibility of RTO deployment at mines with a VAM concentration between 0.2% and 0.4% [21]. There is limited publicly available data around VAM concentrations, which makes it difficult to determine where RTOs may be deployed. However, both Kestrel coal mine (in QLD) and Appin coal mine (in NSW) have applied for grants or prepared plans related to RTO deployment.[14]

[14] Kestrel coal mine received a Commonwealth grant in 2024 for the construction of an RTO [26] and Appin coal mine is planning to deploy an RTO system [59] (and has previously deployed an RTO system at the West Cliff Colliery [31]).

Figure 5

Abatement strategies vary depending on whether they are implemented pre-mining or during mining

Technologies and processes for methane coal mine abatement



1 **Drained gas utilisation**
Gas extracted from drainage boreholes can be injected into pipelines, used to generate electricity, or used on-site. For underground mines, drainage can also occur during mining.

2 **Flaring**
As an alternative to on-site usage, drained gas can be flared. It should not vented.

3 **VAM oxidation**
Between specific VAM concentrations, RTOs can destroy VAM. See Appendix A for details.

This figure was adapted from Environmental Defense Fund, 'Understanding CMM abatement technologies' [64]. For open-cut mines, abatement can only occur pre-mining due to the large and dynamic surface area of the mine. During mining, methane emissions become diffuse and difficult to capture, meaning they escape into the atmosphere from various sources rather than being concentrated in a single point source. In contrast, for underground mines, where methane is trapped in deeper, higher-pressure coal seams, abatement can occur pre-mining or during mining.

Figure 6: Regenerative thermal oxidiser with heat recovery. Image credit: Echo-technology.

Our analysis shows that there are nine underground coal mines in NSW and six underground coal mines in QLD with an emissions intensity between Kestrel and Appin (including the Kestrel and Appin coal mines). Therefore, it is likely that these 15 largest emitting underground mines have the requisite conditions for cost-effective deployment of RTO systems. Conversely, we have assumed that the other underground mines do not have sufficient VAM concentration for RTO deployment. Note that both of these assumptions may not be accurate. For example, some of the largest emitting underground mines may have a high VAM flow rate but a low VAM concentration, which could be incompatible with RTO deployment.

Similarly, some of the less gassy underground mines may have a low VAM flow rate and high VAM concentration, which could allow for RTO deployment. Our assumptions are validated by CSIRO's analysis of VAM concentrations. Their analysis suggests that approximately 60% of VAM is over a concentration of 0.4% in Australia and 90% of VAM is over a concentration of 0.2% (Figure 11 in Appendix A), which would mean that betwen 60% and 90% of VAM in Australia is accessible to RTO deployment [23]. Our assumptions that the largest emitting underground mines have a VAM concentration suitable for RTOs and that other underground mines do not, equate to 82% of VAM in Australia being accessible to RTOs, within the range determined by CSIRO.

Finally, we estimate that RTO efficiency is 90%, accounting for inefficiencies in oxidation, safety considerations and the conversion of methane to CO_2. This is more conservative than RTO developers, who claim an efficiency over 99% [24], the CSIRO VAMMIT trial which had an efficiency of 96% [25] and Rystad who assume an efficiency of 95% [2]. It is less conservative than CSIRO, who estimate a total efficiency of 75% [21]. This is because CSIRO have most likely estimated the efficiency of early RTO deployments, without taking into account learnings and improvements and the connection of RTOs to most ventilation streams.

Multiplying these three factors, the abatement potential of RTOs at the largest emitting underground mines is 55% (Table 1). In NSW, deployment of RTOs at the nine largest emitting underground mines that are currently operational could reduce emissions by 3.5 $MtCO_2e$ per year. In QLD, deployment of RTOs at the six largest emitting underground mines that are currently operational could reduce emissions by 3.8 $MtCO_2e$ per year. The abatement potential of RTOs at other underground mines is unknown, assumed to be zero.

Cost: The cost of RTO deployment is likely to be between $6 and $30/$tCO_2e$, including capital and operational expenditure (Table 1). This is based on modelling from numerous reputable sources [22] [2] [9]. For cost benefit modelling in Part 2, we have assumed that RTO deployment at the largest emitting underground mines costs $15/$tCO_2e$.

CSIRO analysis suggests that RTOs cost between $6 and $12/$tCO_2e$ for mines with a VAM concentration over 0.4% [21]. For mines with a VAM concentration between 0.2% and 0.4%, they estimate a cost of $18/$tCO_2e$. Rystad more conservatively estimates a cost of $27/$tCO_2e$ for RTO deployment at Australian mines [2]. The IEA estimate an average cost of $6/$tCO_2e$ [9]. Two interviewees who had done detailed RTO cost analysis returned results ranging from $9 to $30/$tCO_2e$, depending on VAM concentration.

For the largest emitting underground mines, which are very likely to have a higher VAM concentration, we have therefore chosen a central value of $15/$tCO_2e$. Hence, RTO deployment may be profitable, as it can reduce the obligation on coal mines to purchase ACCUs and SMCs to meet Safeguard baselines and generate revenue from surplus SMCs. The upfront cost of an RTO system is significant, between $40 and $100 million, according to interviewees and Kestrel's grant [26].

Technology readiness: RTOs are technologically ready for deployment. RTOs have been deployed at approximately 15 mines globally. We interviewed four leading global RTO developers, who were all interested in Australian projects. We note that there are safety regulation concerns around RTOs, which are discussed in Part 1.3. The barrier to deployment is not technological readiness.

Enhanced drainage at underground mines

Enhanced underground drainage and abatement involves the suction of methane out of coal seams before, during or after mining. This is followed by combustion in a flare, oxidation to produce electricity, or use of the methane as a gas fuel source. This abatement technology is known as 'enhanced' because many mines already deploy drainage for safety purposes. Extending or 'enhancing' these existing drainage systems could significantly reduce emissions. Our analysis suggests enhanced drainage is technically and commercially ready to cost-effectively reduce a significant fraction of emissions.

Abatement potential: We estimate that enhanced underground drainage can reduce fugitive emissions at the largest emitting underground mines in NSW and QLD by 25% and at other underground mines by 35%. As explained in Appendix A, our estimates of abatement potential are formed from the product of three key factors: the percentage of total underground fugitive methane that is likely to be drained through enhanced drainage, the percentage of total drainage gas that could be abated, and the efficiency of drainage abatement technologies like flaring and oxidation.

We estimate that 30% of current fugitive methane can be drained from more extensive, enhanced drainage programs at the largest emitting underground mines (where RTOs could also be deployed). At other underground mines, where RTOs are less likely to be deployed, we estimate that enhanced drainage could remove more methane – approximately 40%. These assumptions are strongly supported by reputable research. CSIRO has calculated that 22% of current coal mine fugitive emissions are from existing drainage processes (which would increase with enhanced drainage) [21]. Rystad estimated that 33% of underground methane could be abated through drainage [2]. The United Nations Economic Commission for Europe (UNECE) estimate that while in theory 50 – 80% of gas can be captured by post-drainage (i.e., after mining has already commenced), in practice 30 – 50% is more realistic [27]. Ember has assumed that post-drainage can reduce emissions by 40% [28]. Anglo American has demonstrated that extensive drainage at underground mines can mines can reduce emissions by over 60% [31].

We have estimated that 95% of drainage gas can be abated. Both pre- and post-drainage gas typically has methane concentrations over 30% and can therefore be converted to CO_2 through flaring or gas turbines [22].

We have estimated that the efficiency of flaring/oxidation is 90%, accounting for inefficiencies and the conversion of methane to CO_2. This is more conservative than the technology developers, who often claim that flaring or oxidation occurs at an efficiency over 98%. Rystad assumes a total efficiency of 95% [2]. CSIRO assumes an efficiency of around 95% too, without accounting for the conversion of methane to CO_2 [21].

Multiplying these three factors, the abatement potential of enhanced drainage at the largest emitting underground mines is 25% and 35% at the other underground mines (Table 1). In NSW, deployment of enhanced drainage at the nine largest emitting underground mines that are currently operational could reduce emissions by 1.6 $MtCO_2e$ per year, with a further 0.6 $MtCO_2e$ from other underground mines. In QLD, deployment of enhanced drainage at the six largest emitting underground mines that are currently operational could reduce emissions by 1.7 $MtCO_2e$ per year, with a further 0.5 $MtCO_2e$ from other underground mines.

Cost: The cost of underground drainage and abatement deployment is likely to be between \$-17 and \$28/tCO_2e, including capital and operational expenditure (Table 1). This is based on modelling and implementation from numerous reputable sources [22] [9] [2] [32] [31]. The wide range reflects the variation between the cost of drainage and flaring compared to drainage and oxidation or gas use. Oxidation for electricity or gas use provides a revenue stream that greatly reduces the cost (or may be profitable in some circumstances), whereas flaring has no revenue stream to offset the cost. For cost benefit modelling in Part 2, we have assumed that enhanced drainage costs \$10/tCO_2e at the largest emitting underground mines and \$15/tCO_2e at the other underground mines with a lower methane content.

Estimates of underground drainage and generation or utilisation place it between \$-17 and \$9/tCO_2e, while drainage and flaring ranges from \$0 to \$28/tCO_2e. CSIRO estimated that underground drainage and generation would cost \$-17/tCO_2e for Australian mines, while flaring would cost \$0/tCO_2e [21]. The IEA estimated a cost of \$1/tCO_2e for drainage and generation, and \$16/tCO_2e for drainage and flaring [9]. Rystad estimated a cost of \$-3/tCO_2e for drainage and generation, and \$28/tCO_2e for drainage and flaring [2]. At Curragh mine, drainage and abatement of fugitive methane cost between \$2 and \$6/tCO_2e [30]. At Grosvenor mine, drainage and abatement cost of less than \$20/tCO_2e [29].

While our analysis is technology-agnostic between flaring, gas use or oxidation for electricity, our assumptions around cost are in line with the estimates of drainage and flaring, which are significantly more conservative than estimates of drainage and oxidation or gas use.

Technology readiness: Underground mine drainage has been deployed extensively in Australia and globally to reduce methane to safe levels for workers in the mines. Therefore, this technology is commercially ready, and both the supply chains and expertise exist in NSW and QLD. Drainage and abatement has been deployed at Grosvenor, Curragh, Oaky Creek, Mandalong, Ironbark, Carborough Downs, Integra and Ashton coal mines, amongst others [31]. A focus on underground drainage for emissions abatement rather than safety may require more extensive, ‘enhanced’ drainage systems, but the technology and process are the same. There are already over 200 projects that use coal mine methane around the world, the majority from draining active, underground mines [32].

The relationship between enhanced drainage and RTOs at underground mines

We note a significant caveat here, that RTO deployment and underground drainage both use the same feedstock (fugitive methane). Therefore, more extensive drainage may reduce the concentration of methane in the ventilation air, which would reduce the abatement potential of RTOs, or potentially preventing RTOs from being applicable. For our analysis, we have assumed that only the largest emitting underground mines may deploy both drainage and RTOs. We have assumed that drainage is likely to access 30% of the fugitive methane and that RTOs are likely to access 60% of the fugitive methane. However, even if this balance between drainage and RTOs shifted significantly, it would not majorly impact our analysis – as the total abatement potential at each mine would remain similar, and the total cost would be similar. Our analysis would only be impacted if the drainage was sufficiently extensive to prevent the deployment of RTO systems entirely, which could be prevented with planning and foresight, as long as safety outcomes were not impacted.

Abatement at open-cut mines

Open-cut mines have one primary abatement solution: drainage of coal mine methane, which is then either flared or used for power generation. This technology is in the demonstration stage. Abatement potential and costs are not yet certain. Appendix A details our estimates and assumptions of the potential, cost, readiness and limitations of this technology. Here, we synthesise these results to show the potential in the NSW and QLD context in Table 1. We also outline the technology in brief, along with key considerations.

Drainage at open-cut mines

Open-cut drainage involves the suction of methane out of coal seams before, during or after mining. This is followed by combustion in a flare, oxidation to produce electricity, or use of the methane as a gas fuel resource. The technology is similar to coal seam gas drilling and underground coal mine drainage.

Our analysis suggests open-cut drainage has the potential to reduce fugitive emissions from open-cut mines. While it may often be less cost-effective than purchasing ACCUs and SMCs, it may still be a technically feasible to reduce fugitive emissions from open-cut mines.

Abatement potential: There is significant uncertainty around the abatement potential of drainage at open-cut mines. Estimates of total abatement potential range from 5% to 18% to 40% (as estimated by CSIRO, Rystad and Ember, respectively [21] [2] [28]). Abatement potential is significantly increased for new open-cut mines, where pre-drainage can be extensively performed before mining commences. For Table 1 and the cost benefit analysis in Part 2, we have assumed that the total abatement potential of drainage for existing open-cut mines is 10% and for new open-cut mines is 20%. Based on these estimates, open-cut drainage could reduce annual fugitive methane in NSW by 0.2 $MtCO_2e$ and in QLD by 0.3 $MtCO_2e$. These numbers would increase if emissions from open-cut mines were higher than reported.

If effective, open-cut coal mine drainage could become a viable solution for a large percentage of open-cut coal mine methane (including the potentially large fraction of emissions that are not currently measured). The current uncertainty is because the technology has not been deployed at scale, and because there is uncertainty around the methane content of open-cut coal mines.

Cost: The cost of deploying open-cut drainage is uncertain because it has not been deployed at scale. The IEA estimate that open-cut drainage and generation could cost approximately $16/$tCO_2e$, with open-cut drainage and flaring costing $30/$tCO_2e$ [9]. Rystad estimates $16/$tCO_2e$ for drainage and generation as well, with an estimate of $22/$tCO_2e$ for drainage and flaring [2]. CSIRO's analysis is far more conservative, with open-cut drainage and abatement costing anywhere from $25/$tCO_2e$ to $200/$tCO_2e$ [21]. For cost benefit modelling in Part 2, we selected values that were fairly central within these large ranges. Therefore, we estimated that drainage and abatement at new open-cut mines would cost $45/$tCO_2e$, while at existing open-cuts it would cost $60/$tCO_2e$.

We have assumed that cost for new mines would be cheaper, due to the potential to access a much larger portion of the methane emissions before the seam is mined. We acknowledge significant uncertainty in these estimates.

Technology readiness: Open-cut drainage is still in the demonstration stage and may therefore require some time to be deployed widely. However, its technology is very similar to that used for coal seam gas drilling[15] and underground coal mine drainage. As open-cut mines shift to Method 2 in the NGER scheme, the improved understanding of the underground methane may also improve the business case and feasibility of open-cut drainage. Open-cut drainage has not been used historically because it has not been needed for safety in the same way as underground mines. With the new focus on climate mitigation, it has recently become a technology of interest. The QLD LEIP program has recently announced a grant for Stanmore Resources to build an open-cut drainage to generation system at South Walker Creek coal mine, to be operational from 2027 [33]. Coronado have also implemented an open-cut drainage and abatement trial at Curragh coal mine in QLD [34].

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[15] The difference with coal seam gas drilling is that this resource is only extracted when the coal seams are suitable for drainage. The coal seams that are being mined are usually less suitable for this drainage process. These may require greater time and cost to drain, but the technology is likely to be similar.

Summary

We have found that it is likely to be technically feasible and cost-effective to deploy enhanced drainage and RTO systems in the near-term at the largest emitting underground mines (nine in NSW, six in QLD). These technologies have the potential to reduce up to 80% of the fugitive emissions at each mine.[16]

Deploying a combination of these solutions at the current largest emitting underground mines could reduce annual emissions in NSW by approximately 5.1 $MtCO_2e$, equivalent to 53% of NSW's coal mine methane. In QLD, deploying these technologies at the six largest emitting underground mines could reduce annual emissions in QLD by approximately 5.5 $MtCO_2e$, equivalent to 47% of QLD's coal mine methane.

Multiple independent studies of costs suggest that once initial higher FOAK project cost drivers are overcome in each jurisdiction (discussed in Part 1.3), these technologies can be deployed at a net profit for coal mines [9] [21] [2] [29] [30]. This is due to either the avoided need to purchase higher cost ACCUs or SMCs, or through revenue from the sale of surplus SMCs.[17]

The timeframe for the deployment of these technologies is largely dependent on the policy landscape. The barriers to deployment (outlined in Part 1.3) are not related to technological readiness, but rather to other concerns that may be overcome with policy intervention.

Deployment of abatement technologies could significantly support NSW and QLD in reaching their 2035 and 2050 emissions targets. If the coal sector were to reduce emissions at the same rate as the rest of the economy to meet 2035 targets, coal mine fugitive emissions would decline by 59% (5.7 $MtCO_2e$) in NSW and 61% (7.1 $MtCO_2e$) in QLD. The abatement potential at the nine largest emitting underground mines in NSW and the six largest emitting underground mines in QLD is 5.1 $MtCO_2e$ and 5.5 $MtCO_2e$, respectively. This is a significant fraction of the required emissions reductions to meet the 2035 targets.

The cost and abatement potential at less gassy underground mines and open-cut mines is less certain. Deployment of abatement technologies may be able to reduce around 0.8 $MtCO_2e$ in both NSW and QLD (8% of NSW's fugitive emissions, 7% of QLD's fugitive emissions). This may cost more than abatement at the largest emitting underground mines, due primarily to the lower methane content. These mines are more likely to face cost and feasibility barriers to abatement. However, it seems likely that effective state policy can support the deployment of these technologies at a wide range of NSW and QLD's over 80 operational coal mines [24].

[16] It is important to distinguish between the different definitions of 'feasibility' that may be used by stakeholders. We found during our interviews that some stakeholders would only consider a technology 'feasible' if it could make a profit. Others, if it was cheaper than purchasing ACCUs and SMCs. Others, if it was technically ready for deployment.

[17] Abatement is profitable if it costs less than $35/$tCO_2e$, because every tonne of abatement above the Safeguard baseline reduces the requirement to produce ACCUs by $35, and every tonne of abatement below the baseline generates SMCs of $35 (assuming an ACCU and SMC price of $35).

An integrated network of ‘top-down’ methane measurement systems may support accurate quantification of coal mine fugitive emissions

Measurement technologies are important at coal mines, particularly open-cut mines, to accurately determine the fugitive methane emissions and effectiveness of abatement. Historically, Australia has relied on ‘bottom-up’ measurement approaches. ‘Bottom-up’ approaches measure individual methane sources, through NGER methods and other imaging and ‘sniffer’ technologies. As discussed in Part 1.1 and Breakout Box 2, there are important considerations that may impact the accuracy of ‘bottom-up’ approaches. As part of its response to these issues, the Commonwealth is phasing out Method 1 by FY27 [14].

Additionally, ‘top-down’ measurement approaches have improved significantly internationally and in Australia and are likely to continue to do so. ‘Top-down’ approaches measure the total methane emitted from a facility, through ground-based systems, aerial measurements or satellite measurements. The recent improvements in these approaches are in part due to significant commercial, academic, and NGO investment and R&D to deliver international and corporate methane commitments such as the Global Methane Pledge and the Oil and Gas Methane Partnership 2.0 (OGMP 2.0) [36] [37]. In response to the developments in ‘top-down’ methane measurement, in August 2024, the Commonwealth Government committed to commissioning a scientific study to test the capability of “satellite, plane, vehicle and ground-based approaches in an operational open-cut mine setting” [14] and established a panel led by Cathy Foley to investigate the potential of atmospheric methane measurement processes [35]. Appendix A outlines some of these individual ‘top-down’ measurement technologies.

Literature and our extensive consultation with methane measurement and analysis technology providers and researchers suggested that the most effective use of technologies involves an integrated network of ‘top-down’ approaches [36] [37]. Such a measurement network would include an integration of data from continuous ground measurement systems, periodic aerial and satellite measurements, weather data and inverse modelling to attribute variable methane concentrations to their sources. This integrated network would mitigate the limitations of each measurement approach and ‘triangulate’ an accurate estimate of emissions. Our interviewees suggested that a measurement network that integrated different ‘top-down’ measurement approaches could accurately measure methane emissions and attribute the emissions to specific mines.

There is the potential for significant cost savings through shared infrastructure between proximate facilities if this measurement network is deployed across whole coal basins. ‘Learning by doing’ is required to pilot and then scale such a network – it would require state-led phases of planning, location-specific pilots and full deployment.

1.3

Despite low costs, barriers remain to on-site abatement

Overview

State policy mechanisms could complement the Commonwealth to unlock on-site, cost-effective (< $30/tCO_2e) and near-term abatement. This would support the attainment of NSW and QLD's 2030, 2035 and 2050 emissions targets. Making the most of the opportunity for cost-effective abatement is important, as highlighted by the NSW Net Zero Commission's 2024 Annual Report, which states: *"Unless action is accelerated, NSW may not reach net zero by 2050 and we do fail to meet our nearer term targets"* [1]. There are two key reasons why state policy could play a role in complementing the Commonwealth and achieving abatement of fugitive methane emissions from coal mines.

Firstly, our analysis suggests that **NSW and QLD's interim emissions targets are likely to require deeper reductions than those required under the projected Safeguard trajectories.**

Secondly, there are **significant barriers to industry investment in on-site abatement**, despite often costing less than $30/tCO_2e. These barriers may make NSW and QLD's net zero by 2050 targets more difficult to meet, because emissions reductions through ACCUs and SMCs will not contribute to state targets, unless the ACCUs and SMCs are generated within the state itself.

These barriers include:

- **Financial opportunity cost** – Our analysis and interviewees suggest that coal companies are unlikely to invest their limited capital in on-site abatement infrastructure due to the high opportunity cost. Coal companies are likely to prioritise the purchase of ACCUs and SMCs over on-site abatement, choosing to allocate their limited capital to coal production or other more profitable pathways.
- **Core business** – Coal companies, like most companies, focus their capital, resources and attention on their core capabilities. On-site abatement (e.g., RTO deployment and enhanced drainage) is not currently core business for Australian coal miners.
- **First-of-a-kind** – For any new technology, FOAK projects typically face higher upfront cost and regulatory challenges, often leading to a first mover disadvantage in established industries.

- **Policy uncertainty** – Within the coal industry, there is perceived regulatory uncertainty related to the potential removal or softening of Safeguard obligations under a change of government, which disincentivises investment in abatement.

Therefore, there is an opportunity for state policy to work with the Safeguard Mechanism and incentivise cost-effective and on-site coal mine fugitive abatement that is aligned with NSW and QLD's state targets.

The Safeguard Mechanism is likely to drive emissions reductions but not in time to meet NSW's 2030 and 2035 targets or QLD's 2035 target

The Safeguard Mechanism is likely to drive net zero emissions to zero by 2050

The Safeguard Mechanism requires the coal industry to reduce emissions on a trajectory to net zero by 2050. This aligns with national and state 2050 targets. All Safeguard facilities (annual scope 1 emissions over 100,000 tCO_2e) have baselines that decline every year until they reach zero by 2050.[18] Safeguard facilities have two options to meet their Safeguard baselines: they may reduce their scope 1 emissions through direct, on-site abatement or retire ACCUs and/or SMCs. From FY24, the baselines for coal mines will be based on emissions intensity, rather than total emissions [38] [19].

The Safeguard Mechanism requires the most significant emissions reductions from the largest emitting mines

The Safeguard Mechanism requires the coal industry to reduce emissions on a trajectory to net zero by 2050. This aligns with national and state 2050 targets. All Safeguard facilities (annual scope 1 emissions over 100,000 tCO_2e) have baselines that decline every year until they reach zero by 2050.[18] Safeguard facilities have two options to meet their Safeguard baselines: they may reduce their scope 1 emissions through direct, on-site abatement or retire ACCUs and/or SMCs. From FY24, the baselines for coal mines will be based on emissions intensity, rather than total emissions [38] [19].

Our projected Safeguard baselines suggest that they will target the most emissions-intensive underground mines (see Appendix B for the process for calculating future Safeguard baselines). This maximises emissions reductions and minimises impact on coal production.

Figure 7 shows that the 15 largest emitting underground mines in NSW and QLD have the steepest baselines compared to the open-cut and other underground mines.[19]

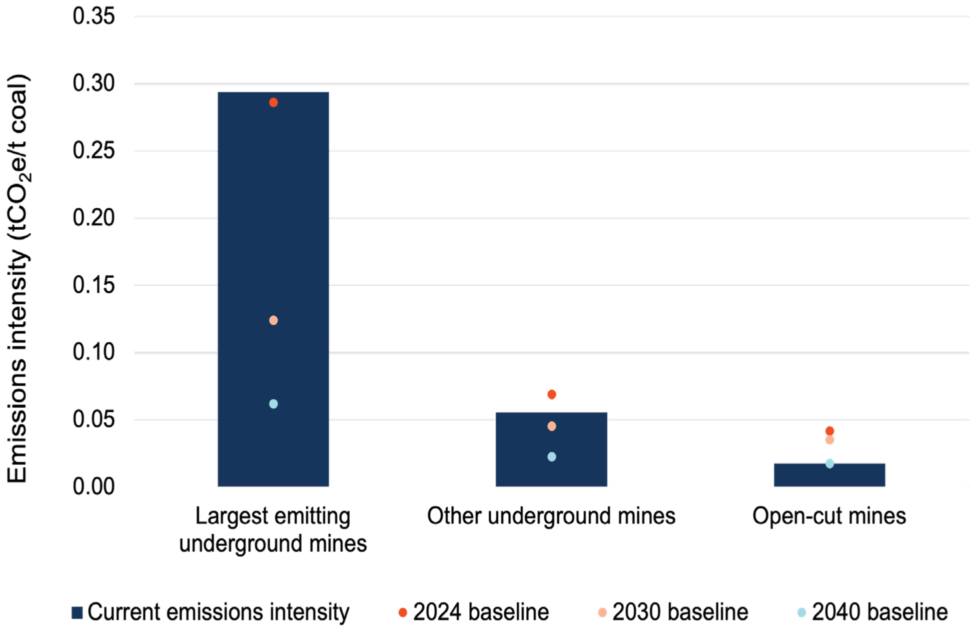
[18] Baselines decline by 4.9% every year to FY30 and are likely to decline by roughly 3.285% every year from FY30 to FY50. Baselines also transition towards an industry-average emissions intensity value each year [38].

