August 2024

Institute for Energy Economics and Financial Analysis

Filling the voids

Pumped hydro proposals could see taxpayers financing mine rehabilitation

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Key Findings

Proposals to build pumped hydro energy storage facilities in the voids left after mining pose risks to taxpayers and the environment.

Government should be wary of providing finance for these projects, as this could set a precedent of taxpayers, at least partially, funding mine rehabilitation.

The National Electricity Market (NEM) has little need for the specific storage capabilities these projects would offer, which recent evidence suggests might be delivered more competitively by alternate technologies like batteries.

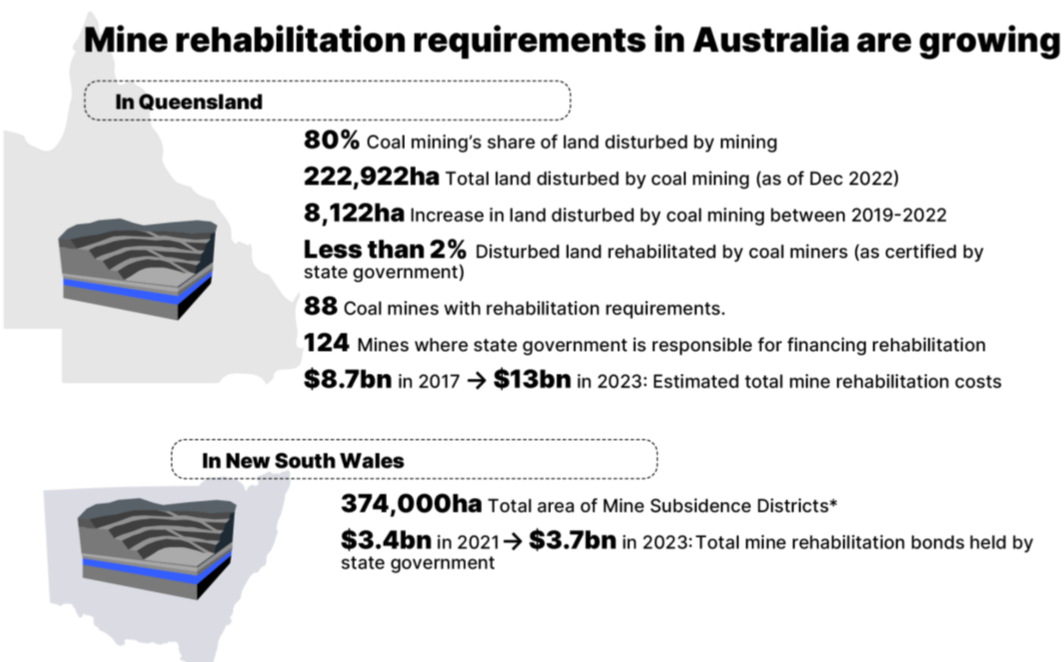
Australia needs to define a clear policy framework for final voids left after mining, to ensure governments are not liable for potential clean-up or rehabilitation costs.

Executive Summary

This report explores the current increase in proposals to install pumped hydro energy storage (PHES) facilities in mine voids. It evaluates the pipeline of PHES proposals in Australian mine sites and analyses the benefits and risks they present. It also examines whether these projects would fulfill the energy storage requirements of the National Electricity Market (NEM), or if other factors may be motivating many of these proposals.

Pumped hydro is increasingly being explored as a rehabilitation option for closed – or soon to close – Australian coal and gold mines. However, IEEFA's research demonstrates that these projects could entail large costs for taxpayers and pose significant risks for the environment, and that the projected storage requirements for additional pumped hydro schemes in the NEM are low.

Many large open-cut coal mining operations in Australia will leave final voids after they finish mining because they will be too big to backfill. However, it is unclear what the rehabilitation strategies are for these giant holes dotted across the country. Australia does not have a clear strategy or policy on how to provide post-mining uses for these final voids.



Pumped hydro in Australian mine voids is increasingly being proposed as an opportunity to kill two birds with one stone:

A. To provide a potential future use for mine voids that fulfills mining companies' rehabilitation obligations; and

B. To increase the amount of energy storage capacity in the NEM.

While pumped hydro projects may be one of few potentially viable post-mining uses suggested for mine voids so far, they present multiple risks that need to be adequately managed.

It has been suggested that by using mines' existing voids and infrastructure, these pumped hydro schemes could reduce overall construction costs, because they would already have at least one existing hole that could be used as a lower pumped hydro reservoir. However, they entail a range of technical and environmental risks, which could impose additional costs compared with traditional pumped hydro projects.

Mining companies are responsible for financing the rehabilitation of their mine sites, both during mining and after operations cease. If these pumped hydro projects do proceed, it is important that mining operators remain accountable to cover the costs of these developments. Otherwise, governments would be setting a precedent that they will fund mine site rehabilitation, meaning taxpayers would essentially be liable for these costs. Existing pumped hydro developments in Australia have largely been funded by taxpayers and have a history of cost blow-outs and delays.

Pumped hydro projects appear set to play a "firming" role in Australia's energy system, particularly by providing deep energy storage (more than 12 hours of storage duration). However, the majority of pumped hydro schemes proposed in Australian mine voids are medium-duration projects, projected to provide up to eight hours of storage. For this duration, alternate energy storage technologies may be more competitive.

Batteries are increasingly able to provide eight hours of energy storage, can be built faster and cheaper, and do not have the same large water requirements as pumped hydro technology. Other energy storage technologies that can provide medium or deep energy duration storage – such as compressed air storage, vanadium redox flow batteries, gravitational energy storage and thermal energy storage – are also advancing rapidly.

IEEFA's analysis of the Australian Energy Market Operator (AEMO)'s Integrated System Plan (ISP) suggests that there is limited need for the pumped hydro schemes being proposed at mine sites. IEEFA argues that if such schemes proceed as a form of mine rehabilitation, they should not be funded by governments, and their risks should be adequately addressed.

Australian governments should establish clearly defined policies defining rehabilitation requirements and options for the management of final voids following mine closures. The policy should set standards and obligations for mining operators for managing the ongoing risks that these structures pose, to ensure taxpayers are not left liable to cover these costs.

Introduction

The Australian mining sector is faced with an extremely challenging task over the next few decades – to propose post-mining uses for mine voids. A mine void is a mined area, typically a pit, that can remain as a residual depressed landform feature after rehabilitation of a large open-cut mine is complete.[1]

There are potentially between 22 and 30 open-cut coal mines across Queensland (QLD) and New South Wales (NSW) that are currently closed, undergoing rehabilitation, or are expected to close and cease mining activities by 2030, depending on the outcome of applications for expansions and extensions (see full list in Appendix A).

Open-cut or surface coal mines make up the majority of Australia's coal mine operations. In NSW, open cuts constitute 80% of coal production.[2] In Queensland (QLD), 80% of land disturbed by mining industry is by coal mines. As the closure dates for these coal mines loom, miners are examining possible options to meet their rehabilitation obligations for these sites.

Mine voids in Australia can be extremely large and the cost of remediating these sites to make them safe and capable of being reused could cost billions of dollars. Rehabilitating a mine site, including the mine void, is a legal obligation that miners enter into with governments when their mining licences are approved, and should be budgeted for ahead of a scheduled mine closure.

Many large open-cut mines in Australia will leave final voids

While the term rehabilitation usually refers to the act of restoring something that has been damaged to its former condition, mine rehabilitation in Australia does not. Instead, rehabilitation of mine sites in NSW and QLD refers to the process after mining of returning disturbed land to a safe and stable condition that is non-polluting and can sustain an approved post-mining land use.[3,4] NSW extends this to include water as well as land.[5] Victoria requires land to be sustainable in addition to safe and stable. One key reason that legal definitions for mine rehabilitation do not require restoring land and water to its former condition is because this is not always feasible. For many large open-cut mines in Australia, filling the voids left after mining will not be possible, meaning the mine void will remain and a future use for it must be proposed.[6]

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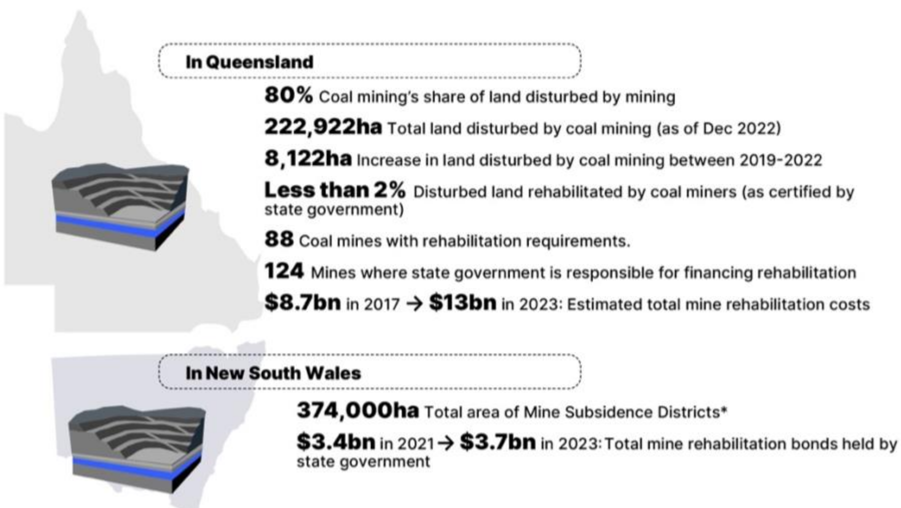
[1] NSW Minerals Council. Mine Voids - NSW Minerals Council Fact Sheet. Accessed 6 July 2024.
[2] IEEFA. Australia's coal mines are getting bigger. 22 November 2023.
[3] Disturbed land refers to a form of environmental damage produced by the mining process. This can include the destruction of existing vegetation, land clearing, landform alteration (digging holes in the ground), or covering areas of land with mine tailings or other waste.
[4] Queensland Government. Queensland Environmental Protection Act (1994). Ver. 2.7.20, Rev. 7491. Section 111A.
[5] NSW Legislation. Mining Act 1992. Dictionary. Current version for 24 October 2023, accessed 3 July 2024.
[6] Whitehaven Coal. Rehabilitation progressing at Sunnyside. 13 July 2022.

Many open-cut metallurgical and thermal coal mines in QLD and NSW are permitted to leave mine voids at the end of mine life.[7] In NSW there at least 45 final voids approved to be left after mining ceases, totalling approximately 6,050 hectares, an area larger than Sydney Harbour.[8] According to the NSW Minerals Council, “Many of the larger Upper Hunter mines were approved decades ago when issues involving final voids were less of a priority.”[9]

This is very different to the mining rehabilitation requirements in other countries such as the US, where open-cut coal mines are required to backfill mine voids (with some exceptions) to *“approximate original contour”* under the Surface Mining Control and Reclamation Act 1977.[10] In QLD, the Mineral and Energy Resources Financial Provisioning (MERFP) Act 2018 prohibits final voids that do not have a sustainable post-mining land use, also referred to as non-use management areas.[11]

Figure 1: The scope of coal mine rehabilitation in Australia



*Sources: Queensland Mine Rehabilitation Commissioner[12]; Queensland Treasury Corporation[13]; Queensland Treasury[14]; CRC TiME Limited[15]; New South Wales Resources Regulator[16]. Note: *Mine subsidence districts are areas where there is the potential for mine subsidence to cause damage from historic, current and/or future coal mining activity. Currencies are Australian dollars.*

[7] Office of the Queensland Mine Rehabilitation Commissioner. A Brief History of Mine Rehabilitation Reforms in Queensland. 2022. Page 76.
[8] Journal of the Royal Anthropological Institute. The final voids: the ambiguity of emptiness in Australian coal mine rehabilitation, 4 March 2022.
[9] NSW Minerals Council. Mine Voids - NSW Minerals Council Fact Sheet. Accessed 6 July 2024.
[10] Office of the Queensland Mine Rehabilitation Commissioner. A brief history of mine rehabilitation reforms in Queensland. 2022. Page 76.
[11] CRC TiME. Hydrological and Geochemical Processes and Closure Options for Below Water Table Open Pit Mines - Final report project 3.3. August 2021.
[12] Queensland Mine Rehabilitation Commissioner. 2022-23 Annual Report. September 2023. Pages 18-19.
[13] Queensland Treasury Corporation. Review of Queensland’s Financial Assurance Framework. April 2017. Page 1.
[14] Queensland Treasury. Financial Provisioning Scheme 2022-23 Annual Report. Page 6.
[15] CRC TiME Limited. Towards an inventory of abandoned mines in Australia: risk, prioritisation, and opportunities. April 2022. Page 11.
[16] New South Wales Resources Regulator, Department of Regional NSW. Exploration and mining compliance and rehabilitation report 2022-23. March 2024. Page 3.

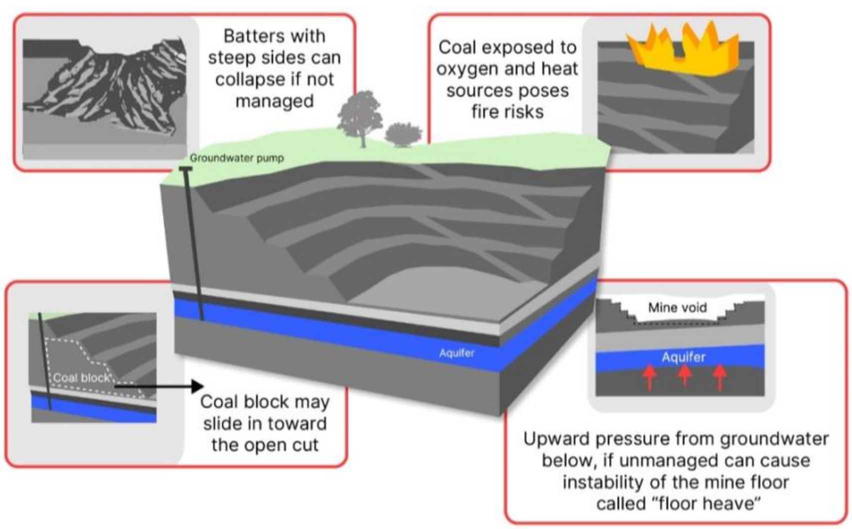
Mine void rehabilitation options

The risks of not rehabilitating mine voids

If mines sites are not rehabilitated and left as they are, they can impose significant risks to humans, the environment and wildlife.[17] Open-cut mining methods can lead to unstable slopes and the potential risk of landslides or soil creep.[18] When abandoned mines are located near communities (for example in the Newcastle and Hunter Valley area in NSW), the geotechnical instabilities associated with historic and abandoned mine workings can threaten the stability of surface and subsurface structures and infrastructures, and cause significant risks to human safety.[19]

Mine voids also have the potential to interfere with floodplains and intercept flows, as well as potentially contaminating groundwater or surface water sources. Mine sites may contain waste material in tailings dams and other storage facilities, which often contain a significant number of contaminants that can affect the quality of surface water and groundwater, the surrounding soils, and the air.[20] Additionally, coal waste piles that are left exposed to oxygen pose a fire risk and produce sulphate, which in the presence of water can result in acid mine drainage.[21]

Figure 2: Risks of an empty mine void



Source: ENGIE, IEEFA

[17] CRC TiME Limited. Towards an inventory of abandoned mines in Australia: risk, prioritisation, and opportunities. April 2022. Page 11.
[18] Ibid. Page 12.
[19] Ibid. Page 11.
[20] Ibid. Page 11.
[21] US Department of the Interior. Emissions from coal fires and their impact on the environment. September 2009. Page 1.

There are very few examples in Australia – or globally – of successful rehabilitations of open-cut mines that have led to sustainable post-mine land use.[22]

There is no existing example in Australia of a large open-cut coal mine completing rehabilitation and relinquishing the land for an alternate use. There is also a high degree of scientific uncertainty on the ability to rehabilitate mine voids. The ARC Centre for Mine Site Restoration stated in its submission for a 2017 parliamentary inquiry that: "The technical capacity and science to achieve this [ecological restoration] for many Australian mine sites is limited and is a key constraint in achieving proven, cost-effective and scalable solutions in restoration."[23] Additionally the submission found that "the time scales required for natural weathering processes to mitigate problem factors such as nutrient stoichiometry and soil pH (**hundreds to tens of thousands of years**) are at odds with the typical **5-7 year** regulatory mine closure expectations" (emphasis added).[24]

Mine pit lakes

The dominant rehabilitation option proposed for final pit voids to date in Australia is to actively or passively fill the void with water and refill this over time as the water evaporates. This is the current option proposed for the closed Hazelwood coal mine in Victoria's Latrobe valley. Its owner ENGIE is proposing to use 637 gigalitres (GL) of water (almost double Melbourne's annual consumption) to fill the mine void, which would take an estimated 10-15 years to complete.[25] According to Environmental Justice Australia, an additional 5GL a year would also be required for approximately 20 years to offset evaporation.[26]

Filling mine voids with water poses several ongoing risks and costs. Previous IEEFA analysis has found that water-related problems are the most common environmental impact when closing mines.[27] These impacts can last for decades or centuries due to the gradual physical and chemical weathering of rocks exposed to water and the atmosphere. Modelling for the Ulan and Moolarben coal mines predict that the groundwater network will be permanently altered, and levels will not recover for more than 300 years.[28]

Gravitational energy storage

Gravitational energy storage is an emerging technology that is based on the principles of pumped hydro, but instead of water, it uses a crane to store potential energy by elevating concrete blocks.

[22] World Mining Congress 2023. More and Better Mine Rehabilitation – Lessons from Queensland. June 2023, page 2083.
[23] ARC Centre for Mine Site Restoration. Submission 64 in Australian Parliamentary Inquiry – Rehabilitation of Mining and resources projects as it relates to Commonwealth responsibilities. Page 2.
[24] Ibid. Page 2.
[25] ENGIE. Hazelwood Rehabilitation Project. July 2023. Page 4.
[26] Environmental Justice Australia. Federal government pulls 'water trigger' over controversial plan to flood Victorian open-cut coal mine. 22 February 2023.
[27] IEEFA. The hidden costs of coalmines' unquenchable thirst. 28 March 2024. Page 8.
[28] Glencore. Ulan coal – Continued Operations: North 1 Modifications Groundwater Assessment; Appendix 3 – Groundwater Assessment. June 2011.

One company, Green Gravity, is proposing to design these gravitational energy storage units using disused mine shafts instead of purpose-built towers, claiming this will present a competitive advantage for the technology.[29]

Pumped hydro as a mine rehabilitation option

What is pumped hydro?

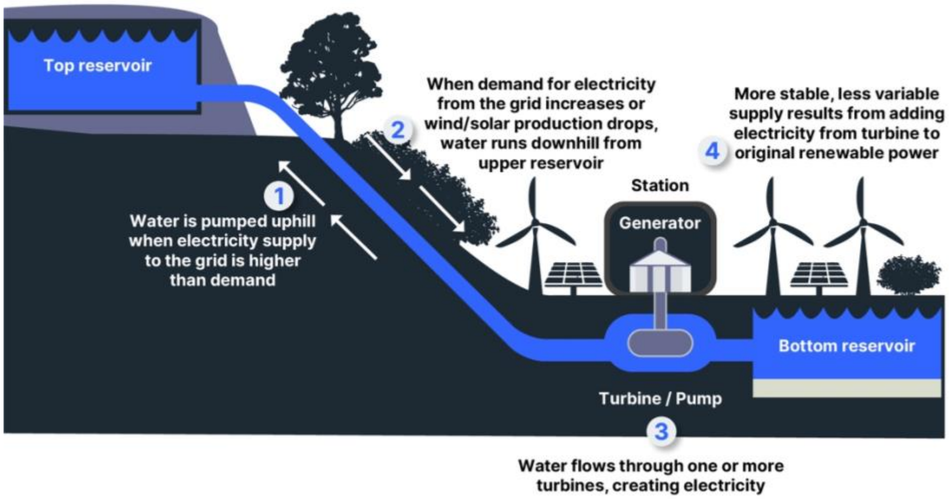
Storage technologies, including pumped hydro and batteries, store electrical energy from a power network when supply is greater than demand, then release or 'dispatch' it when needed. They can provide "firming" for variable wind and solar generation – supporting a grid with a high proportion of wind and solar by storing abundant renewable energy and releasing it later, ensuring power is available at all times.

When electricity supply to the grid exceeds demand, pumped hydro energy storage (PHES) uses electricity from the grid to pump water from a lower reservoir to a higher reservoir. The water is then stored in the top reservoir until more electricity supply is required. Pumped hydro can then generate electricity by releasing water from the top reservoir to the lower reservoir, letting gravity drive the flow of water through a turbine that generates electricity, which can be fed into the grid. The amount and duration of electricity that a single pumped hydro project can generate back into the grid depends mostly on the two reservoirs' sizes, the height difference between them, and the efficiency of the turbine.

Pumped hydro can work on open-loop systems, such as via a hydrologic connection to an existing body of water, or closed-loop systems, located away from natural bodies of water. The majority of pumped hydro projects operating globally are open-loop systems, as are all of Australia's operating projects. However, most pumped hydro proposals for mine sites are closed-loop systems, meaning they are not located on existing water bodies such as lakes, rivers or even the ocean.[30]

[29] Australian Financial Review. Ex-BHP star takes on Leonardo DiCaprio with old mine shafts. 28 March 2022.
[30] Renewable and Sustainable Energy Reviews. Low-head pumped hydro storage: A review on civil structure designs, legal and environmental aspects to make its realization feasible in seawater. May 2022.

Figure 3: How pumped hydro energy storage technology works



Source: Australian Renewable Energy Agency (ARENA), IEEFA.

Pipeline of Australian pumped hydro in mine voids

Research from the Australian National University (ANU) using satellite imaging techniques has suggested there are 37 mine sites (including coal and other mine types) suitable for PHES in Australia.[31] However, this does not guarantee these sites will be suitable locations for the development of pumped hydro, given the geological and planning complexities of these projects.

Moreover, in Western Australia (WA) the state government has shifted away from pursuing pumped hydro in mine voids, and initial proposals in South Australia (SA) have also been discontinued. Therefore, it is mostly NSW and QLD where these projects seem to have any momentum at the moment.

The ANU study identified seven mine voids in QLD and six in NSW that could be suitable for pumped hydro development (see Appendix B). They include the Muswellbrook project in NSW and the Mt Rawdon project in QLD, discussed below.