[19] Baselines were projected by using facility-specific emissions intensity from FY20-23 [38] [19]. See Appendix B for more details.

Figure 7

The Safeguard Mechanism drives the most significant emissions reductions at the most emissions intensive mines

The cumulative projected Safeguard Mechanism baselines compared to current emissions intensity in FY 2024, 2030, and 2040



Projected Safeguard baselines in the financial years of 2024, 2030 and 2040 compared to current emissions intensity for three categories of coal mines in NSW and QLD. Safeguard baselines are projected using methodology outlined in 'Projecting Safeguard baselines' in Appendix B.

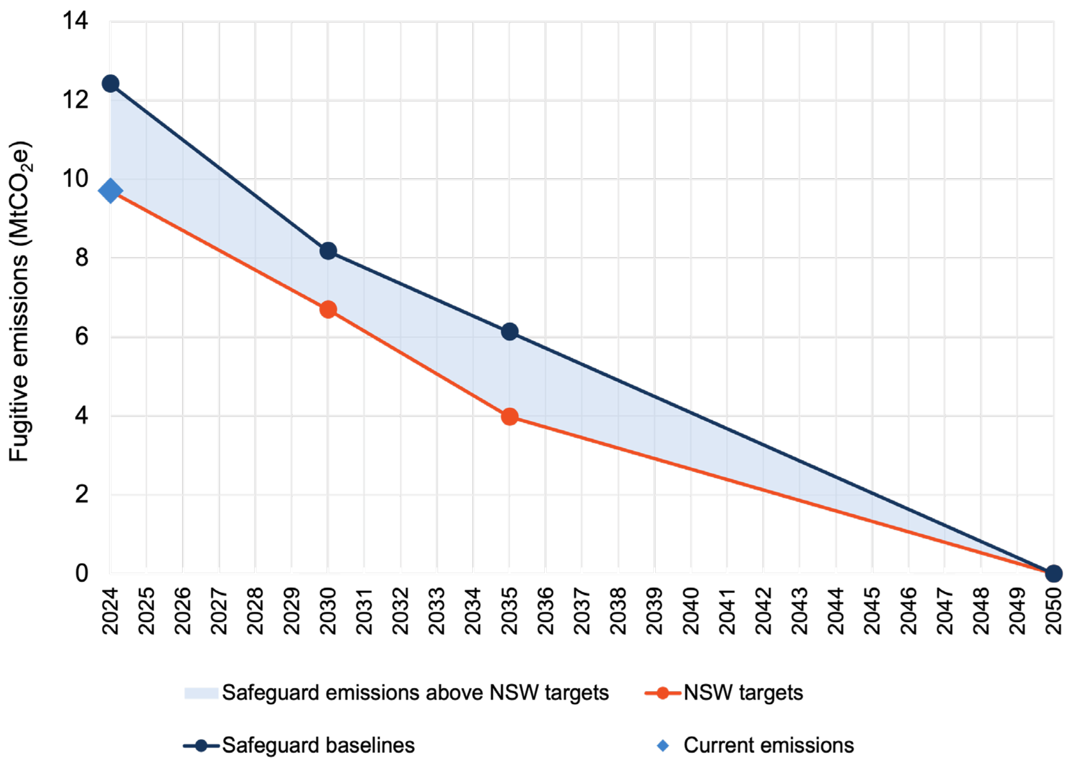
NSW's 2030 and 2035 emissions targets are likely to require deeper reductions than those required under the projected Safeguard trajectories

Figure 8 shows the cumulative projected Safeguard baselines for NSW coal mines, compared to current fugitive emissions, and legislated NSW targets. To align with the 70% by 2035 target, net emissions in NSW must reduce by about 59% from current (2022) levels. If fugitive methane emissions from coal mines in NSW were to decline by this same rate (59%), they would need to reach around 4 $MtCO_2e$ by 2035. However, our projected Safeguard Mechanism baselines (methodology outlined in Appendix B) drive only a 37% reduction to 6 $MtCO_2e$. Between 2024 and 2050, the trajectory of the NSW's targets (orange line) could require the reduction of an additional 38 $MtCO_2e$ of fugitive emissions (the shaded blue area) compared to the trajectory for the Safeguard baselines (the dark blue line). Therefore, further state policies are likely to be required to support and incentivise the coal industry to reduce coal mine methane emissions and support the achievement of NSW's state targets.

Figure 8

NSW's 2030 and 2035 emissions targets are likely to require deeper reductions than those required under the projected Safeguard trajectories

The cumulative projected Safeguard Mechanism baselines compared to current emissions intensity in FY 2024, 2030, and 2040



Projected Safeguard baselines in the financial years of 2024, 2030 and 2040 compared to current emissions intensity for three categories of coal mines in NSW and QLD. Safeguard baselines are projected using methodology outlined in 'Projecting Safeguard baselines' in Appendix B.

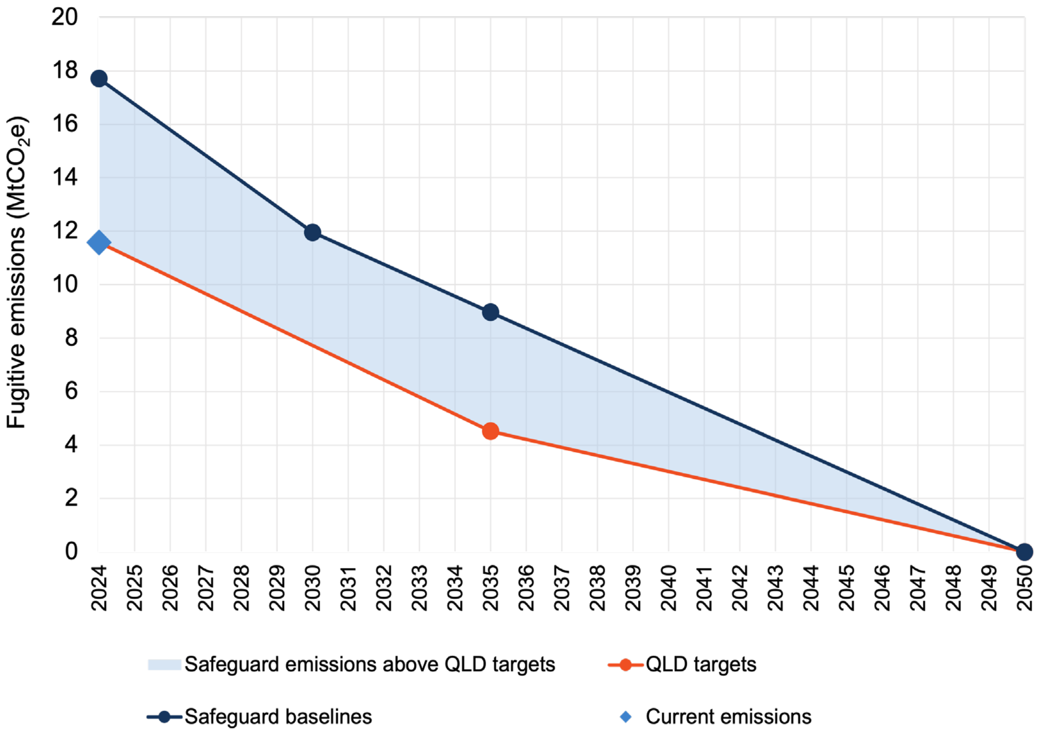
QLD's 2030 and 2035 emissions targets are likely to require deeper reductions than those required under the projected Safeguard trajectories

Figure 9 shows the cumulative projected Safeguard baselines for QLD coal mines, compared to current fugitive emissions, and legislated QLD targets. To align with the 75% by 2035 target, net emissions in QLD must reduce by about 61% from current (2022) levels. If fugitive methane emissions from coal mines in QLD were to decline by this same rate (61%), they would need to reach around 4.5 $MtCO_2e$ by 2035. However, our projections of Safeguard Mechanism baselines (methodology outlined in Appendix B) only require a 23% reduction to 9 $MtCO_2e$. Between 2024 and 2050, the trajectory of the QLD's targets (orange line) could require the reduction of an additional 86 $MtCO_2e$ of fugitive emissions (the shaded blue area) compared to the trajectory for the Safeguard baselines (the dark blue line). Therefore, further state policies are likely to be required to support and incentivise the coal industry to reduce coal mine methane emissions and support the achievement of QLD's interim 2035 emissions target.

Figure 9

QLD's 2030 and 2035 emissions targets are likely to require deeper emissions reductions that projected under the Safeguard Mechanism

The cumulative projected Safeguard Mechanism baselines compared to current emissions intensity in FY 2024, 2030, and 2040



Cumulative projected Safeguard baselines (dark blue) compared to QLD targets (orange) for coal mines. Note that 2030 and 2035 NSW targets are not applied directly to the coal industry, but this chart shows how the coal mine fugitive emissions would need to reduce to meet the QLD-wide average emissions reduction rate required to reach 2030 and 2035 targets from 2022 levels. Methodology to project Safeguard baselines is outlined in 'Projecting Safeguard baselines' in Appendix B. Methodology to estimate the NSW targets is outlined in 'Interim state targets' in Appendix B.

There are barriers that hinder industry's investment into on-site and cost-effective abatement

Coal mines are likely to meet Safeguard baselines through ACCUs and SMCs rather than on-site abatement for the reasons outlined in the following subsections. This will not contribute to NSW or QLD's emissions targets unless the ACCUs and SMCs are generated within NSW and QLD.

The opportunity cost of abatement disincentivises action

From our analysis in Part 1.2, it is likely that many coal companies have the opportunity to pursue abatement projects for less than the cost of purchasing ACCUs and SMCs. While the economics of coal mine fugitive abatement appears to be favourable, we heard consistently in interviews that coal companies also assess these investment decisions from financial and operational perspectives. Coal companies must decide between allocating available capital to on-site abatement infrastructure, coal production infrastructure or paying shareholder dividends. To understand these trade-offs, we assessed the opportunity cost of investment in abatement projects by comparing its costs and benefits to the costs and benefits of other uses of capital.

We found that investment in on-site abatement projects has a high opportunity cost (i.e., is much less profitable than spending available capital on coal production). Figure 10 compares the cost of meeting Safeguard baselines through ACCUs and SMCs to the potential profits of coal production. Our analysis suggests that for every tonne of run-of-mine (ROM) coal that is produced from 2024 to 2050, coal companies in NSW would pay an average of $0.30 (assuming a $35 ACCU/SMC price), up to an average of $0.65 (assuming a $75 ACCU/SMC price, the ceiling price [39]). In QLD, coal companies would pay an average of between $0.08 and $0.17 per tonne of ROM coal. Note that this accounts for the facts that baselines will decline to zero by 2050; the value presented in Figure 10 is an average for every tonne of coal produced from 2024 to 2050.

The economic benefits of investing in on-site abatement is due to the difference in cost between on-site abatement and ACCUs/SMCs; mines may pay between $10 and $30 per tonne of abated CO_2e, rather than between $35 and $75 (depending on the price of ACCUs/SMCs). Therefore, the potential economic benefits to the mines of investing in on-site abatement is up to $0.30 – $0.65 in NSW and up to $0.08 – $0.17 in QLD, for every tonne of ROM coal produced from 2024 to 2050. This finding is supported by the NSW Net Zero Commission, who write: "prevailing and expected [ACCU] price levels in credit markets may not be sufficient to incentivise some options to reduce emissions" [1].

When considering that abatement projects may also generate SMCs, coal mines could earn, on average, up to $2.30 per tonne of coal produced, if all emissions at a mine were abated.[20] In comparison, coal companies earned on average $33 in profit for every tonne of coal produced over eight years from 2014 to to 2021.[21,22] In the future, profit per tonne is likely to be similar or greater.[23] Hence, using their available capital on coal production is much more profitable than investing in on-site abatement.

Note that this financial analysis is intended to show the significant difference between Safeguard compliance costs and coal profits. It is not intended to be a precise calculation of past or future coal mine profits.

The findings are the same when considering the difference between compliance costs and production profits on an individual company level. Table 12 in Appendix B shows that out of the eight companies, South32's portfolio of mines is likely to have the most significant compliance costs as a fraction of historical coal profit.[24] They are projected to pay $6.86 in Safeguard compliance costs for every tonne of coal produced from now until 2050, representing 15% of the historical profit per tonne of coal ($47). The compliance costs for all other companies (apart from Centennial Coal) represents less than 3% of the historical profit per tonne of coal. BHP, Glencore, Stanmore Resources and Whitehaven are projected to earn SMCs for every tonne of coal produced until 2050, as their baselines are, on average, set significantly above current emissions intensity.[25]

It is therefore in the financial interest of coal mines to invest available capital in coal production and reduce additional emissions by purchasing ACCUs and SMCs, rather than utilising the available capital for on-site abatement projects. Our interviewees suggested that there was very low interest in on-site abatement within the coal mining industry, as a result.

Further, the payback period of RTOs and drainage is long and may disincentivise investment, particularly for coal mines closing before 2050. Payback periods depend on the upfront cost and cost per tonne of abatement, but may reach up to and over ten years, particularly for high cost FOAK RTO projects likely. Our analysis suggests that mines with a high emissions intensity are likely to have more favourable payback times, which may be up to five times shorter than for other mines.

These opportunity cost barriers are hindering industry's investment in on-site abatement, despite it being cost-effective and available in the near-term. Should coal mines meet Safeguard obligations through ACCUs and SMCs, this may make NSW and QLD's state targets harder to meet, if ACCUs and SMCs are not generated within the states' inventories. Hence, state policy is required to complement the Commonwealth and unlock on-site abatement.

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[20] Assuming SMCs and ACCUs are both valued at a constant price of $35, the value of $2.30 per tonne of coal can be derived by multiplying $35 with the Safeguard-legislated, industry-average emissions intensity of coal production (0.0653 tCO_2e/t coal) [19].

[21] Profit data (EBITDA) from eight coal companies were used for this calculation. These eight companies are responsible for over two-thirds of Australian coal mine fugitive emissions. See Appendix B for financial analysis methodology and results.

[22] 2022 and 2023 are excluded from the average historical profits, as coal prices spiked in these years, leading to an increase in coal profits that may not be representative of future profit.

[23] This is because the coal price from 2025 to 2029 (for both thermal and metallurgical) is forecast to be greater than the price across 2014 to 2021, as it comes down from its peak. Therefore, profits are likely to be greater than $33 per tonne, on average, although this may be partly offset by increases in operational costs [53] [54] (see Appendix B for more details around the financial modelling).

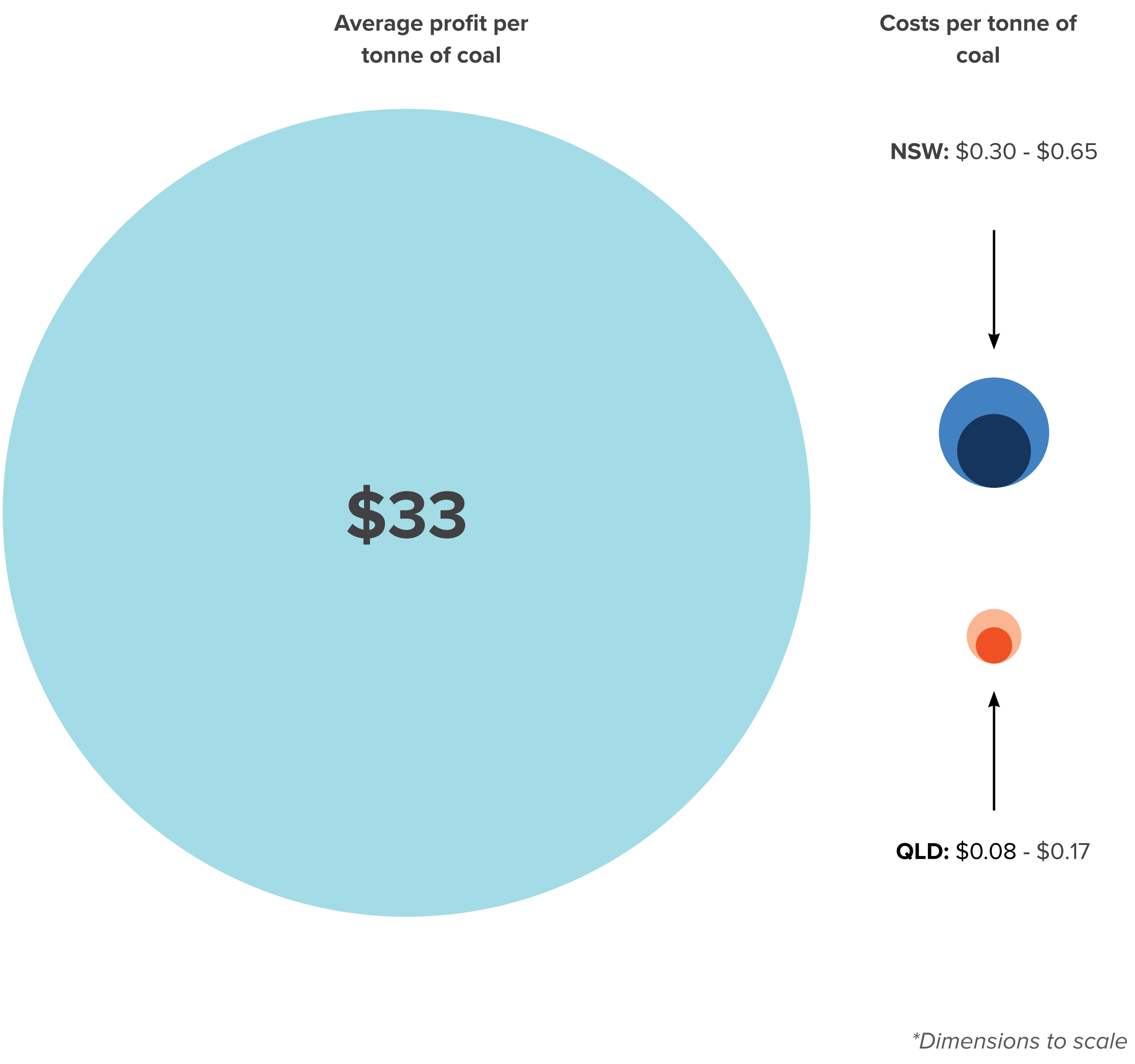
[24] Note that some companies (e.g., South32, Anglo American) are selling their coal mines. We have projected the future Safeguard compliance costs of coal mines under the name of their current owners.

[25] Company-specific compliance costs include coal mines in both NSW and QLD.

Figure 10

For every tonne of raw coal produced from 2024 to 2050, our analysis suggests the average company would incur $0.08 to $0.65 in Safeguard compliance costs and earn approximately $33 in profit

The average cost of meeting Safeguard baselines through ACCUs/SMCs (with two scenarios representing a price of $35 and $75) compared ot the average profit per tonne of raw coal



The average cost for mines in NSW or QLD to meet their Safeguard baselines for every tonne of ROM coal produced from 2024 to 2050 compared to the average historical profit per tonne of coal (2014 to 2021). The range of costs represent the range between scenarios with a $35 ACCU/SMC price and a $75 ACCU/SMC price. This accounts for the decline of the Safeguard baselines to zero by 2050. Methodology outlined in ‘Coal mine financial analysis and Safeguard compliance cost’ in Appendix B.

Coal companies are focused on their core business

We also heard consistently in interviews that another challenge to the adoption of technologies for the first time within both mining companies and individual mines is a competition for resources and attention with core business activities. The design, assessment, financial approval, procurement, implementation, contract management and integration with mining operations of abatement projects requires significant allocation of attention, expertise, time and capital across multiple business units. We heard that responsibility for net zero strategy and emissions compliance obligations tends to sit in centralised environmental and regulatory affairs functions. Comparatively, many of the individual decision-makers and managers required to implement abatement activities sit in centralised corporate finance teams or decentralised and independent mine operations teams. These teams often have differing business and personal objectives and incentives structures which are focused on profits, production and/or safety, rather than emissions.

Furthermore, mining legislation in NSW and QLD places liability for safety on individual managers of a coal mine, at least partially [40]. For example, three individuals were found personally liable for four fatalities at a coal mine in the 1996 Gretley Colliery disaster [40]. As a result, mine managers and officers are understandably disincentivised to deploy 'new' abatement technology with potential uncertainties around safety.

We heard consistently that these factors add significant friction to the adoption of cost-effective abatement solutions, compared with the ease of ACCU or SMC purchases for the teams with emissions and compliance responsibilities.

First-of-a-kind barriers delay abatement

There is a lack of supply chain experience and expertise in deploying coal mine methane abatement and measurement technologies in NSW and QLD. This leads to first-of-a-kind barriers. This is a third reason why these technologies are not being deployed, independent of opportunity cost and core business barriers. This barrier will persist until experience is built through learning-by-doing.

FOAK barriers result in two outcomes:

- They disincentivise coal mines from being the first movers to invest in on-site abatement technology. As we heard from an organisation that has extensively engaged the coal industry in Australia:
- They increase the time and money required to deploy projects [41] [42] [43].

> *"We've spoken to almost every mining company... there are some who are okay with being the first of the second, but no majors who want to be the first of the first.*

We have identified three specific FOAK barriers that are disincentivising and delaying deployment. These apply primarily to open-cut coal mine drainage and RTOs (which have been deployed globally but have not been deployed in NSW and QLD since pilot trials over 10 years ago). These are problems that all require time and capital to solve the first time. Once solved, they are much quicker and cheaper to do again.

The essence of FOAK barriers is captured in the quote below from one of our interviewees.

> *The first mover in this space has a heavy load to bear: technically in mine-to-RTO equipment interface, politically in being the first of a kind to engage in scale deployment within either CFI for ACCUs or [Safeguard Mechanism] for SMCs, politically in terms of process safety with the safety regulators, politically in terms of the mines accepting this technology.*

The three specific FOAK barriers that we have identified are detailed in the subsections below.

The upfront cost of FOAK deployments is increased. We have repeatedly seen that FOAK projects cost more than nth-of-a-kind (NOAK) deployments. From previous projects in renewable energy, energy storage, green hydrogen, atmospheric carbon dioxide removal and other low carbon industries, we have seen that FOAK costs can often be between 50% and 300% more than NOAK deployments [41] [42] [43]. Therefore, while future deployments of RTOs and extensive open-cut drainage may be less than \$30/tCO_2e, the first few projects for a particular company and within a particular jurisdiction are likely to be more costly. Once projects are built, learning curves and economies of scale support continual reductions in upfront (and operational) costs. This is a particular disincentive for first movers who are likely to face high costs.

The safety regulations around RTO deployments must be resolved. Placing a high-temperature combustion unit on the vent shaft of an underground mine creates a material safety risk. Safety outcomes can be affected if a pocket of methane over 1.2% in concentration reaches the RTO. Safety regulators in NSW and QLD have not yet developed policies and procedures around VAM abatement. As a result, many government teams that we consulted suggested that RTO systems would not be ready for deployment until after 2030. To mitigate safety concerns, mine telemetry systems (which are already used in all underground mines) must communicate to the RTO if a pocket of high concentration methane is detected, to allow the vent shaft to detach from the RTO and release the methane directly into the atmosphere.

Based on our interviews, we have found that RTO developers believe they can meet all safety requirements. However, the development of safety regulations, testing of safety systems and approval of RTOs may take time, particularly for the initial projects. It may be determined that RTOs cannot be safely deployed by 2030, but currently, there is insufficient evidence to support this claim. From an RTO developer we heard:

> “ *The process safety concern is absolutely legitimate, but current best practice approach satisfies these concerns (the challenge is that hardly anyone, including the Safety Regulator yet understands these best practices applied to this technology...they know what to do, but not how to do it)”.*

We conclude that it is important to determine the safety risks of RTO systems and acceptable mitigating procedures. A learning-by-doing approach between industry and the regulators is likely to lead to the most effective safety guardrails while valuing the importance of deploying RTO systems quickly for emissions outcomes.

Contractual risk-sharing agreements between coal mines and third-party solution providers may need to be developed. Third-party technology providers may be able to support coal mines in achieving abatement, while overcoming opportunity cost and core business barriers. However, there are important risk-sharing principles that need to be contractually arranged. The development of these risk-sharing principles may increase legal costs and time for FOAK projects.

Coal companies may choose to contract third-party technology providers to deliver abatement outcomes. Third-party technology providers could include experienced RTO developers and drainage and abatement project developers. This could overcome a number of barriers:

- The opportunity cost barrier is partly overcome if the third-party provider pays the upfront CAPEX. Coal companies may now prefer to allow the third party to reduce their emissions, rather than purchasing ACCUs or SMCs. This is because the abatement process may be cheaper, per tonne, than ACCUs or SMCs, and the coal mine is no longer subject to high upfront cost and long payback periods. There is also no opportunity cost barrier for the third party, whose business model is centred on earning a profit from the differential between ACCU/SMC price and the cost of abatement.
- The core business barrier is overcome. The third-party providers are abatement specialists, who have deep expertise and capability in RTO systems, and drainage and abatement systems.

Before the Safeguard Mechanism, companies such as EDL Energy would build and operate (and sometimes own) coal mine waste gas projects. This would involve drainage of the coal mine and flaring or generation with the drained gas. The owner of the project (either the coal mine or EDL) would generate ACCUs, which would turn a profit against the cost of the abatement. EDL have built over 12 waste coal mine gas projects, before the introduction of the Safeguard Mechanism [44].

The landscape for third-party abatement projects has since changed. Now, Safeguard facilities cannot generate ACCUs, which were the source of profit for third-party technology providers. Instead, Safeguard facilities can generate SMCs, which should be similar in value to ACCUs. However, SMCs are subject to a number of uncertainties, which dampens the business case for third parties:

- Although SMCs should be equal in price to ACCUs, no SMCs have yet been generated, so there is greater uncertainty around price and demand.
- SMCs are only generated by abatement below the Safeguard baseline. Therefore, any abatement above the baseline will not produce SMCs (but will reduce the number of ACCUs/SMCs that the coal mine will have to buy to meet their obligations).

Therefore, coal mines and third parties must develop contractual obligations to share the risks in a way that is suitable to both organisations. The risks that must be shared are:

- **Technology risk:** this is the risk that the technology will work less effectively than planned. This is likely to be borne by the third party.
- **Upfront cost and price:** this is the risk that the price of SMCs may fall below the threshold for the project to be profitable or pay off the upfront cost. This is likely to be borne by the third party.
- **Baseline risk:** this is the risk that some amount of abatement may be 'above-baseline', not resulting in SMCs. This is likely to be borne by the coal mine, who may need to develop a contractual obligation to pay the third party for the above-baseline abatement. This, however, further exposes both parties to price risks around SMCs.

Developing these contractual arrangements may accelerate the use of third-party providers to achieve abatement of coal mine fugitive emissions.

Policy uncertainty disincentivises investment in CAPEX-intensive, long-term abatement projects

There is uncertainty around the future of the Safeguard Mechanism under future changes of government. We have heard from interviewees that some coal companies effectively operate under the assumption that the Safeguard Mechanism will be softened or repealed in the future, reducing the incentive for abatement investment.

The next part outlines and analyses a suite of potential state-level policy options that complement the Safeguard and help industry overcome these barriers to deliver deeper and sooner on fugitive methane abatement in NSW and QLD.

PART 2

State policy opportunities to unlock coal mine methane abatement

Part 2.1	Outlines the policy measures analysed to assess the costs and benefits to emissions reduction, the mining sector and the wider state economy.
Part 2.2	Details the results of the cost benefit analysis in NSW.
Part 2.3	Details the results of the cost benefit analysis in QLD.
Part 2.4	Outlines the next steps for policymakers.

Key takeaways

1

In NSW, all policy measures that incentivised on-site abatement result in significant emissions reduction, benefit to the wider state economy and low (or negative) costs to the mining sector.

The scenarios that were the most ambitious in combining different policy mechanisms and bringing forward abatement to 2035 or earlier produced the most favourable results. The most effective policy measures may reduce emissions in NSW in 2035 by 5.4 – 6.9 $MtCO_2e$ and contribute \$3.4 – \$4.3 billion to the economy, at a net cost to the mining sector of \$2.70 – \$4.10 per tonne of CO_2e abated. Even when testing extreme sensitivities, like doubling the cost of abatement, or halving the potential of abatement, the opportunity for state policy to unlock low cost emissions reduction for NSW remains significant.

2

In QLD, there is an opportunity for further state policy to complement the LEIP and the Safeguard Mechanism if abatement is brought forward to 2035 or earlier.

The most effective design options across all three policy measures may reduce emissions in QLD in 2035 by 0.9 – 3.1 $MtCO_2e$. The impact on the wider economy ranges up to a benefit of \$1.8 billion at a net cost to the mining sector as low as \$9.70 per tonne CO_2e abated. However, policy mechanisms that do not bring abatement forward to 2035 or earlier are less likely to have a significant additional impact. This is due to the attribution of significant abatement to the QLD LEIP.

2.1

A suite of new complementary policy measures

State policy in NSW and QLD may complement the Safeguard Mechanism and unlock cost-effective, near-term and on-site abatement of coal mine fugitive emissions. The introduction of complementary state policy may be required to achieve two critical outcomes:

- **The attainment of NSW and QLD's interim 2030 and 2035 emissions targets.** The Safeguard Mechanism is designed to drive net emissions to zero by 2050, but not in time to meet NSW or QLD's interim targets.
- **The attainment of NSW's and QLD's net zero by 2050 targets.** The Safeguard Mechanism is designed to drive net national emissions to zero by 2050, but not net NSW or QLD emissions. NSW's and QLD's state-specific targets may not be achieved if coal mines purchase ACCUs and SMCs generated outside of the state to meet their Safeguard obligations. This is a material risk, as our analysis in Part 1.3 shows that coal companies are incentivised to meet emissions reductions obligations through ACCUs and SMCs.

The introduction of state policy could achieve these outcomes by incentivising cost-effective, on-site abatement at coal mines. State policy would complement the Safeguard Mechanism and other Commonwealth policies by increasing certainty within the coal industry that the policy drivers for abatement are unlikely to be diminished in the future. This provides the confidence to make significant investments in on-site abatement projects.

We conducted a cost benefit analysis (CBA) to analyse the impact of state policy measures on emissions, the coal industry and the broader NSW and QLD economies. Our CBA extended from FY2025 to FY2050 and considered existing mines and projects within the approval pipeline. The estimated closure date of each mine was also considered in the analysis. The policy measures were analysed individually and in combination with each other to form an overarching policy framework.

The policy measures analysed were:

1. A **methane abatement fund** to raise best practice and share higher costs and risks for FOAK projects across the whole industry that would benefit in turn from de-risked, cost-effective abatement technologies. The modelled methane abatement fund raises capital from a levy on coal mining and distributes these funds to abatement projects to cover 50% of the upfront CAPEX. The fund complements the Safeguard Mechanism by supporting first movers in reaching their baselines and improving certainty around the policy support for fugitive emissions abatement. Note, this was not modelled for QLD, which has already implemented the LEIP program. For QLD, the impact of the LEIP was modelled as part of the counterfactual scenario.

2. **Regulated emissions intensity thresholds** to reduce regulatory uncertainty and ensure delivery of cost-effective, on-site abatement in NSW and QLD. Two design options of the emissions intensity thresholds were modelled: the first design option requires all mines above a specific emissions intensity threshold to reduce emissions below the threshold by a specific year (this effectively requires a significant number of mines to undergo moderate abatement); the second option requires all mines with a historical emissions intensity above a specific threshold to undergo maximum feasible and cost-effective abatement (this effectively requires the largest emitting underground mines – nine in NSW and six in QLD – to undergo significant abatement). The thresholds complement the Safeguard Mechanism by ensuring abatement is on-site and on the NSW and QLD inventories, as well as improving certainty around the policy support for fugitive emissions abatement. The regulated thresholds would also provide coal mines with the long-term certainty around policy settings to incorporate the deployment of abatement technologies into their mining and capital investment plans, solving the problem that deployment of technologies could require multiple years of prior planning.

3. A government-led **methane measurement network** to support both the continuous adoption and improvement in best practice of integrated methane measurement technologies and validate the efficacy of public and private investments under national and state policies. The modelled methane measurement network is funded by a cost-recovery mechanism on industry and increases the abatement measured by each mine. The measurement network complements the Safeguard Mechanism and state policies by verifying abatement and accurately demonstrating the value of on-site abatement projects.

Within each of the three policy measures we have further modelled differing impacts of potential design options. More detail on these levers and a high-level sensitivity analysis is provided in the following subsections.

The three policy measures modelled were designed as examples of potential policies that could be explored. The purpose of this modelling was to understand the level of abatement and range of costs and benefits to NSW and QLD from additional state government interventions, rather than to recommend a specific policy design.

Other policy mechanisms that we have not yet modelled include absolute emissions limits, or prescriptive requirements to adopt particular abatement technologies. Our modelling is agnostic to the specific legislative or regulatory instrument that may be used to implement the policies.

We assessed the economic, social and emissions impact of these policy measures when implemented in isolation, and in different combinations. We considered the net economic impact to the NSW and QLD economy (by including a value on reduced emissions) and the net private costs and benefits to the coal mining industry. For the purposes of the results summarised below, we compared costs and benefits to a baseline (counterfactual) scenario where the barriers detailed in Part 1.3 remained and coal mines relied entirely on purchasing ACCUs or SMCs to meet their Safeguard obligations.

We further tested these policy measures against a baseline scenario where coal mines met their Safeguard obligations through on-site abatement – these results are within 'BAU2 results' in Appendix B. We have not considered how the value of ACCUs and SMCs may increase over time beyond 2% per year, as there is increased demand across Safeguard facilities. Conversely, we have not considered the potential for the value to change as state policy mechanisms drive reduced consumption of ACCUs and increased generation of SMCs. However, we have considered a sensitivity scenario, in which ACCUs and SMCs are valued at $75.

The methodology and assumptions of this CBA are outlined extensively in Appendix B.

2.2

Costs and benefits of NSW policy scenarios

There are two key, high-level findings from the CBA of NSW policy options:

Finding 1: All modelled policy scenarios deliver significant emissions and economy-wide benefits. Further, many modelled scenarios result in a low or negative cost to the mining sector.

Finding 2: The more ambitious policies result in greater emissions and economy-wide benefits, as well as improving outcomes for the mining sector. There are three levers for increasing ambition and improving modelled policy outcomes:

- A combination of policy measures improves outcomes: a combination of regulations and a fund delivers higher emissions reductions and net benefits than either policy alone. Further, the monitoring network ensures that abatement is accurately accounted for on the NSW inventory, with a positive impact on emissions outcomes.
- A reduction of timelines for abatement improves outcomes: setting the methane abatement fund and regulated emissions intensity thresholds to bring forward abatement as early as feasible leads to greater reductions in emissions and lower (sometimes negative) net mining sector costs.
- Greater coverage of emissions improves outcomes: increasing the size of the methane abatement fund and reducing the thresholds of the regulated policy mechanisms (while still ensuring they are feasible to achieve) leads to greater emissions reductions and other benefits.

Finding 1 is supported by Table 1. All scenarios deliver an economy-wide benefit ranging from $398 million to $4.3 billion. There are considerable emissions reductions that can be realised through the implementation of one, or a combination of, policies that incentivise on-site abatement at coal mines. The emissions reductions delivered a range from 6.6 to 61.9 $MtCO_2e$ (cumulatively from implementation of the policy in FY28 to FY50). In 2035, state policies may reduce emissions by 0.3 to 6.9 $MtCO_2e$, potentially contributing significantly to NSW's interim emissions target.

Some scenarios, particularly with regulated emissions intensity thresholds, deliver cost savings to the mining sector when compared to the baseline scenario. This is because in the baseline scenario we assume that coal mines will incur costs from purchasing ACCUs or SMCs to meet their Safeguard obligations. As on-site abatement is generally cheaper in the long-term, policies that drive on-site abatement can result in net cost savings.

Finding 2 is also supported by Table 2; the greatest benefits (in emission reductions and economy-wide impact) are achieved when policy measures are implemented together. The regulated emissions intensity thresholds combined with the methane abatement fund and the methane measurement network deliver greater emissions reductions and economy-wide benefit than the standalone emissions intensity thresholds or methane abatement fund. Conversely, it should be noted that the results suggest that standalone regulated emissions intensity thresholds deliver improved outcomes in terms of net mining sector costs and the benefit-cost ratio. This is because this policy mechanism drives a greater proportion of abatement at the more emissions-intensive underground mines. Finally, the results presented in tables throughout the rest of this section show that reducing timelines for abatement and increasing the emissions coverage of policies results in more favourable outcomes for NSW and the mining sector.

The findings throughout the body of Part 2 are based on a counterfactual scenario that assumes all NSW coal mines meet their national Safeguard obligations through purchasing ACCUs and SMCs created in jurisdictions outside of NSW. As explored in Part 1.3, coal mines are incentivised to purchase ACCUs and SMCs rather than invest in on-site abatement.

Table 2

All modelled policy measures for NSW resulted in emissions reductions, benefit to the wider state economy and low or negative costs to the mining sector

Overview of the costs and benefits of state policy in NSW

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($\$/tCO_2e$)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Methane abatement fund				
6.6 to 29.7	0.3 to 3.0	-2.3 to 18.8	398 to 2,285	2.5 to 4.7
Regulated emissions intensity threshold				
16.6 to 37.5	0.4 to 4.9	-7.6 to -2.3	1,356 to 3,057	5.3 to 6.2
Regulated emissions intensity threshold + methane abatement fund				
23.6 to 48.3	1.3 to 5.4	-4.2 to 11.6	1,545 to 3,759	2.9 to 5.1
Regulated emissions intensity threshold + methane abatement fund + methane measurement network				
48.4 to 61.9	5.4 to 6.9	3.0 to 4.1	3,418 to 4,336	3.6 to 3.8

A range of values is presented, showing the low to high scenarios for each policy option modelled and presented in this report.

We have used conservative cost estimates when building the assumptions for this analysis. As such, the economy-wide and mining sector benefits may be higher than modelled. We have conducted a sensitivity analysis in the event that costs are much higher or the level of abatement much lower than our estimates. We found that there is still a strong business case for state policy when using the most conservative cost and abatement assumptions.

Implications

State policy intervention, in a range of forms, is likely to deliver emissions reductions and a net benefit to both industry and the wider NSW society. Policy mechanisms can complement the Safeguard Mechanism to unlock on-site, cost-effective, and near-term abatement to support NSW's 2030, 2035 and 2050 emissions reduction targets. In scenarios with much higher abatement cost, much lower abatement effectiveness and other highly conservative assumptions, state policy mechanisms are likely to continue to deliver significant benefit to NSW (see the sensitivity analysis, below). It is important to note that these policies may have an opportunity cost to the coal mines by limiting their ability to invest in more profitable pursuits and instead incentivising them to invest in on-site abatement.

As discussed, the most beneficial policy measures tend to be a combination of policies with high ambition. Therefore, state policy measures that maximise emissions reduction within the feasibility threshold are likely to maximise emissions reduction, benefit to industry and benefit to the NSW economy.

The following subsections provide a more in-depth analysis of each policy measure and the impacts of varying policy settings and combined policy frameworks.

Methane abatement fund

Description and rationale

We modelled the implementation of a government-run methane abatement fund to share the cost of FOAK on-site abatement projects. For FOAK projects, the fund covers 50% of the upfront CAPEX. The fund is generated from a levy across coal mines.

In this policy mechanism, the mining sector shares the additional cost of FOAK abatement, so that the individual mines that are implementing the technologies have a reduced cost. The methane abatement fund socialises the cost of FOAK projects, supporting first movers to overcome FOAK-specific barriers. This in turn reduces barriers for future projects, expediting the development of industry and supply chain experience in delivering abatement. This brings down cost and timelines for the abatement technology, allowing the wider industry to benefit from the socialisation of the initial FOAK costs. The fund also reduces the opportunity cost barriers to on-site abatement by reducing the upfront cost. Importantly, this government-industry partnership also presents an opportunity to fund high impact abatement projects – reducing emissions directly.

FOAK on-site abatement projects are significantly more expensive. In our model, we have considered that abatement in the early years of implementation would cost up to 2.5 times more than at scale, with this FOAK cost multiplier coming down linearly as abatement increased (see Appendix B). Generally, the additional FOAK costs declined to zero at one to two years before the policy end date.

There are two key design options that we modelled:

- Coverage, or the percentage of fugitive emissions eligible for funding would be supported by the methane abatement fund. We modelled two scenarios: 20% and 50%.[26]
- Timeframe, or by what year the funding had to be distributed. We modelled two scenarios: 2035 and 2040.

Other design options for policymakers exist that have not been modelled. For example, the fund could prioritise specific project types to maximise emissions reduction (by prioritising projects at the largest emitting underground mines) or in order to bring down costs for specific technologies (e.g., by prioritising projects at open-cut mines). In our model, we have assumed that the fund supported emissions reductions equally across the mine groups (the largest emitting underground, other underground and open-cut) and licensee types (existing, new).

[26] For clarity, coverage of 20% means that 20% of all eligible fugitive emissions were abated by projects that had 50% of the CAPEX covered by the methane abatement fund. The remaining 50% of the CAPEX and the OPEX were covered by the mine itself. See Appendix B for the definition of 'eligible' emissions.

Findings

As shown in Table 3, a methane abatement fund under any scenario delivers considerable emissions reductions and an economy-wide benefit. Emissions reductions range from 6.6 to 29.7 MtCO_2e. The Net Present Value (NPV) of societal benefits ranges from $398 million to $2.3 billion. The net cost to the mining sector ranges from $-2.3 to $18.8/t$CO_2$e.

Our analysis in Part 1.3 suggests that $18.8/t$CO_2$e represents approximately 3.5% of the average profit of coal mines per tonne of CO_2e.[27] This analysis shows that earlier on-site abatement will deliver greater emissions reductions in the long-term. Ending the fund in 2035 (Scenario A and C) instead of 2040 (Scenario B and D) will deliver considerably more emissions reductions (12.2 to 29.7 MtCO_2e compared to 6.6 to 16.9 MtCO_2e). In addition, the more ambitious the fund, the better the results. A fund designed for 50% coverage in Scenario C and D resulted in emissions reductions of 16.9 to 29.7 MtCO_2e, compared to a fund with 20% coverage in Scenario A and B (reductions of 6.6 to 12.2 MtCO_2e). The mining sector costs, economy-wide benefits and BCR displayed a similar trend: the shorter the timeline and the greater the coverage, the more favourable the results.

Scenario C therefore delivers the greatest benefits both for the mining sector and the broader NSW economy. In addition, this scenario provides 3.0 MtCO_2e of emissions reductions in 2035 – contributing significantly to NSW's 2035 interim emissions target.

The methane abatement fund in scenario C would be approximately $210 million in NPV. Based on projected 2025 coal production $210 million is approximately equivalent to a five-year levy of $0.20 per tonne – compared to an average profit of $33 per tonne of raw coal produced. The average cost for the 'first mover' mines implementing the abatement technology with support from the fund in Scenario C would be negative (except for open-cut mines) due to the ACCU savings and SMC generation. The cost per tonne CO_2e for the methane abatement fund (in other words, the cost reductions provided by the fund to the first movers) would be an average of $7.1/t$CO_2$e, with the upper range equal to $27.5/t$CO_2$e for existing open-cut mines. Therefore, the fund would significantly reduce the cost of the first mover projects by socialising the cost with the rest of the industry.

It should be noted that some of the benefits of the fund are not properly captured by the model. The fund should bring down the cost of abatement for other mines trying to achieve Safeguard baselines with on-site abatement, which is not captured by the model. It should also allow more ambitious regulated emissions intensity threshold policies to be implemented, as the timeframe and cost for technologies should reduce due to the lessons learnt from the FOAK projects deployed through the methane abatement fund.

[27] In Section 1.3, we showed average profit was approximately $33 per tonne of raw coal. Using the Safeguard-legislated industry-average of 0.0653 tCO_2e/t ROM coal, this is equal to $505/t$CO_2$e.

The methane abatement fund modelled in Table 3 distributes funding equally across six groups:

- largest emitting underground mines that are existing
- largest emitting underground mines that are new
- other underground mines that are existing
- other underground mines that are new
- open-cut mines that are existing
- open-cut mines that are new.

While it would be more cost-effective to further prioritise projects on the largest emitting underground mines, our results suggest that abatement on open-cut mines is still beneficial for the mining industry and economy in NSW in certain policy scenarios. For example, in Scenario C, abatement at open-cut mines in NSW delivers 2.2 $MtCO_2e$ of abatement and $95 million in economy-wide benefits at a BCR of 1.8, despite a high net cost of abatement to the mining sector of between $29 and $48/ tCO_2e.

Table 3

A methane abatement fund in NSW may reduce emissions at a net benefit to the economy

Costs and benefits of a methane abatement fund in NSW

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($/$tCO_2e$)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Scenario A: Funding projects that abate 20% of eligible coal mine fugitive emissions by 2035				
12.2	1.2	11.9	768	2.8
Scenario B: Funding projects that abate 20% of eligible coal mine fugitive emissions by 2040				
6.6	0.3	18.8	398	2.5
Scenario C: Funding projects that abate 50% of eligible coal mine fugitive emissions by 2035				
29.7	3.0	-2.3	2,285	4.7
Scenario D: Funding projects that abate 50% of eligible coal mine fugitive emissions by 2040				
16.9	0.8	8.4	1,196	3.4

Regulated emissions intensity thresholds

Description and rationale

We modelled the implementation of regulated emissions intensity thresholds for individual coal mines. Included coal mines would need to meet the emissions intensity thresholds through on-site abatement by a target year. This policy measure would complement Commonwealth policy by ensuring abatement was delivered on-site, supporting the aim of the Safeguard Mechanism.

It would also improve policy certainty, minimising concern within industry that policy incentives for abatement may be diminished in the future. The regulated emissions intensity thresholds may be designed to ensure that the most cost-effective and feasible abatement is incentivised (e.g., by targeting the largest emitting underground mines). For NSW, this policy mechanism may be designed to drive emissions reduction that aligns with interim emissions targets.

There are a range of ways to design the regulation of emissions intensity thresholds. We have modelled two design options, each ending in either 2035 or 2040:

- Regulation with a broad and shallow focus to achieve a smaller amount of abatement across a larger number of mines. This is achieved by implementing a regulated emissions intensity threshold that all coal mines in NSW must achieve by a specified date. We have modelled an emissions intensity threshold of 0.0653 tCO_2e/t coal, which is the Safeguard-legislated average scope 1 emissions intensity of coal mining production.[28] Note, at this emissions intensity threshold, there are no open-cut mines required to implement on-site abatement as currently all open-cut mines in NSW have reported a lower emissions intensity than the Safeguard average. However, there is the potential for open-cut mines to be included if a methane measurement network were established.
- Regulation with a narrow and deep focus to target maximum abatement in a small number of the largest emitting underground mines that represent 65% of all coal mine fugitive emissions in NSW. This is achieved by implementing a regulated emissions intensity threshold wherein any coal mine with a historical emissions intensity above 0.1306 tCO_2e/t coal (double the 0.0653 industry-average scope 1 emissions intensity) must achieve the maximum feasible on-site abatement (which varies by mine) by 2035 or 2040.
- There are further design options for policymakers that have not been modelled. Regulations may be based on absolute emissions instead of emissions intensity. However, designing thresholds based on emissions intensity rather than absolute emissions may allow a focus on abatement where it is most feasible and cost-effective. Further, we have modelled

[28] Note that this value also includes other scope 1 emissions beyond fugitive emissions. The industry-average fugitive emissions intensity of coal production would be lower.

regulations that aim to achieve emissions reduction outcomes, rather than prescribing activities. Outcomes-focused policy provides coal mines with agency to implement the most effective abatement pathway, rather than picking technology winners which does not provide flexibility to adopt emerging abatement technologies that may be more appropriate. Further, it ensures abatement is deployed commensurate to emissions or emissions intensity – less-emitting mines may not need to deploy abatement at all. However, activity-based requirements (for example, requiring underground coal mines to implement drainage to a specific efficiency) could also be effective in driving reductions in emissions. It would be important to include guardrails to ensure that activities are implemented and operated effectively. two scenarios: 2035 and 2040.

Other design options for policymakers exist that have not been modelled. For example, the fund could prioritise specific project types to maximise emissions reduction (by prioritising projects at the largest emitting underground mines) or in order to bring down costs for specific technologies (e.g., by prioritising projects at open-cut mines). In our model, we have assumed that the fund supported emissions reductions equally across the mine groups (the largest emitting underground, other underground and open-cut) and licensee types (existing, new).

Table 4

Regulated emissions intensity thresholds in NSW may reduce emissions at a net benefit to the mining sector

Costs and benefits of regulated emissions intensity thresholds in NSW

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($/t$CO_2$e)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Scenario A: Regulated emissions intensity threshold (industry average) for all mines by 2035				
37.5	4.8	-7.1	3,057	6.1
Scenario B: Regulated emissions intensity threshold (industry average) for all mines by 2040				
17.3	0.4	-2.3	1,422	5.3
Scenario C: Regulated emissions intensity for largest emitting underground mines (must deploy maximum feasible abatement by 2035)				
36.8	4.9	-7.6	2,994	6.2
Scenario D: Regulated emissions intensity for largest emitting underground mines (must deploy maximum feasible abatement by 2040)				
16.6	0.4	-2.9	1,356	5.3

Findings

As shown in Table 4, there are significant economy-wide benefits that could be delivered by regulated emissions intensity thresholds, regardless of the threshold or end date. The NPV of economy-wide benefits ranges from $1.4 billion to $3.1 billion. Emissions reductions under these scenarios range from 17.3 to 37.5 $MtCO_2e$ until 2050. In addition, all scenarios deliver material negative costs for the mining sector; $-7.6 to $-2.3 per tonne of CO_2e when compared to the baseline scenario. In other words, the mining sector may return a profit of between $-7.6 and $2.3 per tonne of CO_2e.