There are currently three pumped hydro projects proposed at **NSW coal mine sites**: Yancoal's Stratford Renewable Energy Hub (300 megawatts (MW)/3,600 megawatt-hours (MWh)) proposal for its Stratford mine site[32]; Idemitsu and AGL's Muswellbrook mine/Bells Mountain project (500MW/4,000MWh)[33]; and Zen Energy's Western Sydney Hydro Project (1000MW/8,000MWh),

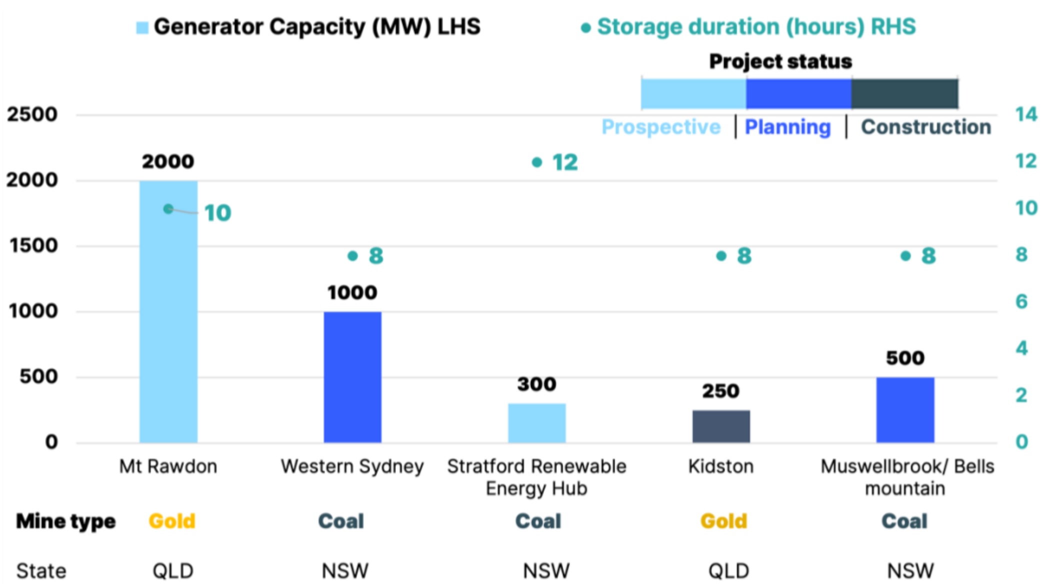
[31] ANU. Researchers found 37 mine sites in Australia that could be converted into renewable energy storage, so what are we waiting for? 28 February 2024.
[32] Yancoal. Stratford renewable energy hub: Scoping report, November 2023. Page 8.
[33] Idemitsu. Muswellbrook Pumped Hydro to deliver reliable, low-cost electricity – strengthening Australia's clean energy future. 5 September 2022.

which has entered into a development agreement with WaterNSW[34]. The Muswellbrook and Stratford projects have also recently both been given Critical State Significant Infrastructure Status by the NSW government.[35]

BHP has also presented pumped hydro as a potential rehabilitation option for its Mt Arthur thermal coal mine, which is one of the largest operating open-cut mines in Australia. However, it remains unclear whether BHP will propose a pumped hydro project at the Mt Arthur mine, as the company's initial management plan stated that the MacDonald's mine void did not have a "suitable elevation differential".[36] Regarding the Windmill void, it stated: "Other locations in the Hunter are likely more suitable. Water storage on the emplacement is costly. Long term access to water to run the project may not be feasible."

Centennial Coal's underground Newstan Colliery was also investigated for its potential as a pumped hydro site (600MW).[37] However, this project has been discontinued after the feasibility study determined the scheme would only be technically viable under a set of very specific conditions.[38]

Figure 4: Projected generation capacity and storage capacity of proposed mine site pumped hydro projects in Australia



Source: IEEFA; Australia New Zealand Infrastructure Pipeline.

[34] Australia New Zealand Infrastructure Pipeline, Project – Western Sydney Pumped Hydro, accessed 3 July 2024.
[35] Renew Economy. NSW gives top priority to new transmission links and pumped hydro plans for old coal facilities. 3 July 2024.
[36] BHP. Management plan: Mt Arthur Coal Rehabilitation Strategy Version 1. 7 July 2023. Page 14.
[37] Australian Renewable Energy Agency (ARENA). A second life for coal mines through pumped hydro and renewable energy. 18 December 2020.
[38] Banpu Energy Australia. Underground pumped hydro energy storage project: Final Report. 1 July 2022. Pages 32-33.

In **Queensland** the Kidston pumped hydro scheme (250MW/2,000MWh) is being constructed in a decommissioned **gold mine,** with planned energisation scheduled in 2025.[39] It is Australia's first pumped hydro project to be completed in more than 40 years, and the first to utilise existing mine voids.[40] Evolution Miners and ICA Partners are currently undertaking a feasibility study for pumped hydro potential in another gold mine in QLD, Mt Rawdon (2,000MW/20,000MWh), after mining ceases at the end of 2024.[41]

The **Victorian** government previously conducted a pre-feasibility study for pumped hydro projects in former gold mine sites in Bendigo, and released an Expression of Interest (EoI), but there haven't been any subsequent projects announced since this was released in 2017.[42]

In **South Australia**, the two pumped hydro proposals in mine voids have been discontinued: the Middelback iron ore mine[43]; and the Kanmantoo Copper Mine[44]. The only remaining pumped hydro proposal in SA at the time of writing is ACEN and RiseRenewable's Baroota project (250MW/ 2,500MWh), which is currently applying for planning permission.[45] The Baroota pumped hydro project is proposed on an existing river creek basin and is not a mine site pumped hydro proposal. Another project in SA, the 242MW/1,835MWh Goat Hill pumped hydro project was approved, but cancelled its connection agreement in 2021 and it is unclear if the project will progress.[46]

Pumped hydro was previously considered as a rehabilitation option for mine voids in **Western Australia**, but the government has since stated it will not proceed with these projects due a range of issues outlined below.

Benefits of pumped hydro projects in mine voids

Commenting in 2021 on the proposed Muswellbrook pumped hydro project, Chris Walsh, Chief Commercial Officer of Idemitsu Australia Resources, stated that: "Innovative rehabilitation solutions, such as the reuse of mine voids … ensure that sites like Muswellbrook can continue to generate investment and long-term employment."[47]

It has been suggested that using mines' existing voids and infrastructure could result in lower construction costs than other pumped hydro schemes.[48] Some analysts favour repurposing mine voids into pumped hydro projects on the basis that less land clearing and social impacts would be

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[39] Genex. Q3 FY24 Investor presentation. 29 April 2024. Page 16.
[40] Genex. 250MW Kidston Pumped Storage Hydro Project. Accessed 18 July 2024.
[41] Australia New Zealand Infrastructure Pipeline. Project – Mt Rawdon Pumped Hydro Project. Accessed 3 July 2024.
[42] Premier of Victoria. Pumped Hydro Study in Bendigo A Success. 21 March 2018.
[43] SIMEC. South Middleback Ranges Pumped Hydro Energy Storage Project – Pre-Feasibility Study. 10 July 2019.
[44] AGL. AGL and Hillgrove resources mutually agree to end Kanmantoo project. 22 February 2020.
[45] Power Technology. Power plant profile: Baroota Australia. 3 June 2024.
[46] Renew Economy. One pumped hydro project still standing as South Australia heads to 100pct wind and solar. 12 November 2021.
[47] PV Magazine. Australian coal mine to transform into pumped hydro facility. 19 April 2021.
[48] ARENA. A second life for coal mines through pumped hydro and renewable energy. 18 December 2020.

required, and in some cases transmission lines or grid connectivity may already be in place.[49] Pumped hydro has generally only been proposed for open-cut mines in Australia; however, its feasibility has also been investigated as a rehabilitation option for underground mines.[50]

Additionally, these pumped hydro projects could provide employment opportunities, mostly during the construction phase. The Kidston gold mine project has reportedly created 900 direct jobs during its construction, a period of about four years, and expects to provide nine ongoing job opportunities.[51,52]

Pumped hydro projects typically have long expected lifespans, of between 50-100 years depending on the project.[53] Therefore, they can present a long-term energy storage solution, though the lifespan of mine void pumped hydro projects may be impacted by various factors. The lining of mine pits is a critical step in repurposing mine voids into pumped hydro projects, but may reduce the lifespan of the project, with the Kidston project estimating its pit lining will last for 30 years. Additionally, if there are water quality issues in mine void pumped hydro sites, this could damage or increase corrosion of equipment, which could also affect the lifespan of the project.

Research from the ANU asserts that closed-loop pumped hydro projects, which would account for most proposed mine site pumped hydro projects, have very small environmental footprints compared with open-loop systems.[54] This is because closed-loop systems do not entail the potential impacts on water sources – such as altering water quality or flow rates – that some open-loop systems do. However, other studies have shown this is not always the case and that these projects can present significant and long-term risks to groundwater sources.

Risks of pumped hydro projects in mine voids

In 2018, as part of a Senate inquiry examining mining rehabilitation risks, ARC Centre for Mine Site Restoration director Kingsley Dixon stated that many mine sites in WA “had so dramatically changed the landscape that restoration on this level was impossible”.[55,56] He described coal pits in Collie as “voids to the horizon” and stated that: “Pit voids, ecologically and naturally, don't provide a surface for the environment to return.”

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[49] Synergy. Synergy’s investigation into pumped hydro. 2024. Accessed 18 July 2024.
[50] Institute for Future Energy Consumer Needs and Behavior (FCN). An Exploratory Economic Analysis of Underground Pumped-Storage Hydro power plants in abandoned coal mines. *Madlener, R. & Specht, J*. 5 November 2013.
[51] Genex Power. Kidston Pumped Storage Hydro Project – Construction Report. November 2022. Page 3.
[52] AECOM for Genex Power. Kidston Pumped Storage Hydro Project – Impact Assessment Report. 11 January 2019. Page 15.
[53] Cleaner Engineering and Technology. Drivers and Barriers to the deployment of pumped hydro energy storage applications: Systematic literature review. December 2021.
[54] ANU. Researchers found 37 mine sites in Australia that could be converted into renewable energy storage, so what are we waiting for? 28 February 2024.
[55] Parliament of Australia. Rehabilitation of mining and resources projects as it relates to Commonwealth responsibilities. 2017-2019.
[56] WA today. Mine rehab in WA is the pits: Inquiry finds few success stories. 9 March 2018.

Driven by the difficulties in rehabilitating some of these mine pits, **pumped hydro development was suggested as an alternative to fulfilling mining rehabilitation requirements in Western Australia.** Seven Group holdings proposed to build a pumped hydro energy storage facility in the Muja coal mine, for an estimated cost of A$650 million, suggesting this could save an estimated A$1.6 billion in rehabilitation costs[57].

However, WA's plans for pumped hydro projects were ultimately scrapped following a Synergy feasibility study that found multiple issues.[58] The study found that these mine sites had inadequate infrastructure to be viable for pumped hydro development as their locations were too remote. It also found that these projects would still require construction of a secondary reservoir, and would be "subject to relatively high development costs" and "present numerous technical risks including stability of mine walls". The study concluded that: "Mine pits also require clearing of native vegetation for the upper reservoir environmental approvals and rehabilitation of the broader mining area."[59]

Instead, WA will investigate alternate long-term energy storage options, which some suspect will be limited to batteries.[60] The WA Government's Whole of System Plan, a report on the next 20 years of the South-West grid, concluded that batteries were the lowest-cost form of energy storage under all scenarios examined.[61] The modelling for the Plan expected batteries would play a key role in the grid, and that pumped hydro would not be built as it did not provide the lowest-cost pathway. The government did, however, leave the door open for the private sector to pursue pumped hydro in WA.[62]

Groundwater risks

A US study[63] found in 2020 that closed-loop systems (which account for most mine void pumped hydro projects) can interfere with existing groundwater sources. Closed-loop projects using groundwater can pose higher risks to soils and groundwater sources than those of open-loop systems connected to naturally occurring surface water systems[64]. Additionally, the large quantities of groundwater required to fill and refill these types of closed-loop pumped hydro projects could have negative environmental impacts and could also reduce the availability of groundwater for other users.[65] A large number of Australian coal mines use groundwater to meet their water needs.[66]

[57] Boiling Cold. Stokes' $650M pumped hydro plan reveals huge Collie clean up cost. 8 February 2021.
[58] Synergy. Synergy's investigation into pumped hydro. 2024. Accessed 18 July 2024.
[59] Ibid.
[60] ABC News. WA government abandons pumped hydro plans to replace Collie coal power. 26 October 2023.
[61] Western Australian Government. Whole of System Plan Report. 6 December 2022.
[62] Boiling Cold. Stokes' $650M pumped hydro plan reveals huge Collie clean up cost. 8 February 2021.
[63] HydroWIRES, US Department of Energy. A comparison of the environmental effects of open-loop and closed-loop pumped storage hydropower. April 2020. Pages x, xiv.
[64] Ibid. Pages x, xiv.
[65] Ibid. Page B.4.
[66] IEEFA. The hidden costs of coalmines' unquenchable thirst. 28 March 2024. Page 15.