Regulated emissions intensity thresholds implemented earlier will deliver greater emissions reductions in the long-term. Implementing thresholds that must be met by 2035 (Scenarios A and C) delivers emissions reductions of 36.8 to 37.5 $MtCO_2e$, compared with 16.6 to 17.3 $MtCO_2e$ for thresholds that must be met by 2040 (Scenarios B and D). Implementing regulated emissions intensity thresholds with shorter timelines may also significantly contribute to 2035 targets. Scenarios A and C deliver approximately 5 $MtCO_2e$ of abatement in 2035 alone, whereas Scenarios B and D deliver 0.4 $MtCO_2e$ of abatement.

Both the industry-average threshold for all mines and the maximum feasible abatement requirement for the largest emitting underground mines produce similar results. This demonstrates that policymakers have significant flexibility in the policy options – if a policy drives on-site abatement early, it is likely to result in reduced emissions and benefits to the economy.

Broadly, the results of the regulated emissions intensity thresholds are more favourable than the methane abatement fund. This is largely because the thresholds drive abatement at the most emissions-intensive mines, where it is cheaper. Conversely, the methane abatement fund also drives abatement at less gassy underground mines and open-cut mines. Therefore, the two policies achieve different but complementary aims.

Combined regulated emissions intensity threshold and methane abatement fund

Description and rationale

Under these scenarios, we have analysed the impact of implementing a regulated emissions intensity threshold supported by a methane abatement fund for the deployment of FOAK abatement projects. These two policy mechanisms complement each other: the fund demonstrates best practice abatement, brings down the cost of implementation and helps the first movers to meet the emissions intensity thresholds. The regulated thresholds then incentivise a broader swathe of mines to implement these de-risked, cheaper technologies. Combining the two policy mechanisms may also allow for more ambitious regulatory settings.

Findings

All scenarios deliver an economy-wide benefit ranging from $1.5 billion to $3.8 billion, a BCR ranging from 2.9 to 5.1 and emissions reductions ranging from 23.6 to 48.3 $MtCO_2e$. Scenarios C and D result in negative costs for the mining sector when compared to the baseline scenario.

Table 5 shows the emissions, economic and societal impacts of combining a regulated emissions intensity threshold with a methane abatement fund. We have shown the two lowest ambition permutations (Scenarios A and B) and the two highest ambition permutations (Scenarios C and D).

Greater ambition in the coverage of the methane abatement fund and the timelines delivers greater emissions reductions in the long-term. Scenarios C and D, which end in 2035, deliver more than double the emissions reductions of Scenarios A and B which end in 2040 (46.2 to 48.3 $MtCO_2e$ compared to 23.6 to 24.2 $MtCO_2e$). In addition, because emissions reductions are realised sooner, Scenarios C and D have a greater contribution to the 2035 interim target (approximately 5 $MtCO_2e$ under Scenarios C and D compared to 1 $MtCO_2e$ under Scenarios A and B).

When regulations are combined with a methane abatement fund, the analysis shows that there is little difference in overall impacts between regulated emissions intensity thresholds that cover all mines, compared to those that just cover the largest emitting underground mines. The most important design components impacting results are ensuring an earlier end date and being more ambitious with the proportion of emissions covered by the fund.

There are many other variations for combining these policies e.g., a fund with ambitious policy settings combined with a softer emissions intensity threshold regulation, or a fund with less ambitious policy settings combined with a more ambitious emissions intensity threshold regulation. These have not been represented but return results within the range of the scenarios shown in Table 5.

Table 5

Combining a methane abatement fund and regulated emissions intensity thresholds in NSW may increase the emissions reductions significantly

Costs and benefits of a methane abatement fund combined with regulated emissions intensity thresholds in NSW

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($\$/tCO_2e$)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Scenario A: Funding projects that abate 20% of eligible coal mine fugitive emissions by 2040 + regulated emissions intensity threshold (industry average) for all mines by 2040				
23.6	1.3	11.5	1,545	2.9
Scenario B: Funding projects that abate 20% of eligible coal mine fugitive emissions by 2040 + regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2040)				
24.2	1.3	11.6	1,577	2.9
Scenario C: Funding projects that abate 50% of eligible coal mine fugitive emissions by 2035 + regulated emissions intensity threshold (industry average) for all mines by 2035				
46.2	5.2	-4.1	3,582	5.1
Scenario D: Funding projects that abate 50% of eligible coal mine fugitive emissions by 2035 + regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035)				
48.3	5.4	-4.2	3,759	5.1

Combined policy options with methane measurement network

Description and rationale

A methane measurement network would be a government-led network of direct methane monitors and measurement systems to quantify fugitive methane emissions from coal mines. It would verify the level of emissions and abatement from coal mines, supporting the Safeguard Mechanism and other state policies (such as the proposed methane abatement fund and regulated emissions intensity thresholds) that aim to drive abatement. It would provide verification and assurance that investments made under these state and Commonwealth policies for emissions abatement are effective. The measurement network would also support the effectiveness of state and Commonwealth policies which rely on accurate emissions quantification.

In the model, we have assumed that a methane measurement network would be applied to all mines and would increase the projected fugitive emissions for each mine by a specific factor (depending on whether the mine is underground or open-cut). We have also assumed that the Safeguard baselines would be reset based on the measurement network, with the industry-average emissions intensity and facility-specific emissions intensity values shifted upwards. This is according to the additional emissions uncovered by the measurement network. The modelled measurement network is funded by a cost-recovery mechanism.

It should be noted that there is significant uncertainty around the actual emissions from underground and open-cut mines. We have assumed a range of factors that generally correspond to the more conservative end of literature discussed in Part 1.1. This includes a low measurement scenario where emissions from open-cut mines increase by 100% and underground mines do not change, a central measurement scenario where emissions from open-cut mines increase by 150% and emissions from underground mines increase by 10%, and a high measurement scenario where emissions from open-cut mines increase by 200% and emissions from underground mines increase by 20%.

The model assumes the implementation of a coordinated measurement network of satellites, aerial measurements and ground-based monitors. Building the measurement network would require repeated demonstrations, trials and deployments to develop an accurate process of site-level emissions attribution.

Design considerations for the methane measurement network include the coverage: it could measure emissions from all mines, or just open-cut mines. The specific technological make-up of the network is also a key consideration that will affect costs.

Findings

Higher emissions reductions are realised in the high measurement scenarios. In Scenarios C and F, cumulative emissions reductions are approximately 60 $MtCO_2e$, compared to 55 $MtCO_2e$ in the central measurement Scenarios B and E, and compared to 50 $MtCO_2e$ in the low measurement Scenarios A and D. The high measurement scenarios result in similar economy-wide benefits and BCR, and a slightly higher cost to the mining sector. Overall, economy-wide benefits from combining all three policy measures range from $3.4 billion to $4.3 billion.

Based on analysis provided by leading methane measurement experts at the University of New South Wales (UNSW) who have repeatedly trialled and demonstrated various direct methane measurement systems, we have estimated the cost of deploying a coordinated ground-, aerial- and satellite-based measurement network capable of attributing emissions to individual sites from 2025 until 2050.

The rough cost per mine (in NPV) was estimated to be approximately $6 million (lifetime costs from FY25 to FY50). This equates to approximately $230,000 per mine per year or $8 million per year for every mine in NSW.. Note that this assumes full deployment of the measurement network and does not account for the trial and ramp up phase.

Table 6 presents a selection of low to high measurement emissions scenarios representing different combinations of policy settings. There are many other variations for combining these policies that could be explored, but the results of these are within the range of the permutations presented below.

Table 6

Different measurement scenarios support and increase the benefit of state policies

Costs and benefits of a methane abatement fund combined with regulated emissions intensity thresholds in NSW

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($\$/tCO_2e$)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Scenario A: Regulated emissions intensity threshold (industry average) for all mines by 2035 + funding projects that abate 50% of eligible coal mine fugitive emissions by 2035 + measurement network that increases reported emissions from open-cut mines by 100% and from underground mines by 0%				
48.4	5.4	3.0	3,418	3.7
Scenario B: Funding projects that abate 20% of eligible coal mine fugitive emissions by 2040 + regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2040)				
53.9	6.0	3.6	3,774	3.6
Scenario C: Regulated emissions intensity threshold (industry average) for all mines by 2035 + funding projects that abate 50% of eligible coal mine fugitive emissions by 2035 + measurement network that increases reported emissions from open-cut mines by 200% and from underground mines by 20%				
59.4	6.6	4.1	4,130	3.6
Scenario D: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035) + funding projects that abate 50% of eligible coal mine fugitive emissions by 2035 + measurement network that increases reported emissions from open-cut mines by 100% and from underground mines by 0%				
50.5	5.6	2.7	3,592	3.8
Scenario E: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035) + funding projects that abate 50% of eligible coal mine fugitive emissions by 2035 + measurement network that increases reported emissions from open-cut mines by 150% and from underground mines by 10%				
56.2	6.2	3.3	3,964	3.7
Scenario F: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035) + funding projects that abate 50% of eligible coal mine fugitive emissions by 2035 + measurement network that increases reported emissions from open-cut mines by 200% and from underground mines by 20%				
61.9	6.9	3.8	4,336	3.6

Sensitivity analysis on NSW CBA

Sensitivity analysis on NSW CBA results shows that a significant opportunity for state policy exists even when costs increase and abatement technology potential decreases.

The assumptions used in the analysis are all relatively conservative and evidence-based assumptions. The modelling appendix (Appendix B) outlines the sources, evidence and assumptions used throughout the CBA. However, the following sensitivity settings have also been analysed to test their impact on results. It should be noted that these are very significant sensitivities, designed to test the results if there are major discrepancies (by a factor of two) between our inputs and the actual abatement effectiveness or cost. These sensitivities do not reflect a standard range of uncertainty. The sensitivities tested were:

- cost of abatement (tested at 200% of the central assumption)
- cost of measurement (tested at 200% of the central assumption)
- effectiveness of abatement (tested at 50% of the central assumption)
- first of a kind costs (tested at 200% of the central assumption)
- ACCU and SMC price (tested at $75, compared to the central assumption of $35).

The first four of these settings provides an understanding of the worst-case scenario if costs are significantly higher than anticipated or the effectiveness of methane abatement is considerably lower. The final sensitivity setting uses a less conservative ACCU and SMC price to understand the potential value that could be delivered to the coal mining sector if these prices were to increase above the $35 baseline.

Table 7 summarises the results of the implementation of all three policy options combined (Scenario E in Table 6) under different sensitivity settings. There is a net economic benefit ($1.5 billion to $4.0 billion) and material abatement (27.7 MtCO_2e to 56.2 MtCO_2e) delivered under all sensitivity settings. If abatement costs are twice as high as anticipated (Sensitivity setting A; noting that conservative cost assumptions have been used in the model), then there would be a cost to the mining sector of $29.7/t$CO_2$e. Our analysis in Part 1.3 suggests that $29.7/t$CO_2$e represents approximately 6% of the average profit of coal mines per tonne of CO_2e.[29] In this scenario, there is still considerable benefit for the broader NSW economy of $2.5 billion. Under the final sensitivity setting (Sensitivity setting D), where the ACCU and SMC price are set at $75/t$CO_2$e, the mining sector returns a profit of $23.1 per tonne CO_2e. This shows that the benefits of state policy to incentivise fugitive methane abatement could significantly increase if ACCU and SMC prices increase.

[29] In Part 1.3, we showed average profit was approximately $33 per tonne of raw coal. Using the Safeguard-legislated industry-average of 0.0653 tCO_2e/t ROM coal, this is equal to $505/t$CO_2$e.

Table 7

Under ‘worst-case’ sensitivities, the potential for low cost emissions reduction through state policy in NSW remains significant

Results of sensitivity analysis on base NSW scenario (Scenario E in Table 6)

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($\$/tCO_2e$)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Base scenario: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035) + funding projects that abate 50% of eligible coal mine fugitive emissions by 2035 + measurement network that increases reported emissions from open-cut mines by 150% and from underground mines by 10%				
56.2	6.2	3.3	3,964	3.7
Sensitivity setting A: Cost of abatement and measurement is doubled				
56.2	6.2	3.3	3,964	3.7
Sensitivity setting B: Effectiveness of abatement is halved				
27.7	3.1	18.6	1,527	2.3
Sensitivity setting C: First of a kind costs are doubled				
56.2	6.2	10.6	3,552	2.9
Sensitivity setting D: ACCU and SMC price increased to $75				
56.2	6.2	-23.1	3,964	3.7

2.3
Costs and benefits of QLD policy scenarios

The key, high-level finding from the CBA of QLD policy options is that state policy can complement the Safeguard Mechanism and the LEIP to significantly reduce emissions if abatement is brought forward to 2035 rather than 2040.

To assess the costs and benefits of state policy in QLD, we have modelled the impact of the LEIP as part of the counterfactual scenario. The LEIP was modelled through the same methodology as the methane abatement fund (details in Appendix B). Therefore, we assessed the impact of the regulated emissions intensity thresholds and methane measurement network additional to the QLD LEIP and Safeguard Mechanism.

This finding is supported by Table 8; when regulated emissions intensity thresholds drive abatement by 2035, cumulative emissions reductions range from 6.4 to 27.9 $MtCO_2e$. In 2035 alone, these policies may reduce annual emissions by 0.9 to 3.1 $MtCO_2e$, supporting interim emissions reductions targets. The cost to the mining sector of these policies ranges from \$9.7 to \$229.9/tCO_2e, while the benefit to the QLD economy ranges from \$-247 million to \$1.8 billion. Therefore, policies that complement the LEIP and the Safeguard Mechanism to bring abatement forward to 2035 or earlier may have significant positive benefits.

By contrast, when regulated emissions intensity thresholds drive abatement by 2040, outcomes are less favourable. The additional emissions impact reduces to 0.0 to 8.7 $MtCO_2e$. This is primarily because our model of the \$520 million LEIP has a significant impact on emissions. For further policies to have a significant additional impact, they must bring abatement forward to at least 2035.

The findings throughout the body of Part 2 are based on a counterfactual scenario that assumes all QLD coal mines meet their national Safeguard obligations through purchasing ACCUs and SMCs created in jurisdictions outside of QLD. As explored in Part 1.3, coal mines are incentivised to purchase ACCUs and SMCs rather than invest in on-site abatement. In practice, some coal mines may carry out on-site abatement to meet their Safeguard obligation. The counterfactual scenario also includes the impact of the QLD LEIP.

We have modelled the LEIP in the same way as the NSW methane abatement fund: a fund that covers 50% of the upfront CAPEX of abatement projects. The emissions impact and cost of the LEIP are considered as part of the counterfactual scenario and are not considered additional. We have modelled the size of the LEIP as \$500 million and assumed that all \$500 million is spent on realised projects.

We have used conservative cost estimates when building the assumptions for this analysis. As such, the economy-wide and mining sector benefits may be higher. We have conducted a sensitivity analysis in the event that costs are much higher or the level of abatement much lower than our estimates. We found that there is still a strong business case for state policy when using the most conservative cost and abatement assumptions.

Appendix B outlines the methodology, assumptions and sources used for the modelling in full.

Table 8

State policy in QLD that brings abatement forward to 2035 or earlier may support significant emissions reductions - potentially at a negative cost to the mining sector in the most effective scenarios

Results of sensitivity analysis on base NSW scenario (Scenario E in Table 6)

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($\$/tCO_2e$)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Regulated emissions intensity thresholds driving abatement by 2035 + methane measurement network				
6.4 to 27.9	0.9 to 3.1	9.7 to 107.8	-247 to 1,789	0.7 to 3.0
Regulated emissions intensity thresholds driving abatement by 2040 + methane measurement network				
0.0 to 8.7	0.0 to 0.2	> 34.2	-750 to 444	0.0 to 1.9

Implications

As shown in Table 8, the most effective policy design options across all policy measures may reduce emissions in QLD in 2035 by 0.9 – 3.1 $MtCO_2e$. The impact on the wider economy ranges up to a benefit of $1.8 billion at a net cost to the mining sector as low as $9.70 per tonne CO_2e abated.

Table 8 also shows less favourable scenarios, where costs to the mining sector and economy are significant. Therefore, our CBA demonstrates that there are key design factors required to produce a favourable outcome in terms of emissions and impact on the mining sector, as these beneficial outcomes are not guaranteed.

Well-designed state policy intervention has an opportunity to deliver emissions reductions and a net benefit to both industry and the wider QLD society. Policy mechanisms that bring abatement forward to 2035 can complement the Safeguard Mechanism to unlock on-site, cost-effective, and near-term abatement to support QLD's 2035 and 2050 emissions reduction targets.

We have modelled the impact of regulated emissions intensity thresholds and a methane measurement network, but other policy measures and design options that incentivise on-site abatement before 2035 are also likely to have a positive impact. In scenarios with much higher abatement cost, much lower abatement effectiveness and other highly conservative assumptions, state policy mechanisms may continue to deliver benefit to QLD (see the sensitivity analysis, below). It is important to note that these policies may have an opportunity cost to the coal mines by limiting their ability to invest in more profitable pursuits and instead incentivising them to invest in on-site abatement.

The following subsections provide a more in-depth analysis of each policy measure and the impacts of varying policy settings and combined policy scenarios.

Modelling the policy measures

To analyse the costs and benefits of QLD Government policy to incentivise abatement of fugitive emissions from coal mines, we modelled regulated emissions intensity thresholds and a methane measurement network.

Regulated emissions intensity thresholds

We modelled the implementation of regulated emissions intensity thresholds for individual coal mines. Included coal mines would need to meet the emissions intensity thresholds through on-site abatement by a target year. This policy measure would complement Commonwealth policy by ensuring abatement was delivered on-site, supporting the aim of the Safeguard Mechanism. The thresholds would also improve policy certainty, minimising concern within industry that policy incentives for abatement may be diminished in the future.

Regulated emissions intensity thresholds would also complement the QLD LEIP, by incentivising mines to make the most of the fund for first mover abatement projects. Conversely, success in deploying FOAK projects through the LEIP could increase the ambition of the regulated emissions intensity thresholds, as best practice abatement is demonstrated. The regulated emissions intensity thresholds may be designed to ensure that the most cost-effective and feasible abatement is incentivised (e.g., by targeting the largest emitting underground mines). For QLD, this policy mechanism may be designed to drive emissions reduction that aligns with interim emissions targets.

There are a range of ways to design the regulation of emissions intensity thresholds. We have modelled two design options, each ending in either 2035 or 2040:

- Regulation with a broad and shallow focus to achieve a moderate amount of abatement across a larger number of mines. This is achieved by implementing a regulated emissions intensity threshold that all coal mines in QLD must achieve by a specified date. We have modelled an emissions intensity threshold of 0.0653 tCO_2e/t coal which is the Safeguard-legislated average scope 1 emissions intensity of coal mining production.[30]
- Regulation with a narrow and deep focus to target maximum abatement in a small number of the largest emitting underground mines that represent 60% of all coal mine fugitive emissions in QLD. This is achieved by implementing a regulated emissions intensity threshold wherein any coal mine with a historical emissions intensity above 0.1306 tCO_2e/t coal (double the 0.0653 industry-average scope 1 emissions intensity) must achieve the maximum feasible on-site abatement (which varies by mine) by 2035 or 2040.

[30] Note that this value also includes other scope 1 emissions beyond fugitive emissions. The industry-average fugitive emissions intensity of coal production would be lower.

There are further design options for policymakers that have not been modelled. Regulations may be based on absolute emissions instead of emissions intensity. However, designing thresholds based on emissions intensity rather than absolute emissions may allow a focus on abatement where it is most feasible and cost-effective. Further, we have modelled regulations that aim to achieve emissions reduction outcomes, rather than prescribing activities. Outcomes-focused policy provides coal mines with agency to implement the most effective abatement pathway, rather than picking technology winners which does not provide flexibility to adopt emerging abatement technologies that may be more appropriate. However, activity-based requirements (for example, requiring underground coal mines to implement drainage to a specific efficiency) could also be effective in driving reductions in emissions. It would be important to include guardrails to ensure that activities are implemented and operated effectively.

Methane measurement network

A methane measurement network would be a government-led network of direct methane monitors and measurement systems to quantify fugitive methane emissions from coal mines. In the model, we have assumed that a methane measurement network would be applied to all mines and would increase the projected fugitive emissions for each mine by a specific factor (depending on whether the mine is underground or open-cut). We have also assumed that the Safeguard baselines would be reset based on the measurement network, with the industry-average emissions intensity and facility-specific emissions intensity values shifted upwards. This is according to the additional emissions uncovered by the measurement network. The modelled measurement network is funded by a cost-recovery mechanism.

It should be noted that there is significant uncertainty around the actual emissions from underground and open-cut mines. We have assumed a range of factors that generally correspond to the more conservative end of literature discussed in Part 1.1. This includes a low measurement scenario where emissions from open-cut mines increase by 100% and underground mines do not change, as well as a central measurement scenario where emissions from open-cut mines increase by 150% and emissions from underground mines increase by 10%. We have also assumed a high measurement scenario where emissions from open-cut mines increase by 200% and emissions from underground mines increase by 20%.

The model assumes the implementation of a coordinated measurement network of satellites, aerial measurements and ground-based monitors. Building the measurement network would require repeated demonstrations, trials and deployments to develop an accurate process of site-level emissions attribution.

The methane measurement network would verify the level of emissions and abatement from coal mines, supporting the Safeguard Mechanism and other state policies (such as the proposed methane abatement fund and regulated emissions intensity thresholds) that aim to drive abatement. It would provide verification and assurance that investments made under these state and Commonwealth policies for emissions abatement are effective. The measurement network would also support the effectiveness of state and Commonwealth policies which rely on accurate emissions quantification.

Design considerations for the methane measurement network include the coverage: it could measure emissions from all mines, or just open-cut mines. The specific technological make-up of the network is also a key consideration that will affect costs.

QLD LEIP

We also modelled the impact of the QLD LEIP within the counterfactual scenario. This was modelled consistently with the methane abatement fund policy mechanism for NSW. The LEIP was modelled to cover 50% of the CAPEX of FOAK abatement projects, up to a total budget of $500 million. This meant that within the model, the total impact of the LEIP changed depending on the measurement scenario. Within the high measurement scenario, the $500 million covered a smaller fraction of total emissions than within the low measurement scenario.

Combining policy measures into a policy framework

For our QLD CBA, we have combined all policy measures into an overarching policy framework. This is because the LEIP is already implemented and therefore part of the counterfactual scenario (i.e., non-additional).

Findings

The findings of the cost benefit analysis of QLD Government policy measures are outlined in Table 9. The key findings are:

- If designed well, state policy could have a significantly beneficial and complementary impact to the QLD LEIP and the Safeguard Mechanism. For example, Scenario G reduces cumulative emissions by 20.4 $MtCO_2e$, reduces emissions in 2035 by 2.6 $MtCO_2e$ (supporting QLD's 2035 target) and results in a minimal cost to the mining sector of $10.0 per tonne of CO_2e abated. The BCR of this policy scenario is calculated to be 2.9.

- Abatement must be brought forward to 2035 for a significant, positive impact on emissions and the economy. Scenarios in which abatement is brought forward to 2035 (Scenarios A, C, E, G, I, K) have a much more positive impact on all reported metrics than scenarios in which regulated emissions intensity thresholds must be met by 2040 (Scenarios C, D, F, H, J, L). For example, cumulative emissions reductions range from 6.4 to 27.9 $MtCO_2e$ in 2035 scenarios, compared to 0.0 to 8.7 $MtCO_2e$ in 2040 scenarios.

- The methane measurement network improves the business case for policy intervention and abatement. The high measurement scenarios (Scenarios I, J, K, L) have more favourable outcomes than the central measurement scenarios (Scenarios E, F, G, H). Further, the central measurement scenarios (Scenarios E, F, G, H) have more favourable outcomes than the low measurement scenarios (Scenarios A, B, C, D). For example, the BCR of the policy interventions in high measurement scenarios ranges from 0.9 to 3.0, with a cumulative emissions reduction of 8.1 to 27.9 $MtCO_2e$. Comparatively, the BCR of policy interventions in the low measurement scenarios ranges from 0.0 to 2.2, with a cumulative emissions reduction of 0.0 to 8.9 $MtCO_2e$.

- There are similar results between regulated emissions intensity thresholds that drive abatement to industry average across all mines (Scenarios A, B, E, F, I, J) and those that drive maximum feasible abatement at the largest emitting underground mines (Scenarios C, D, G, H, K, L), except in net mining sector costs. Generally, the second design option (deeper abatement at fewer mines) results in a slightly greater emissions reduction. Ultimately, this shows that policymakers have flexibility in designing these policy measures. There are many ways to bring abatement forward before 2035 that have significant impacts on emissions and benefits to the QLD economy.

- Based on analysis provided by leading methane measurement experts at the University of New South Wales (UNSW) who have repeatedly trialled and demonstrated various direct methane measurement systems, we have estimated the cost of deploying a coordinated ground-, aerial- and satellite-based measurement network capable of attributing emissions to individual sites from 2025 until 2050. The rough cost per mine (in net present value) was estimated to be approximately $6,000,000 (lifetime costs from FY25 to FY50). This equates to approximately $230,000 per mine per year or $13 million per year for every mine in QLD. Note that this assumes full deployment of the measurement network and does not account for the trial and ramp up phase.