Therefore, the potential for groundwater risks caused by pumped hydro projects in previous mine voids could be significant.[67]

Post-production, mines that operated below the groundwater table are also likely to leave legacy discharges into groundwater sources for an indefinite timeframe. Mines can intercept and drain groundwater, and the impacts can continue far beyond the life of the mine.[68] It remains unclear how pumped hydro projects would mitigate these potential impacts.

Flooding and contamination risks

Whether to create a pit lake or for a pumped hydro development, flooding mine pits with water can result in contaminants escaping into the environment from the mine pit, including seepage into groundwater sources.

Previous analysis by IEEFA has outlined the risks that accompany filling mine voids with water.[69] Due to the small number of fully rehabilitated coalmines in Australia, there is not sufficient research to show how the contamination and pollutants within mine pits can be effectively treated or managed in the long term to avoid contamination of water sources and the environment.[70]

Professor Andrew Blakers is a lead researcher on two global atlas studies on potential pumped hydro sites. Their research found that using mine pits as pumped hydro sites would present risks as they are often contaminated with toxins and mud that could impair the generation equipment.[71] **To mitigate these risks, the mine pit would need to be lined to prevent contamination, which would increase costs of the project.**

The Kidston project required a liner to seal the mine void from leaching contaminants into the reservoir water, which other proposed pumped hydro schemes in mine voids would also require. The project ultimately selected a 2mm thick high-density polyethene (HDPE) geomembrane to line the mine void, which is estimated to have a design life of 30 years.[72]

The NSW Environmental Protection Agency's initial review of Yancoal's Stratford Renewable Energy Hub Scoping Report identified climate change, water quality impacts and rehabilitation requirements as key risks to the project.[73] On 11 April 2024, a delegate of the federal minister for the environment and water determined that Yancoal's Stratford Pumped Hydro and Solar was a controlled action under section 75 of the Environment Protection and Biodiversity Conservation Act 1999 (EPBC

[67] Ibid. Pages 37-42.
[68] Ibid. Pages 42-43
[69] IEEFA. The hidden costs of coalmines' unquenchable thirst. 28 March 2024. Page 41.
[70] Mining Technology. Water resources in Australian mine pit lakes. 118(3-4). September 2009.
[71] ABC News. Brian Burke, Kerry Stokes, Kevin Reynolds among major players in race to unlock Western Australia's green power future. 4 September 2022.
[72] Genex Power. Kidston pumped storage hydro project – construction report. November 2022. Page 24.
[73] NSW Environmental Protection Agency. EPAs advice on secretary's environmental assessment requirements – Stratford Pumped Hydro and Solar. 12 January 2024. Page 1.

Act).[74] A controlled action refers to an action that is likely to have a significant impact on matters of national environmental significance.

Pumped hydro projects can also increase the risk of flooding to the surrounding area during construction or during operation after periods of heavy rainfall.[75] Severe rainfall events are increasing with the impacts of climate change in Australia, particularly across QLD and NSW. Flooding in south-eastern Australia in February, March and October 2022 was the second most costly natural disaster in the world that year; international reinsurer Munich RE reported that the losses amounted to US$8.1 billion, of which only US$4.7 billion was insured.[76]

All PHES schemes need water discharge approvals, but for mine void projects they are more complicated and time-consuming to obtain

To mitigate some of the risks, pumped hydro projects need to be able to discharge water when levels get too high to prevent flooding. However, the regulatory mechanism and approval process for this is more complicated for pumped hydro projects in mine voids than for traditional PHES projects. This is because typically a non-resource approval mechanism would be required for PHES schemes to enable water discharges for the project, but for projects on former mine sites the contamination risks posed by water discharges are higher, meaning additional sampling and higher costs are required to gain approval for water discharges.[77] For instance, the Kidston Gold mine project is awaiting its final water discharge criteria and had to undertake 18 months of sampling to establish water quality baselines for the Copperfield River, which the operators plan to use for water discharges from the Wises Dam if the need arises.[78]

Methane emissions

Pumped hydro and the creation or artificial reservoirs can generate methane emissions.[79,80,81] In addition to impacting on the carbon neutrality of these projects, this also raises the possibility of additional financial burdens under the Safeguard Mechanism to offset these emissions.

Water availability risks

The water requirements of pumped hydro are significant and will be impacted by changing precipitation trends and the effects of climate change.

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[74] NSW Government. Stratford Pumped Hydro and Solar (EPBC 2023/09733). 11 April 2024. Page 1.
[75] Lockton. Addressing the risks of pumped storage hydropower for a net zero world. 21 June 2023.
[76] Munich RE. Climate change and La Niña driving losses: the natural disaster figures for 2022. 10 January 2023.
[77] AECOM. Initial advice statement: Kidston pumped storage hydro project. 21 September 2018. Page 1.
[78] Genex. Kidston pumped storage hydro project – construction report. November 2022. Page 30.
[79] BioScience. Greenhouse gas emissions from reservoir water surfaces: A new global synthesis. 1 November 2016.
[80] European Geosciences Union. Methane emissions due to reservoir flushing: a significant emission pathway. 4 October 2023.
[81] Banpu Energy Australia. Underground pumped hydro energy storage project: Final Report. 1 July 2022. Page 33.

The water requirements for closed-loop pumped hydro projects, such as those proposed in old mine sites, would entail an initial water fill involving significant volumes of fresh water.[82] Fresh water is required for pumped hydro projects to reduce corrosion of turbines, pipes and pumps. For the proposed pumped hydro scheme at Muswellbrook mine, Idemitsu plans to reroute water licences currently applied to coal mining and the running of AGL's Liddell Power Station, which closed in 2023, to fill the void over a period of 18 months.[83]

Additional water fills will be required depending on evaporation rates. Evaporation rates in reservoirs are relatively high at up to 2,500mm per year.[84,85] Climate change is expected to increase the potential evapotranspiration rates in parts of Australia.[86] Reservoir covers could decrease evaporation losses in pumped hydro schemes, but these can significantly increase costs and may not be feasible in all cases, depending on the size of the reservoir.

The efficacy of pumped hydro is also impacted by declining rainfall, the risks of which will vary between different regions and sites, but was a key issue outlined in the Synergy pumped hydro feasibility study in WA.[87] The impacts of climate change on rainfall patterns could also impact on the water security and predictions of pumped hydro projects.[88]

The Kidston project is in an area that is in rainfall deficit, with net evaporation outstripping rainfall inflows. As such, there is a pipeline from the Copperfield Dam (raw water supply dam approximately 15km away) that feeds the local community and will also be utilised to top up Wises Dam (the upper reservoir in the Kidston PHES project) under an existing water licence agreement[89].

Construction delays

The CSIRO has warned that geological constraints and the long development lead times of pumped hydro projects may limit their application in mining, and that further analysis on a site-by-site basis is required to investigate their cost competitiveness.[90]

While operational lifetimes can be around 50 years in some cases, PHES projects take a long time to build, with average construction timeframes of 3-7 years on top of lengthy lead times for approval processes and funding.[91] This can include survey work to ensure the suitability of sites and to plan for unexpected geological conditions during drilling.

[82] Parliament of Australia. Australian electricity options: pumped hydro energy storage. 20 July 2020.
[83] PV Magazine. Australian coal mine to transform into pumped hydro facility. 19 April 2021.
[84] Parliament of Australia. Australian electricity options: pumped hydro energy storage. 20 July 2020.
[85] Applied Energy. Integrated GIS-AHP-based approach for off-river pumped hydro energy storage site selection. 1 May 2023.
[86] CSIRO. Climate projections for Australia. Last updated 23 February 2024.
[87] Synergy. Synergy's investigation into pumped hydro. 2024. Accessed 18 July 2024
[88] CSIRO. Climate projections for Australia. Last updated 23 February 2024
[89] Genex. Kidston pumped storage hydro project – lessons learnt report. December 2023. Page 3.
[90] CSIRO. Renewable Energy Storage Roadmap. March 2023. Page 63.
[91] Ibid. Page 47.

Compared with other energy storage technologies, PHES projects have the longest average construction times (see Figure 5). However, they can have significantly longer operational lifetimes than other energy storage technologies.

Given how fast advancements are being made in new energy storage technologies like thermal energy storage, vanadium redox flow batteries, gravitational energy storage and underground hydrogen, it is important that the long-term cost projections of other energy storage technologies are considered in decisions on pumped hydro developments.

Table 1: Average construction times for different energy storage technologies

Energy storage technology	Average construction times
Lithium-ion batteries	8-20 weeks
Zinc bromine batteries	~9 months
Vanadium redox flow batteries	1 – 1.5 years
Concentrated solar thermal plus storage	< 2 years
Liquid air energy storage systems	~ 2 years
Compressed air energy storage	2.5 – 3.5 years
Underground hydrogen	1 – 5 years
Gravity energy storage	1 – 3.5 years
Pumped hydro energy storage	3 – 7 years

Source: CSIRO[92]; IEEFA.

Financing pumped hydro in mine voids

As the only example to date of a pumped hydro scheme being built in a mine site in Australia, the Kidston gold mine is the only case where we can examine mine site PHES funding in detail at this stage.

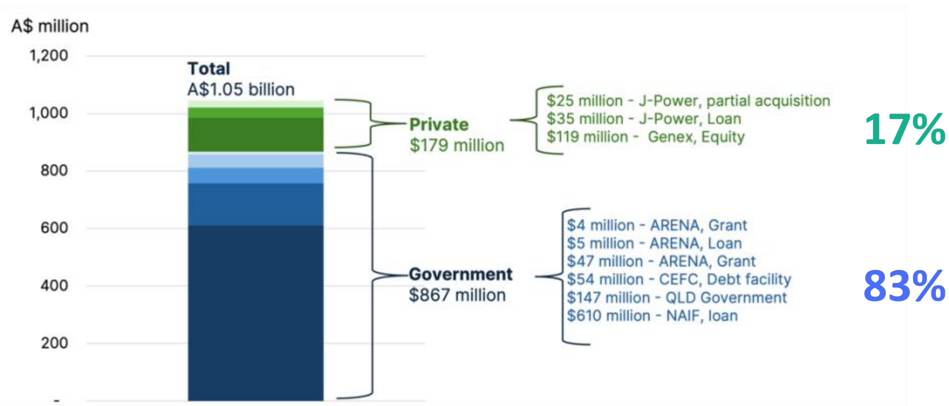
The project was 83% publicly funded, receiving A$804 million from Australian governments via grants and loan facilities. This included: A$610 million from the Northern Australia Infrastructure Facility (federal) via a 15-year loan/debt facility; and a A$47 million grant from the Australian Renewable Energy Agency (ARENA). Additionally, the project received A$147 million in funding from the QLD government for the required transmission line. The Clean Energy Finance Corporation (CEFC), a green bank owned by the Australian government, provided a A$54 million debt facility. During the planning stages of the project, ARENA provided A$4 million towards the feasibility study and a A$5million loan for pre-financial close activities.