Table 9

The state policy framework in QLD of regulated emissions intensity thresholds and a methane measurement network may support emissions reductions at low cost in the most effective scenarios

The costs and benefits of regulated emissions intensity thresholds and a methane measurement network to complement the LEIP in QLD

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($\$/tCO_2e$)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Scenario A: Regulated emissions intensity threshold (industry average) for all mines by 2035 + measurement network that increases reported emissions from open-cut mines by 100% and from underground mines by 0%				
6.4	0.9	107.8	-247	0.7
Scenario B: Regulated emissions intensity threshold (industry average) for all mines by 2040 + measurement network that increases reported emissions from open-cut mines by 100% and from underground mines by 0%				
0.1	0.0	6,889.8	-750	0.0
Scenario C: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035) + measurement network that increases reported emissions from open-cut mines by 100% and from underground mines by 0%				
8.9	1.3	18.1	454	2.2
Scenario D: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2040) + measurement network that increases reported emissions from open-cut mines by 100% and from underground mines by 0%				
0.0	0.0	N/A	-258	0.0
Scenario E: Regulated emissions intensity threshold (industry average) for all mines by 2035 + measurement network that increases reported emissions from open-cut mines by 150% and from underground mines by 10%				
16.6	2.1	43.5	485	1.4
Scenario F: Regulated emissions intensity threshold (industry average) for all mines by 2040 + measurement network that increases reported emissions from open-cut mines by 150% and from underground mines by 10%				
3.3	0.0	229.9	-477	0.4

Scenario G: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035) + measurement network that increases reported emissions from open-cut mines by 150% and from underground mines by 10%				
20.4	2.6	10.0	1,275	2.9
Scenario H: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2040) + measurement network that increases reported emissions from open-cut mines by 150% and from underground mines by 10%				
3.8	0.0	69.4	66	1.2
Scenario I: Regulated emissions intensity threshold (industry average) for all mines by 2035 + measurement network that increases reported emissions from open-cut mines by 200% and from underground mines by 20%				
23.8	2.6	33.2	980	1.7
Scenario J: Regulated emissions intensity threshold (industry average) for all mines by 2040 + measurement network that increases reported emissions from open-cut mines by 200% and from underground mines by 20%				
8.1	0.2	98.9	-110	0.9
Scenario K: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035) + measurement network that increases reported emissions from open-cut mines by 200% and from underground mines by 20%				
27.9	3.1	9.7	1,789	3.0
Scenario L: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2040) + measurement network that increases reported emissions from open-cut mines by 200% and from underground mines by 20%				
8.7	0.2	34.2	444	1.9

Sensitivity analysis on QLD CBA

Sensitivity analysis on QLD CBA results shows that a significant opportunity for state policy exists even when costs increase and abatement technology potential decreases.

The assumptions used in the analysis are all relatively conservative and evidence-based assumptions. The modelling appendix (Appendix B) outlines the sources, evidence and assumptions used throughout the CBA. However, the following sensitivity settings have also been analysed to test their impact on results. It should be noted that these are very significant sensitivities, designed to test the results if there are major discrepancies (by a factor of two) between our inputs and the actual abatement effectiveness or cost. These sensitivities do not reflect a standard range of uncertainty. The sensitivities tested were:

- cost of abatement (tested at 200% of the central assumption)
- cost of measurement (tested at 200% of the central assumption)
- effectiveness of abatement (tested at 50% of the central assumption)
- first of a kind costs (tested at 200% of the central assumption)
- ACCU and SMC price (tested at $75, compared to the central assumption of $35).

The first four of these settings provides an understanding of the worst-case scenario if costs are significantly higher than anticipated or the effectiveness of methane abatement is considerably lower. The final sensitivity setting uses a less conservative ACCU and SMC price to understand the potential value that could be delivered to the coal mining sector if these prices were to increase above the $35 baseline.

Table 10 summarises the results of the implementation of all three policy options combined (Scenario G in Table 9) under different sensitivity settings. There is a net economic benefit ($0.4 billion to $1.3 billion) and material abatement (10.2 MtCO_2e to 20.4 MtCO_2e) delivered under all sensitivity settings. If abatement costs are twice as high as anticipated (Sensitivity setting A; noting that conservative cost assumptions have been used in the model), then there would be a cost to the mining sector of $43.5/t$CO_2$e. Our analysis in Part 1.3 suggests that $43.5/t$CO_2$e represents approximately 9% of the average profit of coal mines per tonne of CO_2e.[31] In this scenario, there is still considerable benefit for the broader NSW economy of $590 million. Under the final sensitivity setting (Sensitivity setting D), where the ACCU and SMC price are set at $75/t$CO_2$e, the mining sector returns a profit of $16.9 per tonne CO_2e. This shows that the benefits of state policy to incentivise fugitive methane abatement could significantly increase if ACCU and SMC prices increase.

[31] In Part 1.3, we showed average profit was approximately $33 per tonne of raw coal. Using the Safeguard-legislated industry-average of 0.0653 tCO_2e/t ROM coal, this is equal to $505/t$CO_2$e.

Table 10

Under 'worst-case' sensitivities, the potential for low-cost emissions reduction through state policy in QLD remains significant

Results of sensitivity analysis on base QLD scenario (Scenario G in Table 9)

Cumulative emissions reductions ($MtCO_2e$)	Annual emissions reduction in 2035 ($MtCO_2e$)	Net mining sector costs ($\$/tCO_2e$)	Economy-wide benefit ($ million)	Economy-wide benefit-cost ratio
Base scenario: Regulated emissions intensity threshold for largest emitting underground mines (must deploy maximum feasible abatement by 2035) + measurement network that increases reported emissions from open-cut mines by 150% and from underground mines by 10%				
20.4	2.6	10.0	1,275	2.9
Sensitivity setting A: Cost of abatement and measurement is doubled				
20.4	2.6	43.5	590	1.4
Sensitivity setting B: Effectiveness of abatement is halved				
10.2	1.3	29.2	441	1.8
Sensitivity setting C: First of a kind costs are doubled				
20.4	2.6	22.3	1,023	2.1
Sensitivity setting D: ACCU and SMC price increased to $75				
20.4	2.6	-16.9	1,275	2.9

2.4

Next steps and considerations for policymakers

This project sought to understand what, if any, actions the NSW and QLD Governments could take, should they wish to complement the Safeguard Mechanism and accelerate the reduction of coal mine methane emissions within their respective state inventories.

Part 1 of this report clearly finds that there are significant untapped opportunities for cost-effective, on-site methane abatement in both jurisdictions. It also finds that there are barriers to the adoption of cost-effective on-site abatement solutions, which require additional complementary policy measures to address. Part 2 sets out a framework of potential state policy measures which NSW and QLD could implement to support and encourage industry to overcome these barriers on timelines that contribute to state emissions targets. The cost-benefit analysis of these measures individually and collectively, as a mutually reinforcing policy framework, finds that there is a strong public benefit for action, and a spectrum of options which deliver net emissions reductions at low (or negative) cost to the coal industry.

The rankings of costs and benefits by policy measure and design option are not intended as prescriptive recommendations. Rather, this analysis is designed to help governments narrow their focus to a portfolio of cost-effective options to be analysed against broader appropriate criteria.

For NSW, the key takeaways from the cost benefit analysis are that many detailed design options for the policy package may result in positive outcomes for emissions and the economy, at a low (or negative) cost to the mining sector. More ambitious policies (a larger methane abatement fund and regulated emissions intensity thresholds that commence earlier) tend to result in more favourable outcomes for the economy and mining sector.

For QLD, the key takeaways are that regulated emissions intensity thresholds must bring abatement forward to 2035 or earlier in order to have a significant emissions reductions impact that is additional to the LEIP and to benefit the economy at a low cost to the mining sector. In both jurisdictions, policymakers have flexibility over the design of the potential policies, particularly over the choice to prioritise deep and cost-effective reductions at the 15 largest emitting mines or incentivise moderate abatement at a larger set of coal mines.

Within these parameters, policymakers have significant flexibility in the detailed design of policy measures that align with important qualitative considerations beyond abatement and cost effectiveness. Some of the key considerations for each policy measure are set out in Table 11 below (noting that considerations around a methane abatement fund are only relevant for NSW).

For each of the three policy measures in the framework, these design elements and considerations need be weighed up with regard to the level of abatement they will support, cost-effectiveness, speed and ease of implementation, stakeholder consultation and alignment with broader government goals.

Table 11

Design considerations for policy measures to complement the Safeguard Mechanism and to accelerate the reduction of coal mine emissions

Policy measure 1: Methane abatement fund (only in NSW)

Measure	Design element	Description	Considerations
Methane abatement fund	Cost sharing mechanism	How does government collect the financial contributions from mines for the fund?	• E.g., New legislation, pollution licencing, mining royalty enhancement
	Financial vehicle	What legal entity does the NSW Government use to administer the fund?	• E.g., New entity, Climate Change Fund, Environmental Trust.
	Fund objectives	What is the scope of the fund?	• E.g., Only coal fugitive FOAK projects, all coal methane, all coal emissions, broader mining abatement or broader methane abatement.
	Financial vehicle scope	What potential future policy should the vehicle enable?	• E.g., Cross sectoral FOAK levies and methane abatement, FOAK levies and methane abatement in other sectors or FOAK levies and abatement of other greenhouse gasses?

Policy measure 2: Regulated emissions intensity thresholds (both NSW and QLD)

Measure	Design element	Description	Considerations
Regulated emissions intensity thresholds	Coverage	Which mines do thresholds apply to?	• E.g., All mines or highest emitting mines.
	Trajectory	Over what period are thresholds lowered to target levels?	• E.g., 5 vs 10 vs 15-year transition.
	Threshold level	At what level should thresholds be set?	• E.g., Mines align with industry-average vs adopting the deepest cost-effective abatement that is feasible.
	Metric	What metric is used to measure and set thresholds?	• Absolute emissions vs emissions intensity.
	Statutory mechanism	What regulatory mechanism and body is used to administer compliance?	• E.g., New legislation, add to existing prescriptive environmental pollution licences, etc.

Policy measure 3: Methane measurement network (both NSW and QLD)

Measure	Design element	Description	Considerations
Methane measurement network	Cost sharing mechanism	How does government collect the financial contributions from mines for the network?	• E.g., Existing Protection of the Environment Operations Act 1997 (NSW) enables cost sharing of Upper Hunter Air Quality Monitoring Network.
	Implementation plan	Develop long term plan from detailed design, pilot, deployment, knowledge sharing and continuous improvement.	• Including major program stages, outcomes, timing and associated key activities, cost drivers, dependencies, land, technology, service and staffing requirements.
	Bottom-up budget	Develop detailed budget in line with agency or Treasury requirements.	• Including year by year CAPEX, OPEX, and labour requirements.

Abbreviations

Abbreviations	Full form
ACCU	Australian Carbon Credit Units
ARA	Airborne Research Australia
BCR	Benefit Cost Ratio
CBA	Cost Benefit Analysis
CCA	Climate Change Authority
EPBC	Environment Protection and Biodiversity Conservation
FOAK	First-of-a-kind
GWP	Global Warming Potential
LEIP	Low Emissions Investment Partnerships
MAF	Methane Abatement Fund
NGER	National Greenhouse Energy and Reporting scheme
NOAK	Nth-of-a-kind
NPV	Net Present Value
NSW	New South Wales
QLD	Queensland
ROM	Run-of-mine
RTO	Regenerative Thermal Oxidisers
SMC	Safeguard Mechanism Credits
UNECE	United Nations Economic Commission for Europe
UNSW	University of New South Wales
VAM	Ventilation Air Methane

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Appendix A: Methane abatement and measurement technologies

This appendix outlines the sources, assumptions and methodology used to calculate the cost, potential and readiness of abatement and measurement technologies.

Abatement technologies

Regenerative thermal oxidation

The RTO is the only cost-effective and commercially ready technology to destroy low-concentration VAM,[32] the largest source of methane from underground coal mines. RTOs could abate 55% of fugitive emissions from the largest emitting underground mines in NSW and QLD for \$6 – \$30/tCO_2e. This could reduce current annual fugitive emissions by 3.5 MtCO_2e in NSW and 3.8 MtCO_2e in QLD. This section will outline the data and sources behind the abatement potential and cost.

RTOs are large combustion chambers connected to vent shafts from underground mines. They operate at high temperatures (around 1000°C), which allow them to combust the low concentration methane (0.2% – 1.2%) [22] [16] [21]. By comparison, flares and generators have a lower operating range of 25% and 30% methane, respectively [45]. Importantly, RTOs have a high level of heat recovery, which allows the combustion chambers to maintain a high temperature without the need for significant amounts of costly and emissions-intensive fuel.

[32] New technologies to destroy VAM include catalytic and adsorption approaches. These are not yet technologically or commercially ready for deployment [22].

Abatement potential

The estimated abatement potential of RTOs at new and existing largest emitting underground mines in NSW and QLD is 55%. In other words, RTOs could reduce total fugitive emissions from the largest emitting underground mines by 55%. When deployed at the NSW largest emitting underground mines, this could reduce emissions by 3.5 $MtCO_2e$ per year (36% of NSW's total coal mine fugitive emissions). When deployed at QLD's largest emitting underground mines, this could reduce emissions by 3.8 $MtCO_2e$ per year (33% of QLD's total coal mine fugitive emissions). The estimated abatement potential of RTOs at other underground mines in NSW and QLD is 0%, although it could be higher in reality.

The total abatement potential is a product of three key factors: the percentage of total underground fugitive emissions that are from ventilation air, the percentage of total VAM that could be abated by RTOs, and the efficiency of RTO abatement.

What percentage of total underground fugitive emissions are from ventilation air? CSIRO's recent analysis (see Figure 10c of the CSIRO report [21]) calculates that 78% of Australia's coal mine fugitive emissions are from ventilation air. Rystad's analysis (see page 24 of Rystad's presentation [2]) returned a more conservative estimate that approximately 62% of current methane emissions from underground mines were in ventilation air. Our interviewees returned various values between 60% and 80%. While RTO deployment in isolation could likely access between 60% and 80% of fugitive methane emissions from an individual mine, this does not account for an extensive drainage process that would cannibalise RTO's abatement potential. Therefore, we will assume that RTOs can access 60% of emissions from a coal mine, and that extensive drainage can access 30%. We will assume that 10% of emissions cannot be abated.

What is the percentage of total VAM that could be abated by RTOs? The answer to this question ultimately depends on which mines RTOs can be deployed at. RTOs can theoretically operate at mines with a methane concentration in ventilation air between 0.2% and 1.2% [22] [16] [21]. However, in practice, questions remain around the practical deployment of RTOs at mines with a VAM concentration between 0.2% and 0.4% [21]. In Australia, many mines operate with VAM concentrations between 0.2% and 0.4% for safety considerations [21]. To further complicate this question, many mines do not publicly disclose their VAM concentration [46]. CSIRO has performed leading analysis into VAM concentrations in Australia, with their results outlined in Figure 11. If it is assumed that RTOs can operate between 0.2% and 0.4%, this analysis suggests that approximately 90% of VAM in Australia is available to RTO abatement (disregarding the unknown fraction). If it is assumed that RTOs cannot operate between 0.2% and 0.4%, this reduces to approximately 60%. Therefore, VAM data would suggest that between 60% and 90% of VAM in Australia could be abated by RTOs.

We have also considered a second approach to answer this question. We know that both Kestrel and Appin mines have applied for, or received, grants to deploy RTO systems at their mines. Our analysis of the emissions intensity of coal production at individual mines (methodology outlined in Appendix B) shows that both Kestrel and Appin mines are among the most emissions-intensive mines in Australia.

We have found that there are nine mines in NSW and six mines in QLD with an emissions intensity between that of Kestrel and Appin (including the Kestrel and Appin mines). There are also two expansion projects that have recently been approved or are awaiting approval in NSW that forecast an emissions intensity between that of the Kestrel and Appin coal mines. Therefore, it is likely that these mines (which we have labelled as the largest emitting underground mines) also have the requisite conditions for cost-effective deployment of RTO systems, considering Kestrel and Appin are very likely to. This may not necessarily be the case. For example, some of these largest emitting underground mines may have a VAM concentration that is too low for RTO deployment, but a very high ventilation flow rate which means total emissions and emissions intensity are high. However, it is reasonable to assume that these nine mines in NSW and six mines in QLD are capable of RTO deployment. To validate this assumption with CSIRO's analysis of VAM concentration, these nine mines in NSW and six mines in QLD collectively account for approximately 82% of total fugitive emissions from underground mines (from Safeguard-reporting coal mines). This sits within the range of CSIRO's assessment that between 60% and 90% of VAM emissions are suitable for RTO deployment [26].

Therefore, in this report, we have assumed that these largest emitting underground mines have VAM that is suitable for RTO deployment. We have assumed all other underground mines do not. Numerically, this means that we are assuming that approximately 82% of VAM in Australia is accessible to RTO deployment. It is feasible that some of the less gassy underground mines could also deploy RTOs, however, we do not have access to data around VAM concentrations to confirm this.

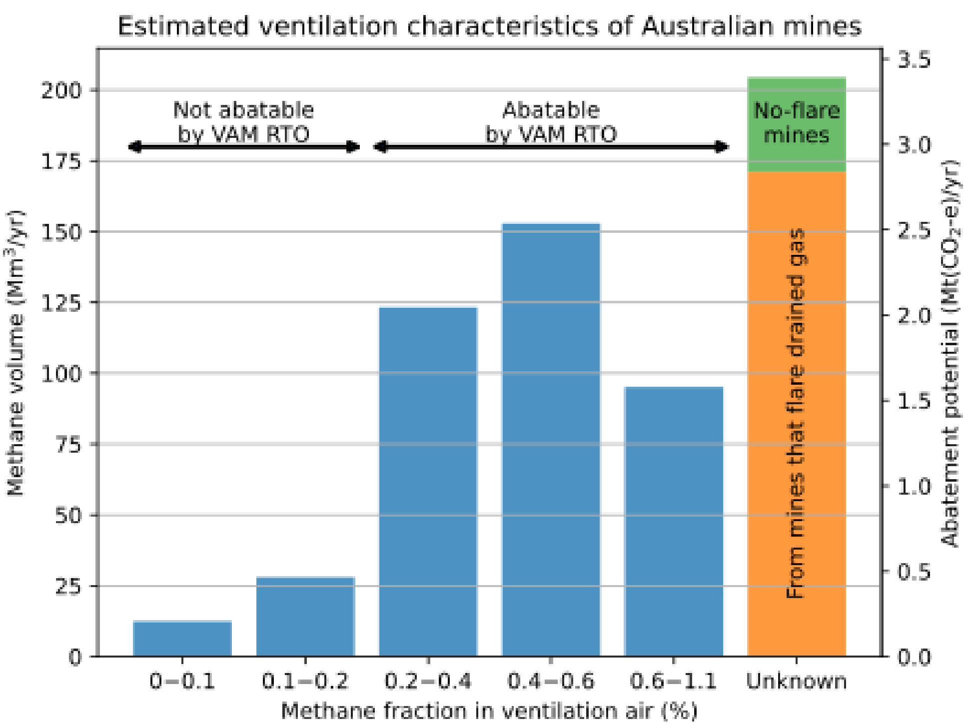

Figure 11: Assessment of VAM concentrations from Australian mines. Entire diagram, including annotations, are from CSIRO's analysis - Wilkins et al. (2024) [23], and also presented within Figure 10 of Regan et al. (2024) [21].

What is the efficiency of RTO abatement? While RTO developers claim that RTO efficiency exceeds 99% (e.g., [27]; not including a discount factor for the conversion of methane to CO_2), practical efficiencies are likely to be lower. Rystad assumes a total efficiency of 95% [2]. CSIRO assumes a total efficiency of 75% “to account for inefficiencies, downtime, logistical constraints such as available space, safety concerns, and the fact that all RTO installations to date have been connected to only a fraction of the ventilation stream” [22]. While an efficiency rate around 75% may be applicable for FOAK deployments, it is likely that over multiple mines and decades, efficiency will increase, and RTOs will be connected to the majority of viable ventilation streams. Therefore, we have assumed a total efficiency (accounting for the conversion of methane to CO_2) of 90%, far more conservative than the >99% estimates of RTO developers.

Putting these three factors together, the abatement potential of RTO deployments at new and existing largest emitting underground mines (rounded to the nearest 5%), is approximately 55%. For and the cost benefit analysis in Part 2, we have used this value of 55%. In NSW, RTOs could therefore abate 3.5 $MtCO_2e$ per year. In QLD, RTOs could abate 3.8 $MtCO_2e$ per year.

Assumptions related to RTO abatement potential

Assumptions
RTOs can access 60% of total fugitive emissions from the largest emitting underground mines.
The entirety of the VAM produced in the largest emitting underground mines is available to RTO deployment. In ‘other underground mines’, 0% of the VAM is of sufficient concentration for RTO deployment.
Efficiency of RTO abatement is 90%, accounting for inefficiencies and the conversion of methane to CO_2.

Cost-effectiveness

The cost of RTO deployment is likely to be between \$6 and \$30/tCO_2e. This is based on modelling from numerous reputable sources [22] [2] [9]. For cost benefit modelling in Part 2, we have assumed that RTO deployment at both new and existing largest emitting underground mines costs \$15/tCO_2e.

CSIRO analysis suggests that RTOs cost between \$6 and \$12/tCO_2e for mines with a VAM concentration over 0.4% [22]. For mines with a VAM concentration between 0.2% and 0.4%, they estimate a cost of \$18/tCO_2e. Rystad more conservatively estimates a cost of \$27/tCO_2e for RTO deployment at Australian mines [2]. The IEA estimate an average cost of \$6/tCO_2e [9]. Two interviewees who had done detailed RTO cost analysis returned results ranging from \$9 to \$30/tCO_2e, depending on VAM concentration. For the largest emitting underground mines, which are very likely to have a higher VAM concentration, we have therefore chosen a central value of \$15/tCO_2e.

The RTO costs are therefore similar or significantly less than the current cost of offsetting at \$35/tCO_2e. Hence, RTO deployment is profitable, as it can save ACCUs and generate SMCs. The upfront cost of an RTO system is significant, between \$40 and \$100 million, according to interviewees and Kestrel's grant [29]. From these interviews, we have assumed that the cost of RTOs is 70% CAPEX, 30% OPEX.

The cost of RTOs depends primarily on the VAM concentration and flow rate [22]. Greater flow rate (i.e., greater volumes of ventilation air coming through the vent shaft) requires larger RTO infrastructure, increasing upfront cost. However, it also increases the amount of methane that is oxidised, meaning the flow rate has a limited effect on cost per tonne. Greater VAM concentration increases the amount of methane that is oxidised, reducing the cost per tonne.

Assumptions related to RTO cost

Assumptions
RTO deployment and operation at the largest emitting underground mines costs \$15/tCO_2e.
RTO cost is 70% CAPEX, 30% OPEX.

Technology readiness

RTOs are technologically ready for deployment at the nine largest emitting underground mines in NSW and the six largest emitting underground mines in QLD. RTOs have been deployed at approximately 15 mines globally. Most deployments took place in the 2000's and 2010's, before a global cooldown in deployments after the collapse of national and international carbon prices. We interviewed four leading global RTO developers, who were all interested in Australian projects.

The barrier to deployment is not technological readiness. The barriers that are delaying deployment are discussed in Part 1.3, and include the need for updated safety frameworks. State policy could overcome these barriers and unlock safe and effective deployment of RTOs.

Limitations

The limitations of RTOs are:

- They create a material, but manageable, safety risk. The safety risk is due to the potential for pockets of methane over 1.2% in the ventilation air to cause an explosive reaction. From our interviews with technology providers and mine safety consultants, it seems that this is a manageable safety risk. Mine telemetry systems monitor methane concentration and can send a signal to disconnect the RTO from the vent shaft in the event of high concentration methane pockets. However, this is a process that requires oversight from the state safety regulators.
- They may not be feasible at less gassy underground mines due to low VAM concentrations.
- They face significant upfront costs.

Enhanced underground coal mine methane drainage and abatement

Underground coal mine drainage and abatement is a cost-effective and commercially ready technology for abating methane from underground mines. Combined with flaring, generation or use, drainage could abate 25% to 45% of coal mine methane from each underground mine in the near-term for between $-17 and $28/t$CO_2$e. This could reduce current annual fugitive emissions by 2.2 MtCO_2e in NSW (1.6 MtCO_2e from the largest emitting underground mines and 0.6 MtCO_2e from 'other underground' mines) and 2.2 MtCO_2e in QLD (1.7 MtCO_2e from the largest emitting underground mines and 0.5 MtCO_2e from 'other underground' mines). This section will outline the data and sources behind the abatement potential and cost.

Underground coal mine drainage encompasses multiple technologies to drain methane from coal seams before, during or after mining. These are widely deployed technologies for underground mine safety – removing methane from the underground mine to limit the potential for the concentration to rise into the explosive range. Using these technologies for emissions abatement does not change the process, although it may entail more extensive drainage programs. Therefore, we refer to this technology as 'enhanced' underground drainage and abatement. The drained methane, usually at a concentration over 30%, can then be flared, used for electricity generation or otherwise combusted. Before mining a coal seam, this drainage process is known as pre-drainage. While mining a coal seam (or after), this process is known as post-drainage. For pre-drainage, pipes can be installed from the surface (surface to in seam) or from underground (underground to in seam). For post-drainage, pipes are often installed from either the surface or the underground into the goaf (the area of the mine where the coal has already been mined, where methane may continue to leak from around the seam) [16].

Abatement potential

The estimated abatement potential of enhanced underground drainage is:

- for the new and existing largest emitting underground mines that will also deploy RTO technologies: 25%
- for existing 'other underground' mines that will not deploy other abatement technologies: 35%
- for new 'other underground' mines that will not deploy other abatement technologies: 45%

When deployed at existing underground mines in NSW and QLD, enhanced drainage could therefore reduce emissions by 2.2 MtCO_2e per year in NSW (22% of total state coal mine fugitive emissions) and 2.2 MtCO_2e per year in QLD (19% of total state coal mine fugitive emissions).

The total abatement potential is a product of three key factors: the percentage of total underground fugitive methane that is likely to be drained through enhanced drainage, the percentage of total drainage gas that could be abated, and the efficiency of drainage abatement technologies like flaring and oxidation.

What is the percentage of total fugitive methane from underground mines that are likely to be drained? The answer to this question will change depending on the type of mine being drained. We will consider three scenarios:

- The largest emitting underground mines (nine in NSW, six in QLD), both new and existing, that will also deploy RTOs for abatement.
- ‘Other underground’ mines that are existing and currently operational, that will not deploy other abatement technologies.
- ‘Other underground’ mines that are ‘new’ and not currently operational, that will not deploy other abatement technologies.

The potential of underground drainage is dependent on the geology, time and budget. For example, it is technically possible to drain 80% of methane from a coal seam with less permeability, but it will likely cost a lot more and take a lot longer than draining 40% of methane from a permeable seam. Historically, underground drainage has been applied to remove enough methane to make the mine safe for workers, rather than trying to maximise methane abatement. CSIRO’s recent analysis (see Figure 10c of the CSIRO report [22]) calculated that 22% of Australia’s coal mine fugitive emissions are from current drainage processes. Rystad’s analysis (see page 24 of Rystad’s presentation [2]) returned an estimate that approximately 33% of underground methane emissions could be abated through drainage and abatement. We have assumed that the largest emitting underground mines (nine currently operational in NSW, six in QLD) undergoing maximum feasible abatement will drain and abate 30% of their fugitive emissions and oxidise 60% of their methane with RTOs. For existing underground mines that are not using other abatement technologies, UNECE suggests that while in theory 50 – 80% of gas can be captured by post-drainage, in practice 30 – 50% is more realistic [30]. Ember has assumed that post-drainage can reduce emissions by 40% (accounting for other inefficiencies) [23]. Therefore, we will assume that existing ‘other underground’ mines can drain 40% of their fugitive methane emissions. For new mines, this potential is greater, because pre-drainage can occur before the coal seam is cracked. Anglo American has demonstrated that extensive drainage at underground mines can reduce emissions by over 60% (which also accounts for other inefficiencies) [31]. We have taken 50% – 55% as a conservative estimate.

What is the percentage of total drainage gas that could be abated? Both pre- and post-drainage gas typically has methane concentrations over 30%, and therefore can be converted to CO_2 through flaring or gas turbines [22]. To be conservative, we will assume that 95% of drainage gas can be abated.

What is the efficiency of flaring or oxidation abatement? While technology developers claim that flaring or oxidation occurs at an efficiency over 98%, we have chosen a more conservative assumption. Rystad assumes a total efficiency of 95% [2]. CSIRO assumes an efficiency of around 95% too, without accounting for the conversion of methane to CO_2 [22]. We have assumed a total efficiency (accounting for the conversion of methane to CO_2) of 90%.

Putting these three factors together, the estimated abatement potential of enhanced underground drainage (rounded to the nearest 5%) is:

- For new and existing largest emitting mines that will also deploy RTO technologies: 25%
- For existing ‘other underground’ mines that will not deploy other abatement technologies: 35%
- For new ‘other underground’ mines that will not deploy other abatement technologies: 45%

In NSW, enhanced underground drainage and abatement could therefore reduce emissions by 2.2 $MtCO_2e$ per year. In QLD, enhanced underground drainage and abatement could reduce emissions by 2.2 $MtCO_2e$ per year.

Assumptions related to enhanced underground drainage and abatement potential

Assumptions
Enhanced drainage at the largest emitting underground mines, both existing and new, drains 30% of fugitive emissions.
Enhanced drainage at other underground mines, that are currently operational, drains 40% of fugitive emissions.
Enhanced drainage at other underground mines, that are new, drains 50% – 55% of fugitive emissions.

Assumptions related to enhanced underground drainage and abatement potential

Assumptions
Of drainage gas from enhanced underground drainage, 95% is of sufficient concentration for abatement.
Efficiency of drainage gas abatement is 90%, accounting for inefficiencies and the conversion of methane to CO_2.

Cost-effectiveness

The cost of underground drainage and abatement deployment is likely to be between \$-17 and \$28/tCO_2e. This is based on modelling and implementation from numerous reputable sources [22] [9] [2] [32] [31].

Estimates of underground drainage and generation or utilisation place it between \$-17 and \$9/tCO_2e, while drainage and flaring ranges from \$0 to \$28/tCO_2e. CSIRO estimated that underground drainage and generation would cost \$-17/tCO_2e for Australian mines, while flaring would cost \$0/tCO_2e [22]. The IEA estimated a cost of \$1/tCO_2e for drainage and generation, and \$16/tCO_2e for drainage and flaring [9]. Rystad estimated a cost of \$-3/tCO_2e for drainage and generation, and \$28/tCO_2e for drainage and flaring [2].

Cost is dependent on permeability, the abatement process attached to drainage, the extent of drainage and whether drainage infrastructure already exists. The permeability and suitability of mines in NSW and QLD to drainage is not known. However, our interviews suggest that unsuitable geology does not make drainage impossible, it just increases cost and time. Secondly, once drained, using the methane for electricity generation provides a revenue stream that reduces the overall cost (although increases the upfront cost), while flaring does not. Thirdly, the extent of drainage is not linearly related to cost. The operational cost of the first 10% of methane to be drained will likely be much lower than the cost of increasing drainage from 50% to 60%. Finally, expanding existing drainage operations reduces the cost, as existing infrastructure can be leveraged. Building new drainage operations greatly increases the CAPEX.

To contextualise the costs to an Australian case study, pre-drainage and abatement at Curragh mine's proposed underground expansion is projected to reduce lifetime emissions by nearly 5 MtCO_2e (68% of total fugitive emissions) at between \$2 and \$6/tCO_2e [32]. Anglo American spend \$100 million annually on post-drainage infrastructure [31]. This investment led to at least 5.3 MtCO_2e in abatement in 2023 at the Grosvenor mine, at a cost of less than \$20/tCO_2e [31].[33] In 2021, Glencore spent \$50 million to set up drainage and generation infrastructure at Oaky Creek mine [48].

For cost benefit modelling in Part 2, we have assumed the following costs:

- Underground drainage and abatement at the existing, largest emitting underground mines: \$10/tCO_2e (50% CAPEX, 50% OPEX).
- Underground drainage and abatement at new, largest emitting underground mines: \$20/tCO_2e (80% CAPEX, 20% OPEX).
- Underground drainage and abatement at existing, 'other underground' mines: \$15/tCO_2e (50% CAPEX, 50% OPEX).
- Underground drainage and abatement at new, 'other underground' mines: \$25/tCO_2e (80% CAPEX, 20% OPEX).

[33] This drainage project extended beyond Grosvenor, but no emissions reductions data is available for the other mines. Therefore, the total cost was a maximum of \$19/tCO2e, but likely to be much smaller.

To derive these numbers, we have selected numbers at the upper range of the reputable estimates of underground drainage and abatement cost. The breakdown of CAPEX and OPEX is based on findings from interviews. We have not specified the abatement technology, but our cost assumptions align much more closely with flaring rather than generation cost estimates. We have assumed that existing mines would have existing drainage operations, and therefore lower cost and lower % CAPEX.

We have also assumed greater gassiness in the largest emitting underground mines would make the technology cheaper per tonne of abatement.

Assumptions related to underground drainage and abatement cost

Assumptions
Underground drainage and abatement at the existing, largest emitting underground mines costs \$10/tCO_2e (50% CAPEX, 50% OPEX).
Underground drainage and abatement at new, largest emitting underground mines costs \$20/tCO_2e (80% CAPEX, 20% OPEX).
Underground drainage and abatement at the existing, ‘other underground’ mines costs \$15/tCO_2e (50% CAPEX, 50% OPEX).
Underground drainage and abatement at new, ‘other underground’ mines costs \$25/tCO_2e (80% CAPEX, 20% OPEX).

Technology readiness

Underground mine drainage has been deployed extensively in Australia and globally to reduce methane to safe levels for workers in the mines. Therefore, this technology is commercially ready, and both the supply chains and expertise exist in NSW and QLD. Drainage and abatement has been deployed at Grosvenor, Curragh, Oaky Creek, Mandalong, Ironbark, Carborough Downs, Integra and Ashton coal mines, amongst others [31]. A focus on underground drainage for emissions abatement rather than safety may require more extensive, 'enhanced' drainage systems, but the technology and process are the same. There are already over 200 projects that use coal mine methane around the world, the majority from draining active, underground mines [32].

Limitations

The limitations of underground drainage are:

- It is more effective before mining commences, when pre-drainage can be applied. Often, pre-drainage is performed three to five years before the commencement of mining [49].
- The cost is dependent on geology. The absolute cost and cost per tonne can be significant in less permeable seams.
- Underground drainage systems require effective planning and coordination around the mining process. Extensive drainage of a seam may take between one and three years. To prevent delays to mining, this must be planned and coordinated effectively.

Open-cut coal mine methane drainage and abatement

Open-cut coal mine drainage and abatement is a technology at the demonstration stage with high uncertainty around cost. The technology is similar to coal seam gas drilling and underground coal mine drainage. While its potential is uncertain, we have estimated that it could abate 10% of open-cut methane from existing mines and 20% from new mines for a cost between $45 and $60/tCO$_2$e. Based on these numbers, open-cut drainage and abatement could reduce current annual fugitive emissions by 0.2 MtCO$_2$e from NSW and by 0.3 MtCO$_2$e from QLD. If open-cut mines are producing more emissions than currently reported, this abatement potential will increase. This section will outline the data and sources behind the abatement potential and cost.

Open-cut coal mine drainage is similar to underground coal mine drainage. It involves the installation of piping and depressurisation to drain methane from coal seams before mining. This methane, usually at a concentration over 30%, can then be flared, used for electricity generation or otherwise combusted.

Abatement potential

There is significant uncertainty around the abatement potential of drainage at open-cut mines. Estimates of total abatement potential range from 5% to 18% to 40% (as estimated by CSIRO, Rystad and Ember, respectively [22] [2] [23]). Abatement potential is significantly increased for new open-cut mines, where pre-drainage can be extensively performed before mining commences. For and the cost benefit analysis in Part 2, we have assumed that the total abatement potential of drainage for existing open-cut mines is 10% and for new open-cut mines is 20%. This total abatement potential accounts for the percentage of total open-cut fugitive methane that is likely to be drained through drainage, the percentage of total drainage gas that could be abated, and the efficiency of drainage abatement technologies like flaring and oxidation.

If effective, open-cut coal mine drainage could become a viable solution for a large percentage of open-cut coal mine methane (including the potentially large fraction of emissions that are not currently measured). The current uncertainty is because the technology has not been deployed at scale, and because there is uncertainty around the methane content of open-cut coal mines.

Cost-effectiveness

The cost of deploying open-cut drainage is uncertain because it has not been deployed at scale. The IEA estimate that open-cut drainage and generation could cost approximately \$16/tCO_2e, with open-cut drainage and flaring costing \$30/tCO_2e [9]. Rystad estimates \$16/tCO_2e for drainage and generation as well, with an estimate of \$22/tCO_2e for drainage and flaring [2]. CSIRO's analysis is far more conservative, with open-cut drainage and abatement costing anywhere from \$25/tCO_2e to \$200/tCO_2e [22]. For cost benefit modelling in Part 2, we selected values that were fairly central within these large ranges. Therefore, we estimated that drainage and abatement at new open-cut mines would cost \$45/tCO_2e, while at existing open-cuts it would cost \$60/tCO_2e. We have assumed that cost for new mines would be cheaper, due to the potential to access a much larger portion of the methane emissions before the seam is mined. We assumed that for both new and existing mines, the cost would be 80% CAPEX, 20% OPEX. We acknowledge significant uncertainty in these estimates.

Like underground mine drainage, cost is dependent on permeability, the abatement process attached to drainage and the extent of drainage.

Assumptions related to open-cut drainage and abatement potential

Assumptions
Total abatement potential of drainage and abatement at existing open-cut mines is 10%.
Total abatement potential of drainage and abatement at new open-cut mines is 20%.

Assumptions related to open-cut drainage and abatement cost

Assumptions
Open-cut drainage and abatement at existing open-cut mines costs \$60/tCO_2e (80% CAPEX, 20% OPEX).
Open-cut drainage and abatement at new open-cut mines costs \$45/tCO_2e (80% CAPEX, 20% OPEX).

Technology readiness

Open-cut drainage is still in the demonstration stage and may therefore require some time to be deployed widely. However, its technology is very similar to that used for coal seam gas drilling[34] and underground coal mine drainage. Open-cut drainage has not been used historically because it has not been needed for safety in the same way as underground mines. With the new focus on climate mitigation, it has recently become a technology of interest. The QLD LEIP program has recently announced a grant for Stanmore Resources to build an open-cut drainage to generation system at South Walker Creek coal mine, to be operational from 2027 [33]. Coronado have also implemented an open-cut drainage and abatement trial at Curragh coal mine in QLD [34].

Limitations

The limitations of open-cut coal mine drainage are:

- It has not been widely demonstrated in Australia or globally. However, as discussed, the technology is very similar to coal seam gas and underground drainage processes.
- It is more effective before mining commences. After starting, neighbouring seams can still be drained before they are mined, but the total emissions reduction potential is lower.
- The cost is dependent on geology. The absolute cost and cost per tonne can be significant in less permeable seams.
- Open-cut drainage systems require effective planning and coordination around the mining process. Extensive drainage of a seam may take multiple years. To prevent delays to mining, this must be planned and coordinated effectively.

[34] The difference with coal seam gas drilling is that this resource is only extracted when the coal seams are suitable for drainage. The coal seams that are being mined are usually less suitable for this drainage process. These may require greater time and cost to drain, but the technology is likely to be similar.

Measurement technologies

A system capable of measuring site-level methane emissions would require an integrated network of ‘top-down’ ground-based systems, aerial, and satellite measurements to estimate total emissions from a site. These measurements could be reconciled with ‘bottom-up’ proponent-led estimates, which are estimates of the different sources of methane at a site, over time. NGER methods for open-cut and underground coal mines are all currently ‘bottom-up’ approaches. Using an integrated network of these measurement approaches minimises the disadvantages of each, combines continuous and periodic measurements, and is likely to ‘triangulate’ a more accurate estimate of emissions [35] [36]. A fully integrated system has not yet been trialled and would require testing and improvements. However, all the individual components (satellites, planes, drones, vehicles and ground-based systems) are developing rapidly and increasingly being deployed to measure methane emissions from the oil and gas industry. There is increasing recognition that within the near-to-medium term, a network of direct methane measurement technologies could accurately quantify emissions from various emissions sources, including open-cut mines.

As a result, the Commonwealth Government have committed to commissioning a scientific study to test the capability of “satellite, plane, vehicle and ground-based approaches in an operational open-cut mine setting” [14]. The study will seek to understand how measurement approaches could be deployed and coordinated in the future for a greater level of accuracy around open-cut coal mine methane emissions [14].

The following section assesses the ‘top-down’ ground, aerial, and satellite methane measurements. It is intended to be a summary to support assessments of cost and technology readiness in the context of coal mine deployment, noting that many of these technologies have been deployed more widely to measure fugitive emissions from the oil and gas industry. More comprehensive analyses of methane measurement technologies can be found here [35] [36].

Most measurement technologies are based on the ability of methane to absorb strongly in the infrared spectrum. Effectively, measurement technologies quantify the concentration of methane by calculating how much infrared light has been absorbed by methane. Measurement processes are either passive or active. Passive measurements rely on quantifying the absorption and reflectance of infrared radiation from sunlight. Active measurements emit infrared radiation and quantify the absorption and reflectance of this light source.

Ground-based methane measurement

Ground-based ‘top-down’ systems for measuring methane are a cost-effective technology at the demonstration stage for coal mines. While most ground-based systems are ‘bottom-up’, some are capable of ‘top-down’ measurements in which ground-based systems measure the methane upstream and downstream of the facility. This can generally be achieved through micrometeorological methods, or inverse dispersion approaches. Both approaches directly and continuously measure methane concentrations in the atmosphere, as well as a range of climate factors, which can be used to model the total methane release [35]. A key advantage of ground-based systems is that they continuously measure methane being emitted.

In Australia, the University of Wollongong is investigating the use of ground-based, inverse dispersion sensors (called EM27/SUN instruments) at coal mines. EM27/SUN instruments measure the absorption of solar infrared radiation by methane in a vertical column of air. By positioning these instruments around a site, the upstream and downstream methane levels can be quantified to attribute emissions to the mine.

Cost-effectiveness

Our interviewees suggested that EM27/SUN instruments were in the order of $350,000 per unit and that at least four were required for each mine. Analysis and maintenance would form the majority of operational costs. There could be significant cost reductions from sharing EM27/SUN infrastructure between nearby mines. One measurement unit may be able to operate for multiple mines, reducing the overall systems required.

Technology readiness

Ground-based systems are still under development for deployment at coal mines. Micrometeorological methods and inverse dispersion methods have been used for the oil and gas industry [35].

Limitations

The primarily limitations of ground-based ‘top-down’ technologies are:

- They require inverse modelling based on wind speeds and other data to attribute to a specific facility. This is a complex process, which is not currently at the accuracy or precision required for site-level attribution.
- There are limited number of people in Australia with the expertise for the modelling process, data analysis and interpretation.
- Their accuracy can be affected by climate factors, such as changing winds.

Drone and aircraft methane measurement

Aerial systems for measuring methane are a cost-effective technology at the demonstration stage for coal mines. Aerial systems usually involve drones or aircraft. A key advantage compared to other technologies is that aerial measurements can view and measure the entire mine and methane plumes. This is unlike ground-based systems, which only measure within a single column of air. They also have a much higher resolution than most satellites, meaning that aerial measurements can more accurately distinguish between emissions and plumes from neighbouring sites. Broadly, drones and aircraft often operate by flux wall, mass balance or spectral imaging approaches. Aerial measurements are periodic, meaning that they do not continuously measure emissions. This is a significant downside as the methane intensity of coal mines can vary significantly from day-to-day. If a measurement is performed on a day that involves blasting of coal and a particularly large release of methane, the aerial 'flyover' will give the impression that the emissions from the mine are higher than the actual average.

In Australia, the UNSW and Airborne Research Australia (ARA) are two groups investigating the use of aerial measurements at coal mines. There are numerous Australian and international organisations using drones to measure oil and gas facilities, that are interested in expanding to coal mines.

Cost-effectiveness

Interviewees that deliver aerial measurement services suggested that ballpark costs for an aerial measurement are at $30,000 per service (including analysis costs). At monthly flyovers, this would cost roughly $360,000 per mine, per year. UNSW analysis suggests that the annual cost of airborne surveying for a whole basin would be between $500,000 and $1 million. There are likely to be significant cost savings when using aerial flyovers across multiple mines or an entire basin, since the major cost is in the hire and deployment of a drone/aircraft and operator, and the analysis. The additional cost of flying over a neighbouring mine and analysing the methane from this source is greatly reduced.

Technology readiness

This technology has recently been commercially deployed for oil and gas facilities. The aerial methane measurement service providers that we talked to said that coal mines were much larger, with less obvious methane sources, which required further demonstration. UNSW and ARA are operating aerial flyovers at coal mines and Carbon Mapper in the US have recently completed a large survey of landfill methane emissions, using aerial surveys amongst other approaches [50].

Limitations

The primary limitations of aerial technologies are:

- They are periodic. This is problematic when methane emissions from open-cut mines are not necessarily constant. Days focused on blasting and production at the mine will lead to more methane than days focused on transport or maintenance. Depending on which day a fly-over occurs, emissions may be much higher or lower than the average.
- They may require favourable atmospheric conditions to operate accurately, and at minimum require accurate measurement of wind conditions.
- They require inverse modelling based on wind speeds and other data to attribute to a specific facility. This is a complex process, which is not currently at the accuracy or precision required for site-level attribution.
- There are limited number of people in Australia with the expertise for the modelling process, data analysis and interpretation.
- Their accuracy can be affected by climate factors, such as changing winds.

Satellite methane measurement

Satellite systems for measuring methane are a cost-effective technology at the deployment stage for coal mines. They are currently in operation (e.g., MethaneSAT, TROPOMI), but primarily for oil and gas systems. Generally, satellites have either high resolution and low breadth of coverage, or low resolution and high breadth of coverage (i.e., satellites either measure a large area without site-level attribution or a small area with site-level attribution). The advantage of satellites is generally the capability to view an entire site or multiple sites at once. This has the potential to greatly reduce operational costs. Satellites operate with periodic flyovers. They can often flyover frequently, but interviewees suggested that between 10% and 50% of days would have usable data, as many climate factors can disrupt the measurement process. Satellite measurements, as with aerial and ground-based approaches, require significant modelling and attribution analysis, which currently has a high level of uncertainty.

In Australia, OpenMethane is using data from the TROPOMI methane monitoring satellite to calculate methane emission from coal mines [13]. TROPOMI and OpenMethane analysis has a low resolution, which means that it can measure a broad area (the entirety of Australia) but only to a resolution of 10x10 km. This means it cannot accurately distinguish between emissions from methane sources that are close by. MethaneSAT has recently launched and measures methane sources to a higher resolution.

Cost-effectiveness

Interviewees suggested that ballpark costs for using data from methane monitoring satellites are low, at much less than $100,000 per year. There are likely to be cost savings when using satellite flyovers across multiple mines or an entire basin, particularly in analysis.

Technology readiness

Satellites are currently operating to measure methane emissions from specific oil and gas facilities (e.g., MethaneSAT, GHGSat) and for broad swathes of land (e.g., TROPOMI). Development is primarily focused on reducing the uncertainties of satellite measurements and increasing their resolution. This has improved significantly in recent years and there has been a growing number of studies using satellites to measure methane from coal mines [12] [13] [51] [9].

Limitations

The primary limitations of satellite technologies are:

- They are periodic. This is problematic when methane emissions from open-cut mines are not necessarily constant. Days focused on blasting and production will lead to more methane than days focused on transport or maintenance. Depending on which day a fly-over occurs, emissions may be much higher or lower than the average.
- Some satellites have limited resolution (e.g., TROPOMI), which currently prevents them from determining facility-specific emissions.
- They currently have a significant degree of uncertainty.
- Satellites cannot operate in a wide range of conditions, including if it is cloudy, near water, dusty, etc. Therefore, while a satellite may flyover a site multiple times in a week, often only one measurement in a month is usable.

Appendix B: Modelling analysis methodology and assumptions

This appendix outlines the sources, assumptions and methodology used to calculate the results in the cost benefit analysis of Part 2, as well as the results related to current and projected fugitive emissions, the Safeguard Mechanism, interim state targets and coal mine financials in Part 1.

The sources, assumptions and methodology used to calculate the cost and potential of abatement technologies are outlined in this appendix, but are presented in greater detail in Appendix A.

Quantifying current and future fugitive emissions, coal production and emissions intensity

The coal mines analysed

All existing, operational coal mines in NSW and QLD that reported to the Clean Energy Regulator under the Safeguard Mechanism were included in this analysis. These mines were known as 'existing' licensees. These mines, their location (i.e., NSW or QLD), and their type (i.e., underground, open-cut or underground and open-cut) were included from three sources: Coal Services Statistics, Queensland Coal Industry Statistics and Global Energy Monitor Coal Mine Tracker.

New coal mine projects and coal mine expansions that are awaiting approval were also included in this analysis. These projects were classified as 'new' licensees. These projects were included from the Australia Institute Coal Mine Tracker, which collates proposals awaiting the federal Environment Protection and Biodiversity Conservation (EPBC) Act approval.

A few other projects were included from other sources. There may be some proposed coal mines and expansions that are currently awaiting state approval that are not in the Federal pipeline. These may not have been included. The location and mine type of these proposals awaiting approval were determined from a range of sources. These new licensees were classified as 'expansion' projects when they were expanding on an existing operation and 'new mines' if they were not expansions.

The tables below outline the key data, sources and assumptions.

Assumptions related to new coal mines

Assumptions
Mine proposals awaiting approvals were considered 'expansions' of existing mines if they were named the same as an existing mine, but were 'new mines' if they did not share a name with an existing mine.