In addition to this, the project received A$143.5 million in private funding (17% of the total project cost), consisting of: a A$118.5 million equity contribution from Genex; A$25 million from J-Power, a

[92] Ibid. Page 49.

Japanese public utility company, which acquired a 10% stake in Genex in May 2021; and an additional A$35 million loan facility from J-Power in June 2023.

Figure 5: Kidston pumped hydro project sources of finance



Sources: IEEFA; Genex; ARENA

It should be noted that the Kidston Gold mine ceased mining activities in 2001, and that QLD's legislative frameworks outlining rehabilitation obligations of mine sites have changed since this time. Additionally, the pumped hydro project at Kidston was developed by Genex (now owned by J-Power) rather than by the original mining operator.

Financial risks to governments

Pumped hydro in mine voids present a double-edged financial risk to governments

Mining companies are responsible for financing the rehabilitation of their mine sites, both during mining and after operations cease. If these pumped hydro projects do proceed, it is important that mining operators remain accountable to cover the costs of these developments. If governments finance pumped hydro developments in mine voids, they would be setting a precedent that governments will, at least partially, fund mine site rehabilitation.

Additionally, if a mining operator does not sufficiently rehabilitate the mine site, the relevant government agency is liable to cover these costs. Given the difficulties in accurately estimating final rehabilitation costs, these costs may be more than the amount of rehabilitation bonds that agency holds for that project.

If a mining operator does not fulfill their rehabilitation requirements, the responsibility and costs fall to the government – and the taxpayer

Mining companies are required to pay for rehabilitation during mining and after it ceases. Australian state and territory governments require mining companies to provide some form of financial surety (bond) before mining can begin, to help ensure rehabilitation commitments are kept. Australian governments collectively hold more than A$10 billion in rehabilitation bonds.[93]

The bond is intended to cover the full cost for the government to rehabilitate a site if a mining operator were to default on their rehabilitation obligations.[94] This is good in theory, but problems emerge if either the rehabilitation bonds held by governments are not sufficient to afford the rehabilitation requirements, or if these bonds are released to the operator after initial rehabilitation has taken place and then problems with the mine rehabilitation emerge later.

Estimating what the total rehabilitation costs will be for a mine site are complicated and difficult to calculate with 100% accuracy. For instance, the Victorian government has increased rehabilitation bonds for Latrobe Valley coal mines at least three times to reflect the growing understanding of the uncertainties and costs associated with rehabilitating these sites.[95] Rehabilitation of large open-cut mines, which create significant landform alterations, can cost hundreds of millions or billions of dollars.[96]

The rehabilitation requirements for miners, and subsequent government financial liabilities, are growing

Due to improvements in estimation methods and increasing amounts of land being disturbed by mining activities, the estimated rehabilitation costs from mining in Australia are growing. Queensland Treasury reported the total estimated rehabilitation costs from mining was A$8.7 billion in 2017.[97] As of 30 June 2023, that number had risen to A$13 billion.[98] In NSW, the government held A$3.7 billion in mine rehabilitation bonds in June 2023, an increase from A$3.4 billion in June 2021.[99]

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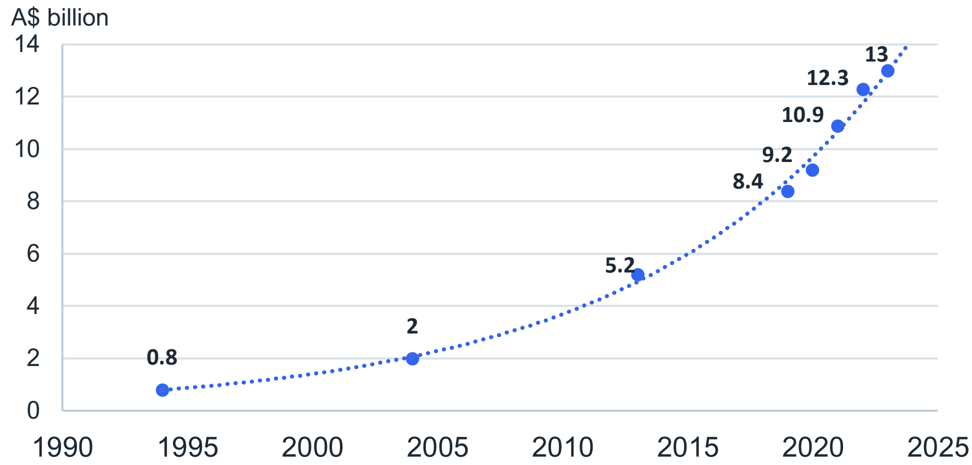
[93] The Australia Institute. Dark side of the boom: what we do and don't know about mines closures and rehabilitation. April 2017. Page 2.
[94] Resources Victoria. Rehabilitation bonds – minerals, exploration, mines and quarries. 15 May 2024.
[95] Resources Victoria. Latrobe Valley coal mine rehabilitation bonds. 27 March 2024.
[96] The Australia Institute. Dark side of the boom: what we do and don't know about mines closures and rehabilitation. April 2017. Page 2.
[97] Queensland Treasury Corporation. Review of Queensland's Financial Assurance Framework. April 2017. Page 1.
[98] Queensland Treasury. Financial Provisioning Scheme 2022-23 Annual Report. 2023. Page 6.
[99] New South Wales Resources Regulator, Department of Regional NSW. Exploration and mining compliance and rehabilitation report 2022-23. March 2024. page 3.

Figure 6: Industry-wide ERC liability (estimated) in QLD 1994-2023



Source: IEEFA; Queensland Mine Rehabilitation Commissioner[100]. Note. ERC = Estimated Rehabilitation Cost.

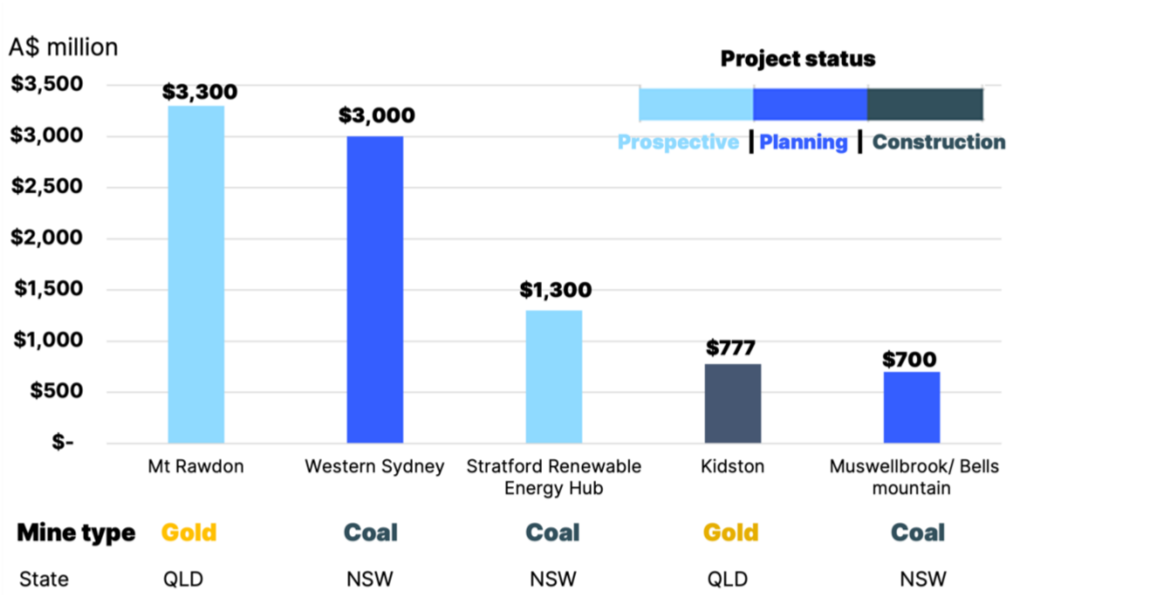
In addition to the potential precedent of governments funding mine rehabilitation, PHES projects in mine voids face the risk of cost blowouts

With governments providing the majority of funding for PHES projects, this leaves taxpayers on the hook for covering the potential increase in costs of these projects. The Snowy 2.0 project has faced large delays, and its costs have increased six-fold, from an initial estimate of A$2 billion, to now sitting at $12 billion.[101],[102] Transmission costs of approximately A$10 billion to connect the project to Sydney and Melbourne could push the total project cost to more than A$20 billion.

The Kidston Pumped Storage Hydro project in QLD was originally due for completion in 2022, but after excavation issues the project experienced a $15 million cost increase and significant delays. Genex Power founder Simon Kidston stated that it would be hard to speed up approvals for what are usually complex projects: “People talk about speeding up the timeframe but it’s very hard to achieve because the time to achieve feasibility, time for permits, time to line up finance and construction is three years. Before you know it, 10 years has gone.”[103]

[100] Queensland Mine Rehabilitation Commissioner. 2022-23 Annual Report. September 2023.
[101] The Guardian. Turnbull to announce $2bn expansion to Snowy hydro-electric scheme. 16 March 2017.
[102] Australian Financial Review. Florence, the Snowy 2.0 machine, is stuck again. 22 May 2024.
[103] AFR. Pumped hydro takes time and stamina (which Australia may not have).10 April 2023.

Figure 7: Estimated project costs of mine void pumped hydro projects, A$ million



Source: IEEFA; Australia, New Zealand Infrastructure Pipeline.

However, the Kidston project costs are at the lower end of the estimated project costs of other proposed PHES schemes in mine voids. Importantly, the Kidston project utilised two existing mine voids as the lower and upper reservoir, which saved on construction costs, whereas almost all other proposed mining PHES schemes will only utilise one existing mine void, to be used as a lower reservoir, meaning they will still require the construction of a second upper reservoir.

Cost comparisons of energy storage technologies

The lowest-cost energy storage technology differs for various storage durations. While research from CSIRO suggests pumped hydro will have lower costs than other storage technologies in 2025 for a range of storage durations, its analysis found that other technologies will take over as the lowest-cost storage options by 2050.[104] Only one pumped hydro energy storage project has been built in Australia in the last 40 years, so input data on the costs of pumped hydro energy storage schemes are limited. CSIRO's Renewable Energy Storage Roadmap projected that the lowest-cost storage options (in terms of levelised cost of storage, LCOS) for 2050 were:

- Short duration (less than 4 hours): lithium-ion batteries
- Medium duration (4-12 hours): concentrated solar thermal (CST) energy storage (with lithium-ion a closer runner-up).

[104] CSIRO. Renewable Energy Storage Roadmap. March 2023.

- Long intraday storage (>12-24 hours): CST energy storage
- Long multiday storage (>24-100 hours): underground hydrogen.[105]

Recent results of the NSW Tender Round 3, which requested storage project proposals with durations of at least eight hours, indicated that other technologies are competitive over pumped hydro for this storage duration.[106] Long-Term Energy Service Agreements were received by five projects, three of which were energy storage projects with a combined total of 524MW of long-duration storage, which in NSW refers to having a continuous discharge capacity of at least eight hours. The energy storage projects that won the tender included a compressed air energy storage system project, and two lithium-ion battery energy storage systems of eight hours duration. **This brings into question whether pumped hydro is the lowest-cost option for the eight-hour storage category and offers further evidence of the fast-moving nature of the energy storage technology space.**

CSIRO also noted that pumped hydro costs have a wider range of uncertainty than other energy storage technologies, owing to the greater influence of site-specific issues that can arise.[107] Pumped hydro projects are geographically specific because they require an upper and lower reservoir to be built at different elevations.[108] Usually the reservoirs would require a minimum elevation difference of 100-200 metres between them. Comparatively, the costs of battery technologies are relatively independent of the site, because they are more modular.[109]

Alternate energy storage technologies

Different amounts of energy can be stored by different energy storage technologies. Energy storage technologies have both a power capacity (in MW), and an energy capacity (in MWh) which can also be referred to as depth. The “duration” of storage (expressed in hours) is the amount of time over which the storage project can continuously deliver its stored energy at its rated power capacity. For example, a storage project of 300MW/600MWh can deliver 300MW of power for two hours.

Shallow storage is typically any grid-connected storage that can dispatch its rated power for under four hours, medium for between four and 12 hours, and deep for over 12 hours, according to

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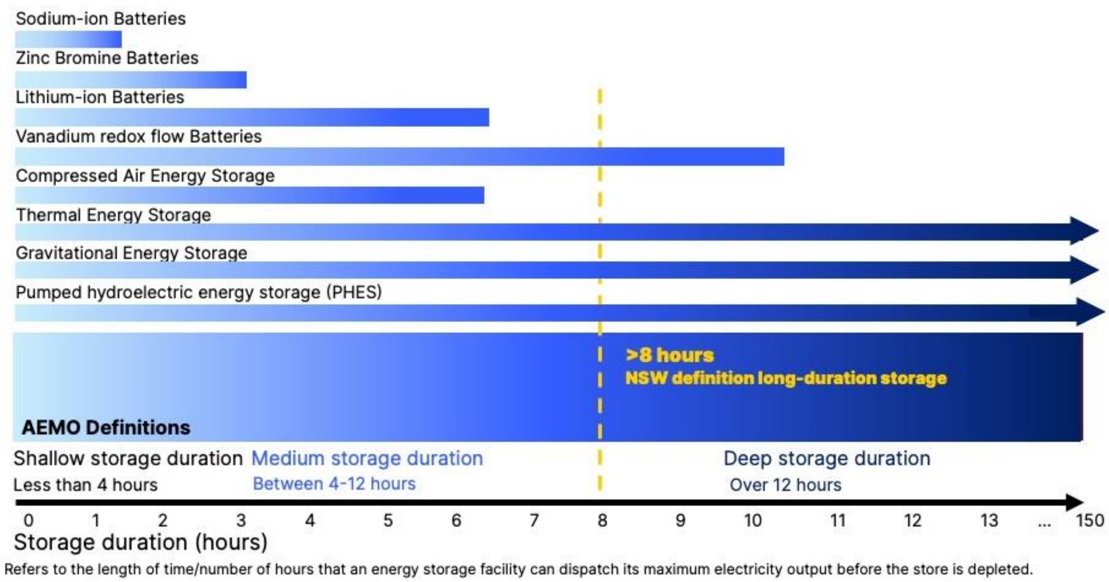
[105] Ibid. Page 55. Note: CSIRO’s figures were based on desktop research and stakeholder consultation, and CSIRO says they are not considered definitive.
[106] AEMO Services. NSW Roadmap – Tender Round 3 generation and long-duration storage infrastructure. 19 April 2024. Note: The NSW government has been using the terms long-duration storage (which is anything over 8 hours duration), medium- and short-duration storage in place of shallow, medium and deep energy storage. This differs from AEMO’s classifications of deep energy storage.
[107] CSIRO. GenCost 2023-24: Consultation draft. 1 December 2023.
[108] Australian Financial Review. Pumped hydro takes time and stamina (which Australia may not have). 10 April 2023.
[109] CSIRO. GenCost 2023-24: Consultation draft. 1 December 2023.

Australian Energy Market Operator (AEMO)'s categories used in the Integrated System Plan (ISP).[110] Currently the deepest storage available to the NEM are its existing deep-reservoir hydro assets.

Figure 8: Understanding energy storage durations



Source: IEEFA; CSIRO Renewable Energy Storage Roadmap data, March 2023 Note. The storage durations shown per technology are indicative of current technology developments and proposals only. Advancements in this space are occurring rapidly and that energy storage duration the options here could increase.

Batteries

Batteries use chemicals to absorb and release energy on demand. There are multiple types of batteries, but lithium-ion is the most common battery used to store grid electricity.[111] Battery storage is easily installed, modular, fast and flexible, and can deliver multiple different services, including inertia and system strength to the grid.

There are at least 24 utility-scale batteries currently operating in Australia, around nine committed to construction, two in the commissioning process, 22 anticipated projects and 279 publicly announced projects.[112] Previously, utility-scale batteries have mostly been used to provide shallow energy storage for less than four hours – mostly around two hours. However, new battery projects in Australia show that this is changing with multiple planned battery projects providing medium-duration storage for four to eight hours.

[110] AEMO. 2024 Integrated System Plan for the National Electricity Market. 26 June 2024.
[111] ARENA. Battery storage. 4 July 2024.
[112] AEMO. Generation information. May 2024.

Energy Australia is planning to build Australia's first four-hour (350MW/1,400MWh) utility-scale battery in the Latrobe Valley.[113] Additionally, two lithium-ion battery energy storage projects, the Goulburn River BESS and Richmond Valley BESS, are proposed in NSW and would each provide eight hours of energy storage, making them the biggest batteries in Australia.[114] Notably, these two projects won out over pumped hydro in Round 3 of the NSW Electricity Infrastructure Roadmap tender.[115,116]

Some forms of battery storage present other environmental risks throughout their value chain depending on the method and location of mining. Additionally, the disposal of batteries at their end of life will also present environmental considerations that will need to be addressed. However, this depends on the type of battery energy storage technology. For example, vanadium redox flow battery units will be recyclable at end of life, and the required minerals for these batteries can be mined in Australia.

Vanadium redox flow batteries

Additionally, the advancement of vanadium redox flow battery systems is showing that batteries could store energy for four to 12 hours.[117] The world's largest vanadium flow battery is currently being developed in SA and is expected to have capacity for up to 12 hours of storage.[118] This would mean that battery technology could provide shallow, medium and deep storage duration solutions in Australia. Vanadium flow batteries also do not contain conflict minerals and are recyclable at their end of life, which presents advantages over lithium-ion batteries.[119]

Compressed air energy storage projects

Compressed air energy storage (CAES) pressurises atmospheric air, converting it into stored potential energy (like compressing a spring). When electricity is needed, the compressed air is released to flow through an expander (turbine-generator) to produce energy.[120] CAES projects can provide energy storage for a medium duration of between four and 12 hours, with technological advancement potentially enabling up to 24 hours. They can provide grid inertia and resilience.

Hydrostor plans to build a 200MW/1,600MWh fuel-free energy storage facility at a disused silver mine in Broken Hill, NSW.[121] Once built, the project will be one of the world's largest compressed air projects, providing eight hours of storage.

[113] Energy Australia. Wooren Energy Storage System. Accessed 6 July 2024.
[114] Renew Economy. Eight hour big battery trumps pumped hydro in NSW long duration storage tender. 1 May 2024.
[115] NSW Government. NSW secures more renewable energy projects. 19 December 2023.
[116] AEMO Services. NSW Roadmap – Tender Round 3 generation and long-duration storage infrastructure. 19 April 2024.
[117] CSIRO. Renewable Energy Storage Roadmap. March 2023. Page 48.
[118] AEMO. South Australia goes with the flow battery. 23 December 2020.
[119] Yadlamalka Energy. World's largest solar-powered vanadium flow battery coming to South Australia. 13 December 2020.
[120] CSIRO. Underground storage of compressed air. 6 October 2022.
[121] Energy Storage News. Hydrostor's advanced compressed air energy storage project. 25 October 2022.

Thermal energy storage

Thermal energy storage stores cold or heat energy to use at a later stage. There are various forms of thermal energy storage under development including steam accumulators, which are the storage component of concentrated solar thermal (CST).[122] In SA, an ARENA project is currently underway for Vast Solar to construct a 30MW/288MWh CST plant in Port Augusta, supported in part by the federal government.[123] The project plans to have ten hours of thermal energy storage and to supply power to the grid at night.[124]

Gravitational energy storage

Swiss company Energy Vault has been trialling a technology that recreates the pumped hydro fundamentals of storing and generating energy through gravity, but with cranes and concrete blocks instead of by pumping water up and down two reservoirs.[125] Gravitational energy storage systems work by using surplus energy to lift and store large concrete blocks at a certain height. When demand from the grid increases, the blocks are released in a controlled, coordinated manner. As they descend under the force of gravity, they drive generators to produce electricity.[126] This technology is also being investigated to be deployed on existing skyscrapers, with initial investigations taking place on the world's tallest building – the Burj Khalifa in Dubai.[127]

Energy Vault recently announced construction of two battery energy storage system projects totalling 400MWh in NSW, with construction due to begin in H2 2024.[128] BHP has also signed a memorandum of understanding (MoU) with Energy Vault to explore the use of this technology to provide deep energy storage that could power energy-intensive processes such as green hydrogen production.[129]

Other energy storage technologies

There are a range of other energy storage technology options that are currently emerging, such as underground hydrogen, which could potentially "firm" electricity networks for weeks, months or even entire seasons[130]; or iron air battery tech, which could potentially provide 100 hours of energy storage duration[131]; among other innovations. **Energy storage is fast-moving technology space.**

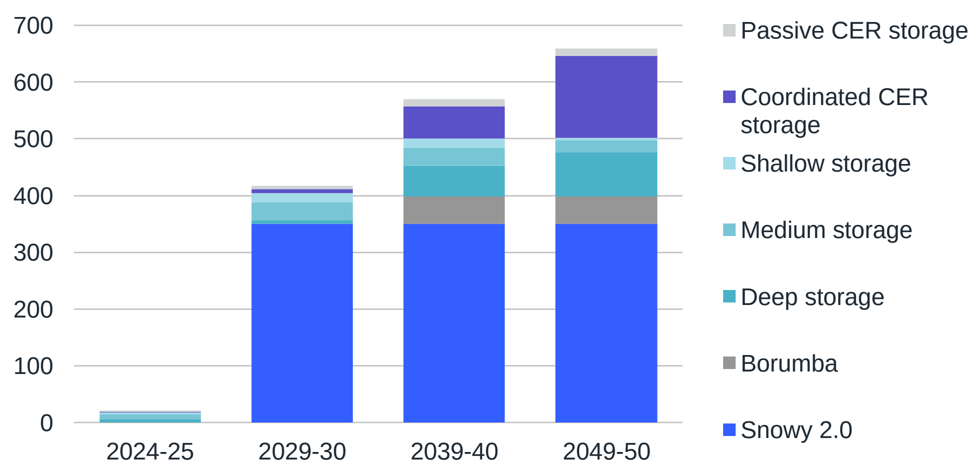
[122] CSIRO. Renewable Energy Storage Roadmap. March 2023.
[123] ARENA. Vast solar Port Augusta concentrated solar thermal power project. Last updated 15 February 2023.
[124] CSIRO. Batteries won't cut it – we need solar thermal technology to get us through the night. 12 April 2023.
[125] OneZero Medium. A new type of battery, made of concrete. 28 October 2021.
[126] Enel Green Power. Gravity storage becomes reality. 21 May 2024.
[127] NewsAtlas. Kilometre-tall skyscrapers to double as massive batteries. 4 June 2024.
[128] PowerTechnology. Energy Vault to deploy 200MW battery energy storage systems in Australia. 10 May 2024.
[129] Barron's. BHP signs energy storage deal in its plan to go carbon neutral. 15 December 2021.
[130] CSIRO. Making Hydrogen while the sun shines. 30 April 2024.
[131] Energy Storage news, Startup Form Energy's '100-hour' iron-air battery tech attracts another US utility's attention, 8 January 2024.