Data and sources for existing and new coal mines

Data	Unit	Value	Sources
Existing, operational coal mines	Names of each mine	Not included	Coal Services Statistics: Production and Stock Reports QLD Coal Industry Statistics (https://www.data.qld.gov.au/dataset/coal-industry-review-statistical-tables) Global Energy Monitor Coal Mine Tracker (https://globalenergymonitor.org/projects/global-coal-mine-tracker/tracker-map/)
Mine type	Underground, open-cut or underground & open-cut	Not included	Coal Services Statistics: Production and Stock Reports QLD Coal Industry Statistics (https://www.data.qld.gov.au/dataset/coal-industry-review-statistical-tables) Global Energy Monitor Coal Mine Tracker (https://globalenergymonitor.org/projects/global-coal-mine-tracker/tracker-map/)
Mine state	NSW or QLD	Not included	Coal Services Statistics: Production and Stock Reports QLD Coal Industry Statistics (https://www.data.qld.gov.au/dataset/coal-industry-review-statistical-tables) Global Energy Monitor Coal Mine Tracker (https://globalenergymonitor.org/projects/global-coal-mine-tracker/tracker-map/)
New mine and mine expansion proposals awaiting approval	Names of each mine	Not included	The Australia Institute Coal Mine Tracker (https://australiainstitute.org.au/coal-mine-tracker/) Global Energy Monitor Coal Mine Tracker (https://globalenergymonitor.org/projects/global-coal-mine-tracker/tracker-map/)
Mine type of 'new licensees'	Underground, open-cut or underground & open-cut	Not included	Various sources – this relied on mine-by-mine research. Usually, the specific project proposal in the EPBC public portal (https://epbcpublicportal.environment.gov.au/all-referrals/) was used to identify the mine type. Sometimes, the Global Energy Monitor Coal Mine Tracker was used (https://globalenergymonitor.org/projects/global-coal-mine-tracker/tracker-map/).
State of 'new licensees'	NSW or QLD	Not included	The Australia Institute Coal Mine Tracker (https://australiainstitute.org.au/coal-mine-tracker/) Global Energy Monitor Coal Mine Tracker (https://globalenergymonitor.org/projects/global-coal-mine-tracker/tracker-map/)

Current and future coal production, fugitive emissions and emissions intensity

The average coal production for each existing mine was averaged from FY20-23. It was assumed that coal production at each mine from FY25-50 would be the same as the average production from each mine from FY20-23 until closure. For new licensees, coal production was estimated as per the Australia Institute's Coal Mine Tracker. It should be noted that mines often produce less than their licence limit, so this process may overestimate coal production of new licensee to a small extent. It was assumed that upon expiry of the mining licence, coal production would cease.

The average scope 1 emissions for each existing mine were averaged from Safeguard-reported data from FY20-23. This means that current emissions estimated throughout the report (e.g., Figure 2) were an average of the four years from FY20-23, rather than from any single year. This methodological decision was made to negate significant year-by-year fluctuations in coal production that may have occurred at individual mines between FY20 and FY23. For new licensees, the Australia Institute Coal Mine Tracker estimated annual scope 1 emissions. These estimates were either directly taken from the proponents' reports or, when not available, an average emissions intensity of 0.0825 tCO_2e/t ROM coal was used.

The average scope 1 emissions for both existing and new licensees was converted to the average fugitive emissions, by multiplying the scope 1 emissions by a fugitive:scope 1 emissions factor. This ratio was estimated for FY23 data by the CCA, as 95% for underground mines and 41% for open-cut mines. It was assumed that these ratios were applicable to other years and new licensees.

The emissions intensity of each mine could be calculated from the coal production and emissions data. For each mine, its scope 1 emissions intensity and fugitive emissions intensity was calculated by summing total reported emissions from FY20-23 and dividing it by total reported coal production from FY20-23. If either coal production or emissions data was missing for a year, both the coal production and emissions data of that year were excluded from the emissions intensity calculation. This produced a historical scope 1 emissions intensity specific to each mine (the facility-specific emissions intensity) that was used to project Safeguard baselines (outlined below).

Future emissions from each mine were estimated by multiplying the projected coal production by the historical fugitive emissions intensity of each mine. Therefore, this assumed that fugitive emissions intensity of coal production would remain constant at each mine without abatement technology or ACCUs/SMCs.

Note that the estimates around measurement and the potential for unmeasured emissions is all outlined in the main text, in Part 1.1.

The tables below outline the key data, sources and assumptions.

Data and sources related to emissions and coal production

Data	Unit	Value	Sources
Coal production from FY20-23 for existing mines	Tonnes of ROM or raw coal	Not included	Coal Services Statistics: Production and Stock Reports QLD Coal Industry Statistics (https://www.data.qld.gov.au/dataset/coal-industry-review-statistical-tables)
Projected coal production for new licensees	Projected coal production (megatonnes of coal)	Not included	The Australia Institute Coal Mine Tracker (https://australiainstitute.org.au/coal-mine-tracker/)
Mine licence expiry date	Year	Not included	Various sources – this relied on mine-by-mine research. Usually, the specific project proposal in the EPBC public portal (https://epbcpublicportal.environment.gov.au/all-referrals/).
Closure date of new licensee projects	Year	Not included	The Australia Institute Coal Mine Tracker (https://australiainstitute.org.au/coal-mine-tracker/)
Scope 1 emissions from FY20-23 for existing mines	$MtCO_2e$	Not included	Clean Energy Regulator Safeguard data (https://cleanenergyregulator.gov.au/markets/reports-and-data/safeguard-facility-reported-emissions-data/safeguard-facility-reported-0)
Projected scope 1 emissions for new licensees	$MtCO_2e$	Not included	The Australia Institute Coal Mine Tracker (https://australiainstitute.org.au/coal-mine-tracker/)
Fugitive:scope 1 emissions ratio for underground mines	%	95%	CCA's 2023 review of the NGER scheme (https://www.climatechangeauthority.gov.au/sites/default/files/documents/2023-12/2023%20NGER%20Review%20-%20for%20publication.pdf)
Fugitive:scope 1 emissions ratio for open-cut mines	%	41%	CCA's 2023 review of the NGER scheme (https://www.climatechangeauthority.gov.au/sites/default/files/documents/2023-12/2023%20NGER%20Review%20-%20for%20publication.pdf)

Assumptions related to emissions and coal production

Assumptions
Coal production at each mine from FY25-50 would be equivalent to the average production from FY20-23 until closure. This assumption was made to negate significant year-by-year fluctuations in coal production that can occur at individual mines.
Coal production would cease at the expiry of the mining licence.
Coal production for new licensees would be equivalent to their maximum licenced limit. This may overestimate coal production from these mines, as often production is less than maximum permitted capacity.
The fugitive:scope 1 emissions ratio would be the same for all underground and all open-cut mines, and consistent with the CCA's 2023 calculation. The fugitive:scope 1 emissions ratio for mines with both underground and open-cut operations would be an average of the ratio of underground and open-cut ratios.
Fugitive emissions intensity of coal production would remain constant for each mine from its historical fugitive emissions intensity for FY25-50 (excluding any purchases of ACCUs/SMCs or investment in abatement).

Projecting Safeguard baselines and emissions under the Safeguard Mechanism

Safeguard baselines were projected for each existing and new licensees, based on the legislated process for determining standard baselines. This process meant that baselines would decline each year towards zero by 2050, but would also transition towards the industry-average emissions intensity. The process for projecting Safeguard baselines was to multiply the facility-specific scope 1 emissions intensity (calculated in the above section, based on emissions and coal production from FY20-23) by the transition proportion plus the industry-average emissions intensity multiplied by the transition proportion. This value was multiplied by the emissions reduction contribution for each year. This was multiplied by the projected coal production for each mine in each year to return the final Safeguard baseline. Note that it was assumed that the emissions reduction contribution would decline by 3.285% each year from FY30 to FY50, as per DCCEEW guidance. This decline rate may be re-adjusted at a later year to ensure the Safeguard Mechanism will drive emissions to zero by 2050.

The tables below outline the key data, sources and assumptions.

Data and sources related to the Safeguard Mechanism

Data	Unit	Value	Sources
Coal production from FY20-23 for existing mines	Tonnes of ROM or raw coal	Not included	Coal Services Statistics: Production and Stock Reports QLD Coal Industry Statistics (https://www.data.qld.gov.au/dataset/coal-industry-review-statistical-tables)
Projected coal production for new licensees	Projected coal production (megatonnes of coal)	Not included	The Australia Institute Coal Mine Tracker (https://australiainstitute.org.au/coal-mine-tracker/)
Mine licence expiry date	Year	Not included	Various sources – this relied on mine-by-mine research. Usually, the specific project proposal in the EPBC public portal (https://epbcpublicportal.environment.gov.au/all-referrals/).

Assumptions related to the Safeguard Mechanism

Assumptions
If new licensees were expansions on existing projects, then the facility-specific scope 1 emissions intensity was designated as the same as the existing facility, rather than the emissions intensity projected for the proposal.
New licensees were required to transition towards industry-average emissions intensity, rather than best practice emissions intensity.
Emissions reduction contribution would decline by 3.285% each year from FY30 to FY50, as per DCCEEW guidance. This decline rate may be re-adjusted at a later year to ensure the Safeguard Mechanism drives emissions to zero by 2050.

Coal mine financial analysis and Safeguard compliance cost

Financial analysis

We analysed the annual reports of eight major coal companies from 2014 to 2023[35] for profit and saleable coal data. Collectively, these eight coal companies were responsible for over two-thirds of Australian coal mine fugitive emissions from FY20-23.

We assessed the profit, represented by earnings before interest, tax, depreciation and amortisation (EBITDA), per tonne of saleable coal. The average historical profit per tonne was calculated by averaging each company's EBITDA per tonne from 2014 to 2021, excluding 2022 and 2023 as outliers with particularly high coal prices. Note that this was a weighted average, dividing total EBITDA from 2014 to 2021 by total coal production. The profit per saleable tonne was converted into profit per raw tonne by using company-specific scaling factors (this was done to compare to previous calculations of emissions intensity, which used raw coal production). The total saleable coal from 2020-23 from annual reports was divided by total raw coal production from 2020-23 from Safeguard-reporting mines. This produced a company-specific factor of saleable to raw coal. The results of this calculation are presented in Table 12. Between 2014 and 2021, profit per tonne was between $16 and $62 per tonne of raw coal for most companies (Table 12 in Appendix B). The average EBITDA per raw tonne from 2014 to 2021, weighted by coal production, was $33 (Figure 10).

Coal price data, both historical and forecast, was sourced from the Australian Government Department of Industry, Science and Resources [52]. Both metallurgical and thermal coal prices are projected to fall from their peaks in 2022 and 2023. However, the average forecast coal price from 2025 to 2029 is greater than the average coal price from 2014 to 2021. Therefore, coal profits are likely to increase, although labour and operational costs are likely to be greater than the historical average, potentially offsetting increases in profit [53] [54]. However, some interviewees suggested operational costs would decline slowly after reaching a peak under the coal price extremes of 2022 and 2023.

The tables below outline the key data, sources and assumptions.

[35] Australian companies report in Australian financial years, international companies report in Australian calendar years.

Data and sources related to coal mine financials

Data	Unit	Value	Sources
Coal company EBITDA per tonne saleable coal (FY24-21)	$AUD/tonne saleable coal	Not included	Annual reports of each coal company from FY14-21.
Historical coal price (FY14-24)	$AUD/tonne saleable coal	Not included	DISR Resources and energy quarterly June 2024 Historical data (https://www.industry.gov.au/publications/resources-and-energy-quarterly-june-2024)
Forecast coal price (FY25-29)	$AUD/tonne saleable coal	Not included	DISR Resources and energy quarterly June 2024 Forecast data (https://www.industry.gov.au/publications/resources-and-energy-quarterly-june-2024)

Assumptions related to coal mine financials

Assumptions
Some coal companies reported in calendar years, others in financial years. In general, this had minimal impact on analysis, which simply produced a weighted average of EBITDA per tonne of saleable coal across FY or CY14-21. The ratio of saleable coal to raw coal was consistent within each company. This ratio was calculated between 2020 and 2023 and then applied for 2014 to 2019.

Safeguard compliance cost

We assessed the impact of the Safeguard Mechanism on the coal mines by projecting Safeguard baselines from FY24 to FY50 (as described above).

Safeguard compliance cost was calculated by first quantifying the difference between projected fugitive emissions (calculated as per methodology above) and Safeguard baselines for each mine in each year from FY24 to FY50. This difference was multiplied by the projected cost of ACCUs/SMCs ($35 + 2% each year). This provided a real cost of Safeguard compliance for each mine in each year. This was aggregated to the company level by calculating a weighted average of the compliance cost for each company based on their portfolio of mines in 2024. The results were averaged over FY24 to FY50. This, therefore, produced the average real cost of complying with the projected Safeguard Mechanism from FY24 to FY50 for each company. For clarity, this calculation included all years from FY24 to FY50 and therefore accounted for the decline of the baselines to zero.

Table 12 represents the average annual cost of Safeguard compliance from FY24 to FY50, assuming a $35 price of ACCUs and SMCs (+ 2% each year).

Table 12: *Projected cost of compliance to the Safeguard Mechanism (from FY24-50) and average historical profit (FY14-21), per tonne of raw coal. Note that some of these companies (South32, Anglo American) are selling their coal mines, but our analysis has projected the compliance cost of their current portfolio under their name.*

Coal company	Projected Safeguard compliance cost FY24-50 ($ per tonne coal)	Average historical profit from FY14-21 ($ per tonne coal)
Anglo American	$1.84	$62
BHP	-$0.09	$50
Centennial Coal	$2.02	$16
Glencore	-$0.38	$44
South32	$6.86	$47
Stanmore Resources	-$0.35	$36
Peabody Energy	$0.33	$18
Whitehaven	-$0.18	$19

Data and sources related to coal mine financials

Data	Unit	Value	Sources
Majority owner of each coal mine	Company name	Not included	Global Energy Monitor Coal Mine Tracker (https://globalenergymonitor.org/projects/global-coal-mine-tracker/tracker-map/)
ACCU/SMC price	$AUD/tonne saleable coal	$35 in FY25 + 2% each year	Clean Energy Regulator, Quarterly Carbon Market Reports (e.g., Figure 1.3 in December Quarter 2024 https://cer.gov.au/markets/reports-and-data/quarterly-carbon-market-reports). This shows prices are approximately $35 and have fluctuated around $35 since June 2022. The ceiling price for ACCUs is set at $75 and indexed by CPI plus 2% per annum. Therefore, we included the indexation of 2% per annum into the ACCU/SMC price esti-mate (https://cer.gov.au/markets/reports-and-data/quarterly-carbon-market-reports/quarterly-carbon-market-report-june-quarter-2023/australian-carbon-credit-units-accus).

Assumptions related to ACCU prices

Assumptions
ACCU/SMC price was assumed to be $35 + 2% each year. This does not consider the potential for price to increase as demand increases, or conversely for the price to decrease as supply increases. In the main text, we discuss the theoretical compliance cost if the price were $75 per unit, which is the legislated ‘ceiling’ price.

Interim state targets

NSW and QLD have legislated emissions reduction targets for 2050, 2035 and 2030. These targets are economy-wide. We sought to understand the rate that current coal mine emissions would need to reduce by to meet these targets, assuming that these emissions reduction rates were applied evenly across the economy. In reality, some sectors would likely decarbonise to a greater extent than other sectors. To calculate this, we first calculated the 2035 emissions target by applying the emissions reduction rate to 2005 emissions for NSW and QLD (resulting in 45.8 $MtCO_2e$ and 48.0 $MtCO_2e$, respectively). We then determined the rate that total emissions would need to reduce from 2022 levels to meet these 2035 targets. This rate was calculated to be 59% for NSW and 61% for QLD. From our assumption then, coal mine fugitive emissions in NSW and QLD would need to reduce by 63% and 61%, respectively, by 2035.

We further sought to understand how this economy-wide emissions reduction rate required from 2022 to 2035 would be affected under different scenarios of coal mine fugitive emissions. To calculate the economy-wide emissions reduction rate required from 2022 to 2035 if coal mine fugitive emissions were not addressed, we subtracted the current coal mine emissions from both 2022 levels and the 2035 emissions target. We then divided the 2035 result by the 2022 result. To calculate the economy-wide emissions reduction rate required from 2022 to 2035 if coal mine fugitive emissions were not addressed and future emissions from new/expansion coal mines and improved measurement were included, the following process was followed: the current coal mine emissions and the current estimate of unmeasured emissions were subtracted from the 2022 levels. The current coal mine emissions, the current estimate of unmeasured emissions and the projected emissions from new/expansion projects were subtracted from the 2035 target. The resulting 2035 target was divided by the 2022 levels to calculate the required emissions reduction rate.

The tables below outline the key data, sources and assumptions.

Data and sources related to interim state targets

Data	Unit	Value	Sources
NSW 2050 emissions reduction target	% (of 2005 emissions)	100%	NSW Government (https://www.energy.nsw.gov.au/nsw-plans-and-progress/government-strategies-and-frameworks/reaching-net-zero-emissions)
QLD 2050 emissions reduction target	% (of 2005 emissions)	100%	QLD Government (https://www.legislation.qld.gov.au/view/pdf/asmade/act-2024-016)
NSW 2035 emissions reduction target	% (of 2005 emissions)	70%	NSW Government (https://www.energy.nsw.gov.au/nsw-plans-and-progress/government-strategies-and-frameworks/reaching-net-zero-emissions)
QLD 2035 emissions reduction target	% (of 2005 emissions)	75%	QLD Government (https://www.legislation.qld.gov.au/view/pdf/asmade/act-2024-016)
NSW 2005 emissions	$MtCO_2e$	152.7	Australian National Greenhouse Accounts (https://www.greenhouseaccounts.climatechange.gov.au)
QLD 2005 emissions	$MtCO_2e$	191.9	Australian National Greenhouse Accounts (https://www.greenhouseaccounts.climatechange.gov.au)
NSW 2022 emissions	$MtCO_2e$	111.0	Australian National Greenhouse Accounts (https://www.greenhouseaccounts.climatechange.gov.au)
QLD 2022 emissions	$MtCO_2e$	124.1	Australian National Greenhouse Accounts (https://www.greenhouseaccounts.climatechange.gov.au)

Fugitive:scope 1 emissions ratio for underground mines	%	95%	CCA’s 2023 review of the NGER scheme (https://www.climatechangeauthority.gov.au/sites/default/files/documents/2023-12/2023%20NGER%20Review%20-%20for%20publication.pdf)
Fugitive:scope 1 emissions ratio for open-cut mines	%	41%	CCA’s 2023 review of the NGER scheme (https://www.climatechangeauthority.gov.au/sites/default/files/documents/2023-12/2023%20NGER%20Review%20-%20for%20publication.pdf)

Assumptions related to interim state targets

Assumptions
Interim emissions reduction targets would be applied evenly across the sectors of the economy, so each sector would reduce emissions by the same proportion from current levels. In reality, some sectors are likely to decarbonise to a greater extent, and others to a lesser extent.

Cost benefit analysis modelling process and scenarios

Summary

Our model sought to analyse the costs and benefits of different state policy measures to incentivise on-site abatement of fugitive emissions from coal mines. It assessed the emissions impact, the cost/benefit to industry and the overall societal cost/benefit. The costs and benefits were analysed on a mine-by-mine level, a mine type and licensee type level and a jurisdiction-wide level. These cost benefit analyses were compared to two counterfactual, or business-as-usual, scenarios. The first business-as-usual scenario (BAU1) assumed that coal mines would meet their Safeguard baselines by purchasing ACCUs and SMCs. The second business-as-usual scenario (BAU2) assumed that coal mines would meet their Safeguard baselines with on-site abatement solutions (e.g., drainage and RTO systems).

The policy measures considered were:

- A methane abatement fund. This fund supported the deployment of on-site abatement at coal mines by covering a fraction (50%) of the upfront cost at FOAK projects. Note that this was only modelled for NSW, as QLD has already implemented the LEIP. For the QLD CBA, the LEIP was modelled as part of the counterfactual scenario – therefore, it's costs and emissions reductions were not considered additional. The same process used to model the methane abatement fund in NSW was used for the LEIP in QLD.
- A regulated emissions intensity threshold. Two different ways of implementing a regulated emissions intensity threshold were considered. The first required mines to reduce their emissions intensity below a set threshold (e.g., the industry average of 0.0653 tCO_2e/t ROM coal) by a specific year. The second required that mines with a historical emissions intensity above a set threshold reduce emissions by the maximum feasible abatement potential by a specific year.
- A methane measurement network. This policy mechanism integrated with the above measures, to show the additional costs and benefits of direct measurement of coal mine fugitive emissions. The modelled methane measurement network was deployed at all mines and showed that emissions and abatement at each mine were higher than previously estimated, by a specific factor. This increased the BAU emissions and the potential for abatement.

The key design criteria of each of these policy measures could be modified to test the costs and benefits of different settings, including start date, end date, coverage of the methane abatement fund, emissions intensity thresholds, and the percentage of additional emissions revealed by the methane measurement network.

Importantly, these policy measures could be combined: the methane abatement fund, regulated emissions intensity threshold and methane measurement network were integrated to assess the cumulative cost/benefit compared to the counterfactual scenarios.

The counterfactual scenarios

Two counterfactual or business-as-usual scenarios were assessed. In both instances, coal production and fugitive emissions were projected from FY25 to FY50, as per the methodology previously described. Safeguard baselines were also projected for each mine from FY25 to FY50, as per the methodology previously described.

Baseline scenario one (BAU1) assumed that coal mines would meet Safeguard baselines by purchasing ACCUs and SMCs. As per our results in Part 1.3, coal mines are likely to prioritise this pathway. As we quantified on-site emissions rather than net emissions, the purchase of ACCUs and SMCs did not contribute to modelled emissions. Further, because we assumed that coal production and fugitive emissions intensity would remain constant (as previously described), this effectively meant that emissions for each mine under BAU1 would remain constant until closure. Baseline scenario two (BAU2) assumed that coal mines would meet their Safeguard baselines with on-site abatement solutions (e.g., drainage and RTO systems). This meant that the projected fugitive emissions of each mine under the baseline scenario one would be equal to the lower value of: 1) the projected Safeguard baseline, and 2) the BAU1 emissions. This assumes that mines with emissions below the Safeguard baseline would remain constant, until the baseline declined below this level.

The table below outline the key assumptions.

BAU2 results

In practice, some coal mines may carry out on-site abatement to meet their Safeguard obligation. We completed an analysis using a second counterfactual/ baseline scenario (BAU2), where each coal mine's Safeguard obligation is met entirely through on-site abatement. Modelling this scenario increases complications around the attribution of costs and emissions reductions – which costs and emissions reductions are assigned to the state policy instead of the Safeguard Mechanism is more complex to determine.

However, using this counterfactual, the additional annual emissions reductions from NSW state policy range up to 1.1 $MtCO_2e$ in 2035. In QLD, the additional annual emissions reductions from state policy range up to 1 $MtCO_2e$ in 2035. Whilst the potential for emissions reductions is lower than under the standard counterfactual scenario, there is still significant emissions reduction potential, as the modelled state policy options drive emission reductions at a faster rate than under the Safeguard.

Assumptions related to the counterfactual scenarios

Assumptions
In BAU2, mines with projected emissions below the Safeguard baseline would remain constant, until the baseline declined below this level.

Abatement and measurement cost and potential

The costs and potential of abatement technologies were determined through numerous sources outlined in Appendix A.. The costs per tonne of CO_2e were determined and broken down into % CAPEX and % OPEX. The total abatement potential of each technology was a product of a number of factors, including the effectiveness at individual mines, the percentage of mines at which the technology would be feasible and the percentage of GWP reduction through the conversion of methane to CO_2. It was also a product of the percentage of fugitive emissions that were CO_2 to start (and therefore not amenable to oxidation) and standard inefficiencies of drainage and RTO deployment at coal mines.

The tables below outline the key data, sources and assumptions.

Data and sources

Technology	Mine group	Licensee type	Cost ($/ tCO_2e)	CAPEX (%)	OPEX (%)
Underground drainage + RTO	Largest emitting underground mines	Existing	$13	64%	36%
Underground drainage + RTO	Largest emitting underground mines	New	$17	73%	27%
Underground drainage	Other underground	Existing	$15	50%	50%
Underground drainage	Other underground	New	$25	80%	20%
Open-cut drainage	Open-cut	Existing	$60	80%	20%
Open-cut drainage	Open-cut	New	$45	80%	20%

Sources: These values were determined by a variety of interviews, research reports, and assumptions. All are outlined in detail in Appendix A. Key sources include the IEA [9], Rystad [2], CSIRO [21], and UNECE [27] [16].
Note: To calculate cost and cost drivers for the largest emitting underground mines, the cost of the individual technologies was multiplied by the percentage of their total contribution to abatement. RTOs contributed 55% of a total abatement potential of 80%, drainage contributed the remaining 25%.

Data and sources related to abatement potential of technologies

Technology	Mine group	Licensee type	Abatement potential (%)
Underground drainage + RTO	Largest emitting underground mines	Existing	$13
Underground drainage + RTO	Largest emitting underground mines	New	$17
Underground drainage	Other underground	Existing	$15
Underground drainage	Other underground	New	$25
Open-cut drainage	Open-cut	Existing	$60
Open-cut drainage	Open-cut	New	$45

Sources:

Summary: These values were determined by a variety of interviews, research reports, and assumptions. All are outlined in detail in Appendix A. Key sources include the IEA [9], Rystad [2], CSIRO [22], and UNECE [30] [16]. This table contains further evidence that validates our data as a whole.
The total abatement potential of all existing mines is equivalent to 57% when weighted by emissions. This is supported by Rystad analysis, which estimated 58% [2].