NEM requirements for pumped hydro in mine voids

Australia's additional pumped hydro needs are likely to be relatively small

According to AEMO's projections, the Snowy 2.0 project will provide the majority of required deep storage duration needs in the NEM, up to 2.2 gigawatts (GW) / 350 gigawatt-hours (GWh), or about 160 hours duration. The Borumba pumped hydro project in QLD, which is under procurement, is projected to provide additional deep storage with 2GW/48GWh of energy capacity planned (24 hours duration). **This leaves only a small requirement for an additional 2.5GW/77.8GWh of deep storage duration by 2049-50, according to the Step Change scenario in the ISP.**[132] The additional medium storage duration requirements projected under the Step Change scenario will be 2.7GW/21.5GWh by 2049-50.

Figure 9: NEM energy storage requirements ISP (Step Change scenario), GWh



Source: AEMO.[133]

According to AEMO, "Firming technologies will smooth out the variations in renewable supply: batteries for everyday variations, and strategic pumped hydro projects for longer-term and seasonal variations."[134]

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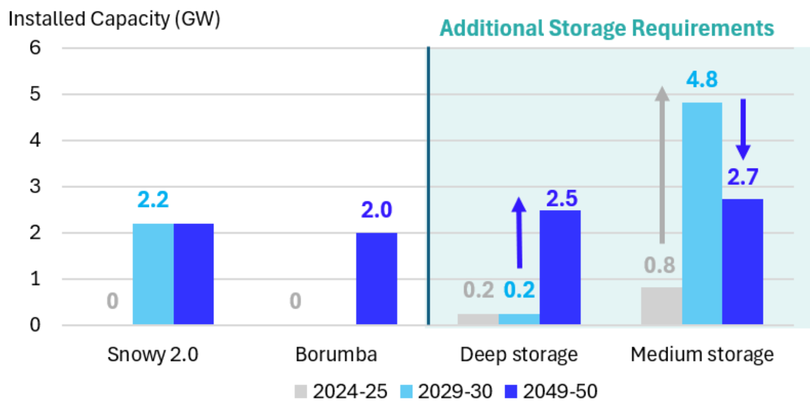
[132] AEMO. 2024 Integrated System Plan- 2024 ISP chart data. 26 June 2024.
[133] AEMO. 2024 Integrated System Plan for the National Electricity Market. 26 June 2024.
[134] Ibid. Page 24.

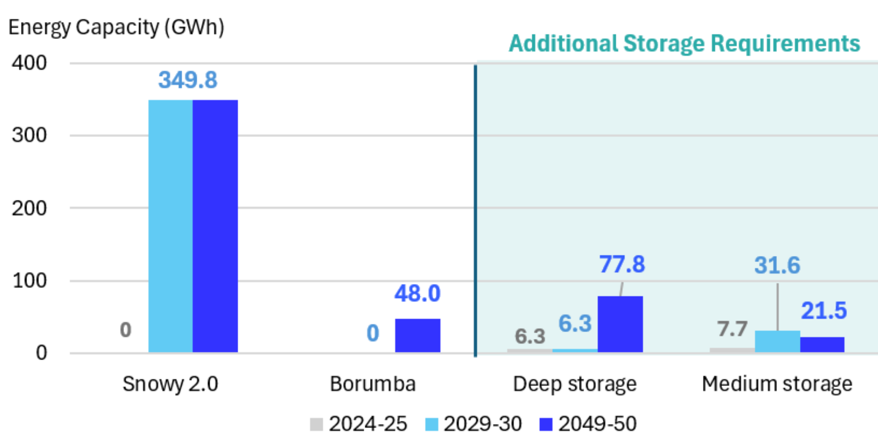
Figure 10: Medium and deep installed capacity requirements in the NEM to 2049-50



Source: IEEFA; AEMO[135].

It should be noted that AEMO projects that additional medium- and shallow-duration energy storage buildout will be needed in the next few years, with higher medium storage duration required by 2029-30. This will likely be filled by quick-to-deploy solutions such as utility-scale batteries. As coordinated consumer energy resources (CER) solutions, such as residential batteries and electric vehicles, are anticipated to grow, less shallow-duration storage is expected to be needed at the end of the forecast period, and medium-duration storage needs decline by 2049-50. Given their long development timeframes, high capital costs and longevity, pumped hydro projects are unlikely to be best suited to meeting the additional needs for medium-duration storage in the NEM in the short-to-medium term. However, in the longer term they could provide deep storage duration solutions.

Figure 11: Medium and deep energy capacity requirements in the NEM to 2049-50



Source: IEEFA; AEMO[136].

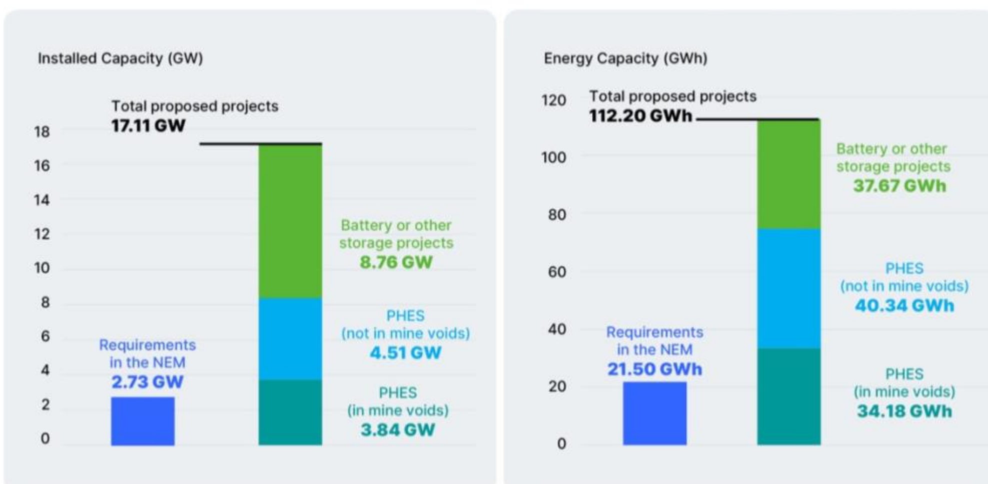
[135] Ibid.
[136] AEMO. 2024 Integrated System Plan for the National Electricity Market. 26 June 2024.

If the current pumped hydro proposals in the NEM proceed as planned, there is no requirement for additional projects in mine sites

With the exception the Stratford Renewable Energy Hub, the current pipeline of proposed mining PHES projects will only provide medium storage duration, meaning they are all estimated to provide less than 12 hours of storage duration when complete.

There is already 10.96GW/232.62GWh deep storage and 5.26GW/48.59GWh of medium storage projected from the pipeline of non-mine site pumped hydro projects currently proposed in the NEM. This far exceeds the additional 2GW/78GWh of deep storage and 3GW/22GWh of medium storage that AEMO projects is required by 2049-50 (shown in Appendix C).[137]

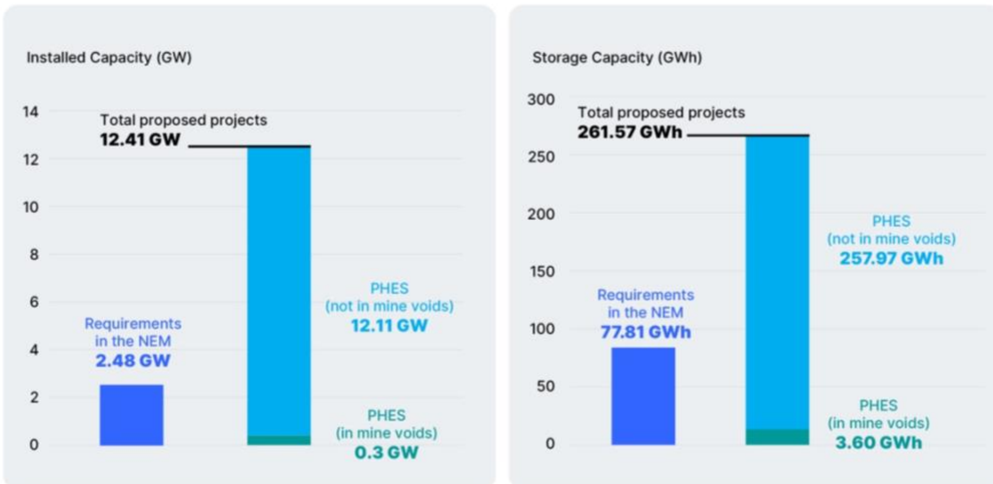
Figure 12: Medium storage duration projects proposed in the NEM by 2050, versus AEMO requirements under Step Change scenario



Source: IEEFA, AEMO Generation Information, May 2024

[137] AEMO. 2024 Integrated System Plan- 2024 ISP chart data. 26 June 2024.

Figure 13: Deep storage duration projects proposed in the NEM by 2050, versus AEMO requirements under Step Change scenario



Source: IEEFA, AEMO Generation Information, May 2024
Note: Snowy 2.0 and Borumba are excluded as these are reported on separately in the AEMO ISP installed energy storage projections.

Australia currently only has four operating pumped hydro energy storage facilities, which are all open-loop, river-based projects in NSW and QLD (plus a very small project in Tasmania called Tods Corner).[138] They are: Wivenhoe (QLD, 570MW/6000MWh), Shoalhaven (NSW, 247MW/9680MWh), Tumut 3 (NSW, 600MW) and Burrinjuck (NSW, 50MW).[139] NSW and QLD are also the only states with additional pumped hydro projects under construction at the moment, but there are several proposed PHES projects in both these states, as well as Tasmania, and one in SA (a detailed list can be found in Appendix C).

Pumped hydro plays a critical role in the 2022 Queensland Energy and Jobs Plan. In addition to the Borumba Pumped Hydro project (2,000MW/48,000MWh, currently under procurement[140]), and the Kidston project (250MW/2,000MWh, under construction), there are six additional non-mine void pumped hydro projects proposed in QLD. **If these six projects go ahead, they would provide an additional 7.40GW/167.90GWh of deep storage duration and 1.21GW/10.46GWh of medium storage duration requirements to the NEM.** For comparison, AEMO's ISP Step Change scenario states that QLD will require only 0.08GW/1.94GWh of deep storage by 2049-50, and 1.28GW/11.38GWh of medium storage by 2049-50.[141]

[138] AEMO. Generation Information Spreadsheet. May 2024.
[139] Open NEM. Hydro operating facilities, v4.26.26. Last accessed 18 July 2024.
[140] Australian and New Zealand Infrastructure Pipeline. Borumba Pumped Hydro.
[141] AEMO. 2024 Integrated System Plan. 2024 ISP generation and storage outlook, Step Change scenario. 26 June 2024.

Figure 14: Medium duration storage projects proposed in QLD and NSW

Source: IEEFA, AEMO Generation Information, May 2024.

If the current pipeline of announced and proposed pumped hydro projects go ahead in NSW, they would provide 2.35GW/22.18GWh of medium-duration storage, and 1.41GW/16.92GWh of deep-duration storage, which is higher than AEMO's medium-duration requirements for 2049-50 of 1.22GW/8.27GWh, but doesn't quite meet the 1.25GW/42.27GWh deep-duration requirements.

Appendix D outlines the potential installed capacity per state (both medium- and deep-storage duration) that would be generated if the PHES projects already in the pipeline are completed. This suggests that additional PHES development in mine voids is not required in QLD and NSW, particularly to meet medium-duration storage needs, which are increasingly being met by batteries and alternate energy storage technology.

Conclusion and recommendations

Overall, this report has discussed the risks associated with pumped hydro in mine voids including contamination potential, ongoing water requirements, and a range of cost and geological uncertainties. Further, based on an analysis of AEMO's Integrated System Plan and the pipeline of non-mine site pumped hydro and other energy storage projects proposed in the NEM, there is little to no requirement in the NEM for the pumped hydro proposed in mine voids. Except for the Stratford Renewable Energy Hub, PHES projects proposed in mine voids would only provide medium storage duration, meaning they are estimated to provide less than 12 hours of storage when complete. Mature, competitive alternatives to pumped hydro already exist to provide medium-duration storage, and alternate deep energy storage technologies are advancing rapidly.

1. Pumped hydro projects in mine voids should not be funded by governments

Based on the findings above, the primary driver for pumped hydro proposals in mine voids appears to be an attempt to find a suitable post-mining use for mine voids rather than to fill the energy storage requirements in the NEM. Additionally, as the Western Australian proposals highlight, these projects might be being proposed as an opportunity for miners to obtain government funding for mine rehabilitation, in effect transferring at least part of their rehabilitation liabilities to the taxpayer. It is important that final voids, if they are permitted to be left after mining, are managed or repurposed appropriately. However, rehabilitation of a mine site is the financial responsibility of the mining operator (or mining licence holder) before the land is relinquished for another purpose. In IEEFA's view, governments should not be responsible for financing these projects.

If governments cover the cost of developing pumped hydro in mine sites as a form of rehabilitation, they would be setting a precedent that taxpayers will be responsible for financing mine site rehabilitation.

2. Australia needs a final voids policy to avoid significant costs to taxpayers

The lack of a clearly defined final voids policy in Australia means rehabilitation requirements and options for closed or soon-to-close coal mines where a final void is planned to be left are unclear. If Australian law continues to permit final voids to be left after mining ceases, then Australia requires a final voids policy. The policy would need to set standards and long-term financial obligations on mining operators for managing the ongoing risks that these structures pose, to protect taxpayers from covering the costs of managing these final voids and paying for mining operators' rehabilitation responsibilities. Additionally, if future costs arise from these projects, such as contamination or pollution issues, governments should not be responsible for covering the cost of cleaning up or paying compensation to those affected in addition to having funded the project in the first place.

An effective management plan for final voids would involve implementing a cost to miners for leaving final voids or for not managing future risks of final voids appropriately. There is currently no financial incentive for miners to minimise the size of the final void left by the mining process if their licence permits them to leave a final void.

Appendix A

Table 2: Open-cut coal mines already closed or undergoing rehabilitation, under care and maintenance, or scheduled to close by 2030

Mine Name	State	Coal type	Mine Status	Scheduled closure	PHES proposal
Jeebropilly	QLD	Thermal	Rehabilitation	2019	
Sunnyside Coal Mine	NSW	Thermal	Rehabilitation		
Minerva	QLD	Thermal	Rehabilitation	2021	
Rocglen	NSW	Thermal	Rehabilitation	2022	
Muswellbrook	NSW	Thermal	Rehabilitation	2022	
Newlands	QLD	Met / Thermal	Closed/Rehabilitation	2023	
Newlands Eastern Creek	QLD	Met / Thermal	Closed/Rehabilitation	2023	
Newlands Suttor Creek	QLD	Met / Thermal	Closed/Rehabilitation	2023	
Newlands Wollombi	QLD	Met / Thermal	Closed/Rehabilitation	2023	
Liddell	NSW	Met / Thermal	Closed	2023	
Stratford	NSW	Met / Thermal	Closed	2025	Yes
Duralie	NSW	Met	Care and Maintenance	2021	Yes
Cullen Valley	NSW	Thermal	Operating	2025	
Pine Dale Coal Mine	NSW	Thermal	Care & maintenance		
Bluff Mine	QLD	PCI	Care and Maintenance	2031	
Ensham OC	QLD	Thermal	Operating Mine	2024	
Broadlea	QLD	Met / Thermal	Operating mine	2025	
Blair Athol	QLD	Thermal	Operating Mine	2030	
Clermont Coal	QLD	Thermal	Operating Mine	2030	
Mangoola	NSW	Thermal	Operating Mine	2030	
Tarrawonga	NSW	Met / Thermal	Operating Mine	2030	
Burton Coal	QLD	Met / Thermal	Operating Mine	2030	

Table 3: Open-cut coal mines currently applying for an expansion or extension

Mine Name	State	Coal type	Mine type	Mine Status	Scheduled Closure
HV Operations North	NSW	Met / Thermal	Open Cut	Operating Mine	2025
HV Operations South	NSW	Met / Thermal	Open Cut	Operating Mine	2030
Vulcan	QLD	Met / Thermal	Open Cut	Operating Mine	2025
Mt Arthur Coal	NSW	Thermal	Open Cut	Operating Mine	2026
Mt Pleasant	NSW	Thermal	Open Cut	Operating Mine	2026
Bloomfield	NSW	Met / Thermal	Open Cut	Operating Mine	2030
German Creek	QLD	PCI / Thermal	Open Cut	Operating Mine	2028
Capcoal – Oak Park	QLD		Open cut	Closed	

Appendix B

Table 4: Mine sites with pumped hydro potential identified in ANU Study, QLD, Vic, NSW

Mine Name	State	Mine Type	Mine Status	Majority Owner
Site identified Northeast of Goonyella and Broadmeadow coal mines	QLD	**Coal**		
Site south of Centurion Coal Mine (AKA North Goonyella)	QLD	**Coal**	Operating, scheduled closure 2023, applying for extension	Peabody
Coppabella Coal mine	QLD	**Coal**	Operating, 2027	Peabody
Muswellbrook mine	NSW	**Coal**	Closed since 2022	Idemitsu
Hunter Valley Operations	NSW	**Coal**	Scheduled to close north pit June 2025, south pit 2030, but applying for expansion	Glencore
Lake Liddell	NSW	**Coal**	Closed 2023	Glencore
Mount Owen Glendell (south part)	NSW	**Coal**	Scheduled for closure 2025, last coal Dec 2024, but applying for extension	Glencore
Mount Rawdon gold mine	QLD	Gold	Mining ending 2024, ore processing ending 2025	Evolution Mining
Ernest henry Mining	QLD	Gold / copper		
Cadia valley Mine North	NSW	Gold / copper	Operating	Newcrest
Cadia valley mine South	NSW	Gold / copper	Operating	Newcrest
New Century Mine	QLD	Zinc, Lead, silver		Sibanye-Stillwater Group
Gold Coast Wake Park, water recreation park (west of a quarry)	QLD	NA	NA	-
Loy Yang (north)	VIC	**Coal**	Operating, scheduled closure date 2035	AGL Energy
Yallourn coal mine	VIC	**Coal**	Operating, scheduled closure date 2028	Energy Australia
Hazelwood cooling pond	VIC	**Coal**	Closed in 2017	ENGIE (72%) & Mitsui & Co Ltd (28%

Appendix C

Table 5: Pipeline of non-mine site PHES projects in the NEM

Facility Name	Sum of Nameplate Capacity (MW)	Sum of storage capacity (MWh)	Hours	State	Status
Existing					
Shoalhaven	247	9,680	~39	NSW	Operating
Wivenhoe	570	6,000	~10	QLD	Operating
Tumut 3	600			NSW	Operating
Burrinjuck	50			NSW	Operating
Tods Corner	1			TAS	Operating
Included in AEMO projections					
Snowy 2.0	2200	349,980	~160	NSW	Construction
Borumba	1,998	48,000	24	QLD	Anticipated
Additional PHES projects (non-mine)					
Medium storage duration					
Lake Parangana Pumped Hydro	300	2,100	7	TAS	Yet to be approved
Central West pumped hydro	325	2,600	8	NSW	Detailed Planning
Baroota	250	2,000	8	SA	Applying for planning permission
Lake Lyell	335	2,680	8	NSW	Feasibility study
Hells Gates Dam	808	6,464	8	QLD	Prospective
Lake Rosebery	400	3,600	9	TAS	Prospective
Glennies Creek	620	6,200	10	NSW	Feasibility study
Glenbawn	770	7,700	10	NSW	Feasibility study
Dungowan pumped hydro	300	3,000	10	NSW	Announced
Big T project	400	4,000	10	QLD	FID due Q2 2024, Draft EIS
Total medium storage duration	**4,508**	**40,344**			
Deep storage duration	**10,962**	**232,620**			
Oven mountain PHES	600	7,200	12	NSW	Prospective
Phoenix pumped hydro (Burrendong)	810	9,720	12	NSW	Prospective
Capricornia Energy Hub	750	12,000	16	QLD	Under Procurement
Flavian superhybrid	600	10800	18	QLD	Prospective
Lake Margaret-Burbury	800	15100	19	TAS	Prospective
Lake Cethana	750	15,000	20	TAS	Announced
Tarraleah Re-development	220	4,400	20	TAS	Announced
Bowen PHES	750	18,000	24	QLD	Announced
Bunkers Hill	296	7,104	24	QLD	Announced
Pioneer-Burdekin	5,000	120,000	24	QLD	Announced
Lake Rowallan	750	12,000	16	TAS	Announced
Tribute Pumped Hydro	750	18,750	25	TAS	Announced
Wilmot Redevelopment	32	7,900	247	TAS	Prospective
Total deep storage duration	**12,108**	**257,974**			
Additional PHES project (mine)					
Medium storage duration					
Kidston project (Gold mine)	250	2,000	8	QLD	Construction
Western Sydney (Coal) (Burragorang /Nattai Mining)	1,000	8,000	8	NSW	Detailed Planning
Muswellbrook Coal mine (Bells Mountain PHES)	500	4,000	8	NSW	Detailed planning, NSW, SEARs approval granted
Mt Rawdon PHES (Gold mine)	20,40	20,000	~10	QLD	Announced
Mount Leyshon (Gold mine)	20			QLD	Prospective
Bendigo (Gold mine)	30	180	6	VIC	Prospective
Total medium storage duration	**1800**	**34,180**			
Deep storage duration					
Stratford coal mine	300	3,600	12	NSW	Proposed
Total deep storage duration	**300**	**3,600**			

Sources: IEEFA; AEMO; Project announcements and company websites.

Appendix D

Table 6: Proposed (non-mine) PHES and other energy storage projects by State versus AEMO projected requirements

		QLD		NSW	
	Storage Duration	**Medium**	**Deep**	**Medium**	**Deep**
Proposed PHES (non-mine)	**Proposed generation Capacity (MW)**	1,208	7,396	2,350	1,410
	Proposed storage capacity (MWh)	10,464	167,904	22,180	16,920
Batteries or other energy storage	**Proposed generation Capacity (MW)**	1,550	0	3,763	0
	Proposed storage capacity (MWh)	6,700	0	17,180	0
AEMO projected requirements 2049-50	Generation Capacity requirements (MW)	1,281	81	1,217	1,247
	Storage capacity requirements (MWh)	11,379	1,936	8,265	42,271
Difference	**MW**	1,477	7,315	4,896	163
	MWh	5,785	165,968	31,095	-25,351

Note: Excluding Snowy 2.0 and Borumba

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