Underground mines: The total abatement potential of all existing underground mines (largest emitting underground and other underground) is equivalent to 72%. This is supported by CSIRO analysis, which estimated 71% when it is assumed that RTO units can abate 90% of the ventilation air methane (which is consistent with our assumptions but opposed to their assumption of 75%) [22]. Our assumption is explained in Appendix A and supported by CSIRO's VAMMIT trial, which achieved an efficiency of 96% [28]. RTO developers claim to achieve an efficiency over 99% (e.g., [27]).
As explored in Appendix A, when combining RTOs and drainage for largest emitting underground mines, the abatement potential of RTO is 55% and the abatement potential of drainage is 25%. This sums to 80% in total. This is much more conservative than Rystad, which suggests that up to 95% of methane can be abated from gassy mines [2]. The first paragraph under 'underground mines' in this cell further validates the input used for existing, largest emitting underground mines.

Assumptions related to abatement technologies

Assumptions
When modelling on-site abatement, largest emitting underground mines would pursue underground drainage and RTOs, 'other underground' mines would pursue underground drainage and 'open-cut' mines would pursue open-cut drainage.

Data related to methane measurement network cost

Data	Unit	Value	Sources
Cost per mine of the methane measurement network from 2025 to 2050 (NPV)	$(NPV) per mine	$6 million	UNSW analysis that conservatively estimated the costs of deploying coordinated, ground-, aerial- and satellite-based measurement systems capable of attributing emissions to individual sites.

The policy scenarios modelled

The methane abatement fund

We modelled the implementation of a government-run methane abatement fund (MAF) in NSW to share the cost of FOAK on-site abatement projects. For FOAK projects, the fund would cover 50% of the upfront cost. The fund would be generated from a levy across coal mines. In this way, the mining sector bears the cost of abatement (as well as the administrative cost of running the scheme), but the individual mines that are implementing the technologies would have a reduced cost.

For the MAF, there were three key settings: start date, end date and coverage. The start date was set to 2028, as for all policies, to reflect a quick adoption and execution of the policy mechanism. The end date was set at 2035 or 2040, in different scenarios. No more funding would be distributed after the end date. The coverage was set at 20% or 50%. The coverage represented the fraction of total emissions by mines eligible for MAF funding that would be abated by projects supported by the MAF. In other words, a coverage of 50% would mean that 50% of all emissions from mines eligible for MAF funding in 2028 would be abated by projects supported by the MAF. Eligibility is outlined in Step 1 of the modelling process, below.

The QLD Low Emissions Investment Partnerships (LEIP)

The QLD LEIP was modelled as part of the counterfactual (BAU) scenarios for the QLD CBA. This was modelled in the same way as the NSW methane abatement fund. Specifically, the fund was designed to cover 50% of the CAPEX of FOAK projects until $500 million was spent. The distribution of the projects was the same as the NSW fund, described below. The modelled LEIP started in 2025 and concluded in 2030, as per the program details. In scenarios with a measurement network, the size of the LEIP remained anchored to $500 million. This meant that the total coverage of the LEIP (i.e., the total emissions reductions funded by the LEIP) reduces with the high measurement scenario.

The regulated emissions intensity thresholds

We modelled two design options of this policy. They will be known colloquially in the Appendix as 'broad and shallow' and 'narrow and deep'.

'Broad and shallow' emissions intensity thresholds would require all mines to reduce the emissions intensity of coal production to a specific threshold by a specific end date. This is named 'broad and shallow' because it theoretically applies to a broader fraction of mines but may not require as significant abatement at any one mine as the 'narrow and deep' design option. For this design option, the start date was set at 2028. The end date was set at 2035 or 2040 in different scenarios. The threshold was set at 0.0653 tCO_2e/t ROM coal. This is the Safeguard-legislated industry average emissions intensity of coal production [19]. Therefore, this design option required all mines to reduce emissions intensity below this threshold, but no further.

'Narrow and deep' emissions intensity thresholds would require all mines with a historical, facility-specific emissions intensity above a specific threshold to apply maximum feasible abatement by a specific end date. This is considered 'narrow and deep', because it may target a smaller number of the most emissions-intensive mines and require them to undergo deeper abatement. For this design option, the start date was set at 2028, the end date at 2035 or 2040 in different scenarios and the emissions intensity threshold at 0.1306 tCO_2e/t ROM coal. This represented twice the industry-average emissions intensity and was selected to specifically target the six largest emitting underground mines in QLD and the nine in NSW. These 15 mines were required to undergo maximum abatement, while other mines were unaffected by this policy.

The methane abatement fund + regulated emissions intensity thresholds

Policy measures were modelled which combined different design options for the MAF with different design choices for each of the regulated emissions intensity threshold options.

The methane measurement network

We modelled the impact of a methane measurement network, capable of directly quantifying the emissions from each mine. We assumed that the network would measure all mines in NSW and QLD. We used three scenarios to understand the potential impact of the measurement network: a low, central and high measurement scenario. It should be noted that there is significant uncertainty around the actual fugitive methane from coal mines. As explored in Part 1.1, independent estimates suggest that Australia's coal mine methane emissions could be up to 172% greater than reported. Our three scenarios (which vary from 32% to 78%) are designed to test a conservative range of measurement scenarios, rather than representing the true range of potential under-estimation.

The low measurement scenario assumes that emissions from underground mines (and underground and open-cut mines) are as reported and that emissions from open-cut mines are 100% greater than reported. This results in an Australia-wide estimate that emissions are 24% greater than currently reported.

The central measurement scenario assumes that emissions from underground mines (and underground and open-cut mines) are 10% greater than reported and that emissions from open-cut mines are 150% greater than reported. This results in an Australia-wide estimate that emissions are 43% greater than currently reported.

The high measurement scenario assumes that emissions from underground mines (and underground and open-cut mines) are 20% greater than reported and that emissions from open-cut mines are 200% greater than reported. This results in an Australia-wide estimate that emissions are 62% greater than currently reported.

The methane measurement network + methane abatement fund + regulated emissions intensity thresholds

We modelled the integration of the methane measurement network into the counterfactual (BAU) and policy scenarios. Introducing the measurement network resulted in the following changes to the model:

- The historical facility-specific emissions intensity of each mine was multiplied by the new measurement factor, as was the Safeguard-legislated industry-average emissions intensity of 0.0653 tCO_2e/t ROM coal. Therefore, this scaled the Safeguard projections by the measurement factor, and increased BAU1 emissions projections for each mine by the measurement factor.
- The ‘broad and shallow’ regulated emissions intensity thresholds were multiplied by the measurement factor, specific to underground and open-cut mines for each mine. This means that the BAU emissions of each mine would increase by the same factor as the regulated emissions intensity threshold. In contrast, the ‘narrow and deep’ regulated emissions intensity thresholds were not modified. This is because they were based on historical emissions intensity, and were designed to target the largest emitting underground mines in each state that are most likely to be able to deploy RTOs and enhanced drainage.

The process of modelling policy impacts

The process of modelling the policy impacts is displayed diagrammatically in Figure 12. The following section goes into more detail on this diagram and the process. The modelling process is broken down into steps, which are applied across all policy scenarios.

Step 1: which mines are affected by the policy?

The first step in modelling the policy impact was to determine which mines were affected by the policy.

For all policies, we introduced requirements that the mine must start operations before the end of the policy and close after the end of the policy to be affected by the policy. In other words, if the policy was set to end in 2035, then only mines that were operational before 2035 and closed after 2035 could receive funding from the MAF or would be required to meet emissions intensity thresholds.

For the regulated emissions intensity thresholds, further requirements were introduced for a mine to be subject to the policy requirements. For the 'broad and shallow' thresholds, only mines with an emissions intensity above the threshold would be impacted. If at any point the emissions intensity of a mine dropped below the threshold, it would no longer be subject to the requirements. For the 'narrow and deep' thresholds, only mines with a historical emissions intensity (i.e., the facility-specific emissions intensity calculated for each mine from FY20-23) above the threshold would be impacted.

Step 2: what are the emissions before the policy is enacted?

The second step was to calculate the starting emissions, before the policy is enacted.

For all the mines that were determined to be affected by the policy in Step 1, the BAU1 emissions at the start date of the policy (2028) were taken as the starting emissions. This process did not account for emissions from new licensees that opened after 2028 but before 2035, and closed after 2035, and were therefore still eligible for funding. Therefore, the BAU1 emissions of these mines in any year before closure were also taken as starting emissions.

Step 3: what are the emissions after the policy is enacted?

The third step was to calculate the final emissions, after the policy is enacted. This would then allow for a calculation of the total emissions reductions, by subtracting final emissions from starting emissions.

For the methane abatement fund, the following process was used to calculate the final emissions for each mine:

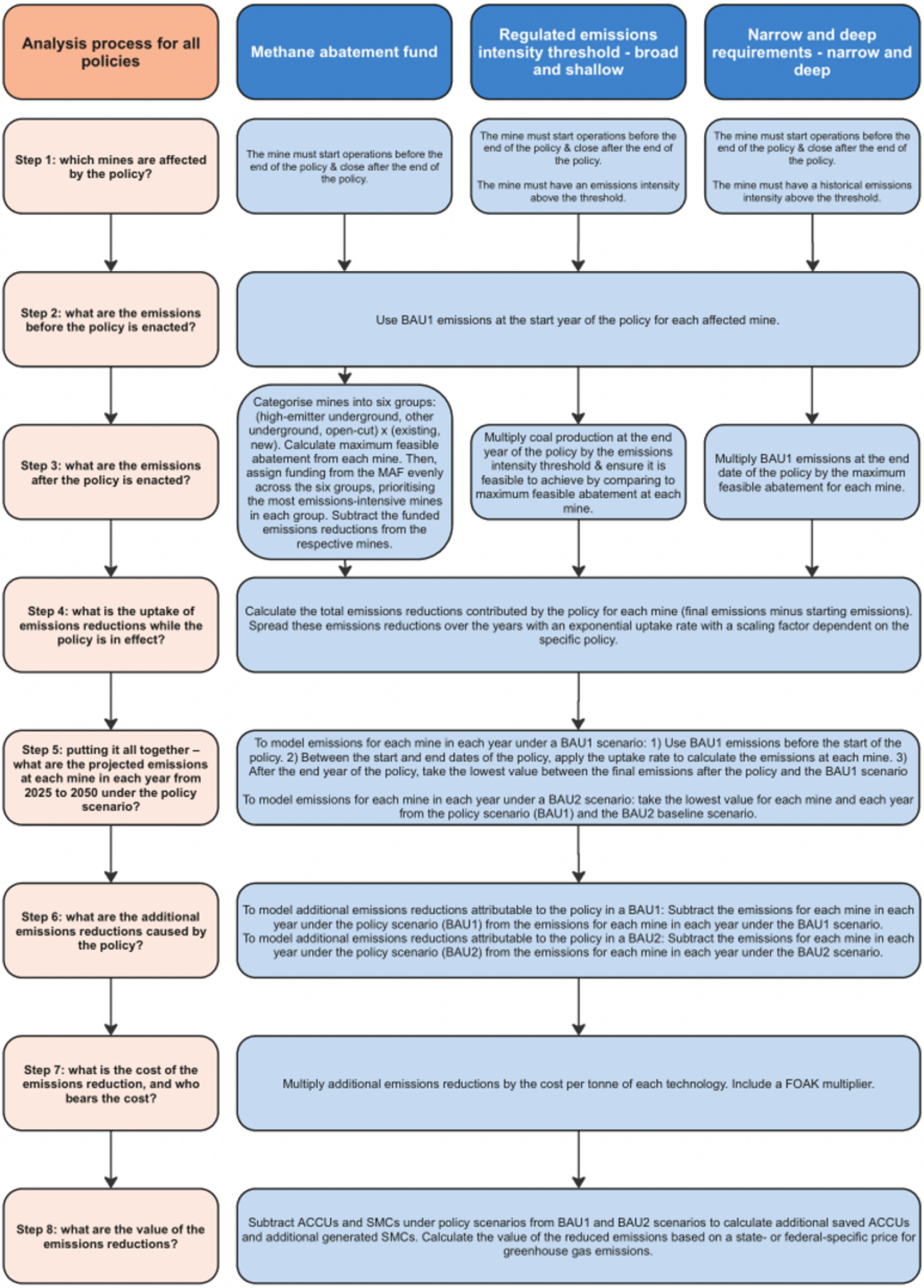

Figure 12: Simplified methodology for modelling policy scenarios.

1. Mines were categorised into six groups (existing high-emitter underground, new high-emitter underground, existing other underground, new other underground, existing open-cut, new open-cut).
2. The maximum feasible abatement at each mine was calculated by multiplying starting emissions by the total abatement potential.
3. The mines in each of the six groups were ordered from most emissions intensive to least.
4. The amount of emissions reductions that would be funded in each of the six groups was calculated by multiplying the coverage input (either 20% or 50%) by the total starting emissions of mines in each of the six groups. In other words, if the coverage of the fund was set to 50%, the MAF would support projects that would abate 50% of the starting emissions within each of the six groups.
5. Within each of the six groups the MAF 'budget' (the total amount of emissions reductions available for funding) were distributed across the groups by order of emissions intensity. The total abatement potential of the most emissions intensive mines in each group was funded, until the remaining budget could fund less than 100% of a mine's total abatement potential. The remaining MAF budget was applied to that mine. Any other mines that were lower on the list in order of emissions intensity would not, therefore, have their abatement projects funded by the MAF. In this way, the total abatement for each mine, because of the MAF, was calculated.

Note that the LEIP was modelled the same way. This may not necessarily reflect the actual distribution of funding from the QLD LEIP.

For the 'deep and shallow' regulated emissions intensity thresholds, the final emissions for each mine affected by the policy was calculated by multiplying the projected coal production by the emissions intensity threshold. As a validation process, the maximum feasible abatement for each mine was also calculated, to ensure that this was achievable for each mine.

For the 'narrow and deep' regulated emissions intensity thresholds, the final emissions for each mine affected by the policy were calculated by multiplying the starting emissions by the total abatement potential, representing the maximum feasible abatement.

Step 4: what is the uptake of emissions reductions while the policy is in effect?

The total emissions reductions at each mine were calculated by subtracting the final emissions from the starting emissions. These emissions reductions then needed to be distributed across the years of the policy from the start to end date (e.g., 2028 to 2035).

An exponential uptake rate was applied, as shown in the example in Figure 13. The fraction of time that the policy had occurred for (e.g., if the policy ran from 2028 to 2035, in 2030, 2/7ths of the policy timeframe was complete) was taken to the power of two or four (depending on the policy scenario).

If the policy scenario involved the MAF (i.e., when modelling the MAF or a combination of the MAF with other policies), a power of two was used. If the policy scenario did not involve the MAF, a power of four was used. This meant that the MAF would increase the uptake rate of emissions reductions. This reflects the role of the MAF in overcoming FOAK barriers and de-risking the technology for future adopters. It also reflects the role of the government in working with industry to accelerate uptake of abatement technology. In a scenario without the MAF, it is likely that uptake of abatement technology would be slower. Figure 13 represents the exponential uptake rate for a hypothetical policy that starts in year 0, ends in year 10, and results in emissions reductions of 50 tCO_2e.

Step 5: putting it all together – what are the projected emissions at each mine in each year from 2025 to 2050 under the policy scenario?

We can now put our results together to show the emissions at each mine at each year under the policy scenario in either a BAU1 or BAU2 setting.

To determine this in a BAU1 setting, the following steps were taken: before the commencement of the policy, the BAU1 emissions were taken. During the policy (i.e., after the start date and before the end date), the policy emissions with the uptake rate were calculated. After the end of the policy, the lowest value was taken from between the BAU1 emissions and the final emissions for each mine. The reason that BAU1 emissions were taken if they were lower in value was to account for mine closure – this would be the only reason for BAU1 emissions to be lower than final emissions.

To determine the policy emissions in a BAU2 setting, the lowest value was taken from the BAU2 emissions and the policy emissions under a BAU1 setting, calculated above.

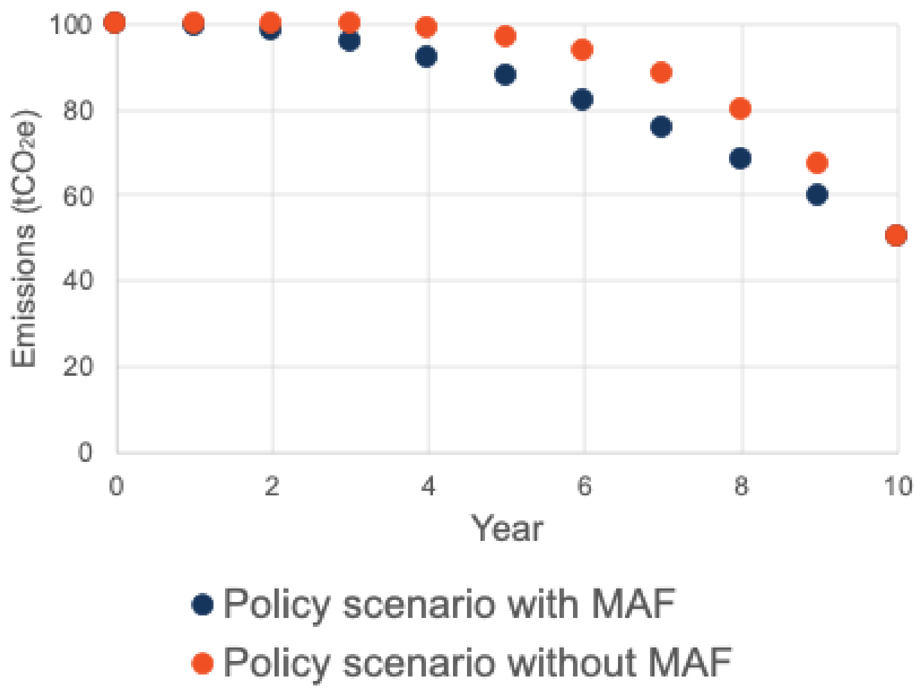

Figure 13: Uptake of emissions reductions for a theoretical policy, commencing in year 0, ending in year 10, and resulting in 50 tCO_2e of emissions reductions. The uptake rate for policy scenarios with and without the MAF are shown.

This means that where the state policy scenario or mine closure has resulted in emissions below the Safeguard baseline, these are chosen as the projected emissions. Where the state policy has not reduced emissions below the Safeguard baseline, the Safeguard baseline emissions are chosen as the projected emissions.

Step 6: what are the additional emissions reductions caused by the policy?

The additional emissions reductions caused by the policy were calculated for each mine and each year by subtracting the policy emissions scenario from the appropriate BAU emissions projections. In other words, the policy emissions in a BAU1 setting were subtracted from the BAU1 emissions and the policy emissions in a BAU2 setting were subtracted from the BAU2 emissions.

Step 7: what is the cost of the emissions reduction, and who bears the cost?

The cost of these additional emissions reductions, calculated in Step 6, was then quantified. For each mine, the additional emissions reductions were multiplied by the cost of abatement at that mine. As shown earlier, the cost of abatement changed for the six mine groups. Cost estimates were already in net present value, therefore, no discounting took place.

FOAK cost multipliers were also included at this stage. FOAK multipliers were included to represent the additional cost of early projects. The FOAK multiplier was expressed as a percentage, dependent on the maturity of abatement technology. The maturity of abatement technology was approximated by calculating the total emissions reductions in a given year as a percentage of projected fugitive emissions in 2025. Over 30% (i.e., if in 2034, additional emissions reductions were over 30% of projected BAU1 emissions in 2025), we assumed that FOAK costs would reduce to zero. From 0% to 30%, we assumed the FOAK multiplier would decline linearly from 250% to 0%. This meant that the first year of emissions reductions would cost 2.5 times higher than at scale. Figure 14 below represents the FOAK multipliers used. Ultimately, this was an approximate method used to estimate a factor that can be very difficult to quantify. In practice, this meant in our model that until one or two years before the end date of the policy, costs were still over 1.5 times higher than at scale. We tested the impact of doubling the FOAK multiplier and increasing the FOAK threshold from 30% to 45% as a sensitivity, to ensure that the results were robust to changes in FOAK assumptions. We found that our results had very low sensitivity, to even the most extreme FOAK cost estimates.

For the regulated emissions intensity thresholds, the cost of emissions reductions were borne directly by the individual mines that were affected.

For the methane abatement fund, the total cost of emissions reductions was split into CAPEX and OPEX, as per the CAPEX/OPEX breakdown for each of the technologies in Appendix A. The MAF would fund 50% of the CAPEX, while the rest of the cost would be borne directly by the individual mines. The 50% of the CAPEX funded by the MAF would be raised by a levy applied equally across all mines in the jurisdiction. Therefore, industry would still bear the whole cost, but the cost (and particularly the high cost of early FOAK projects) would be partly shared across the industry, reducing the costs faced by early movers.

Administrative costs were also included and borne by industry. The table below outlines our assumptions of the administrative costs for each policy.

The cost of the methane measurement network was also assumed to be borne evenly across industry, through a cost recovery mechanism.

Step 8: what are the value of the emissions reductions?

We then calculated the value of the emissions reductions through ACCUs, SMCs and the value on emissions used by NSW and QLD. In other words, the policy drove emissions reductions, which have a value.

Firstly, we calculated the saved ACCUs. These are the ACCUs (and SMCs) that mines in a BAU1 scenario would have had to purchase to meet their Safeguard baselines, that no longer need to be purchased. The value of ACCUs and SMCs was outlined earlier, in the table in the Part titled 'Safeguard compliance cost'. They were priced at $35 in FY25, indexing upwards at 2% per year. Note that in a BAU2 scenario, there would be no saved ACCUs, as all mines are assumed to meet their Safeguard baselines through on-site abatement.

Then, we calculated the additional SMCs generated by each mine as a result of the policy. This was done in both a BAU1 and BAU2 setting.

Finally, the value of the total, additional emissions reduction for both NSW and QLD was calculated by multiplying the emissions reductions by the value on carbon used by each state. These values are outlined below.

Step 9: putting it all together – what is the overall impact of the policy on our key metrics?

Based on these results, we could then determine our key metrics for each policy scenario.

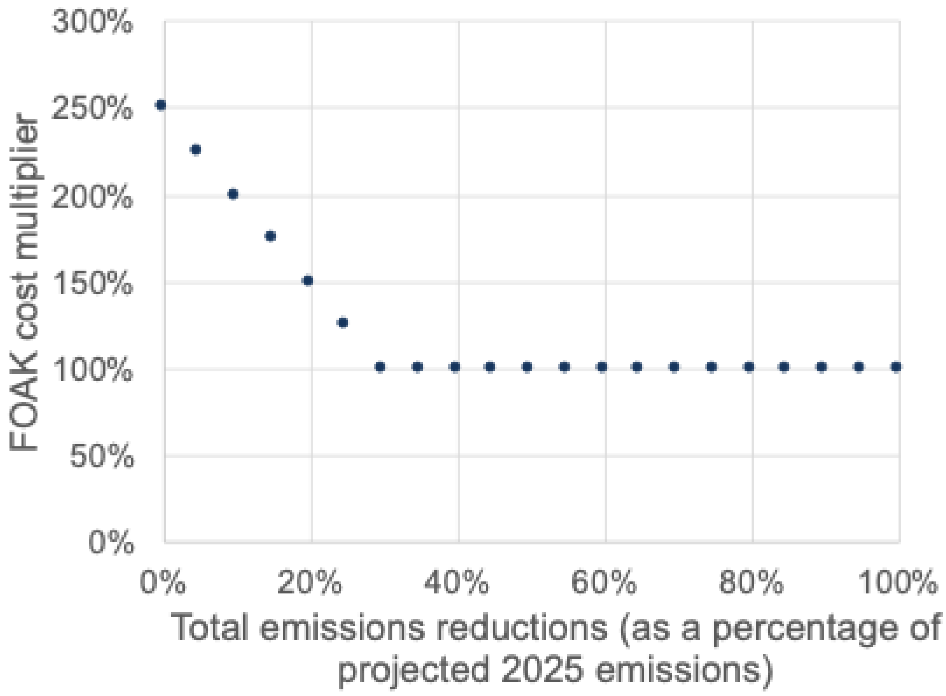

Figure 14: Uptake of emissions reductions for a theoretical policy, commencing in year 0, ending in year 10, and resulting in 50 tCO_2e of emissions reductions. The uptake rate for policy scenarios with and without the MAF are shown.

The cumulative emissions reductions were calculated by summing the additional emissions reductions in each policy scenario from 2025 to 2050. The annual emissions reductions by 2035 was calculated by determining the total emissions reductions compared to the BAU1 scenario in 2035. The net mining sector costs per tonne of CO_2e involved dividing the net cost to industry by the total emissions reductions. The net cost to industry was calculated by adding the total cost of abatement and subtracting the benefit from saved ACCUs and generated SMCs. The economy wide benefit involved multiplying the total emissions reductions by the NSW or QLD value on CO_2e and finding the net present value with a discount rate of 5%. The economy-wide BCR was calculated by dividing the total benefits (the state value on CO_2e, the value of saved ACCUs and the value of generated SMCs) by the total costs (the cost of abatement, the administrative cost and the cost of measurement).

Data and sources related to administrative costs

Data	Unit	Value	Sources
Methane abatement fund administrative cost	%	5% (of total abatement cost)	Assumption
Regulated emissions intensity thresholds administrative cost	%	3% (of total abatement cost)	Assumption
Methane measurement network administrative cost	%	5% (of total measurement cost)	Assumption

Data and sources related to coal mine financials

Data	Unit	Value	Sources
NSW and QLD value per tCO_2e	$	Not included, but ranges non-linearly from $75 in FY25 to $420 in FY50	Energy ministers & AER (https://www.aer.gov.au/industry/registers/resources/guidelines/valuing-emissions-reduction-final-guidance-may-2024).
Discount rate	%	5%	Assumption

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