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Can we transition mines to their post-mining land use earlier?

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Abstract

Very few mines in Australia have successfully transitioned to a post-mining land use and had their environmental approvals surrendered under contemporary environmental legislation. Those that have are relatively simple or short-lived operations. Globally there are examples of successful closures driven by longstanding legislative requirements: US coal mines under the Surface Mining Control and Reclamation Act 1977 being the exemplar. However, there are fewer examples of the successful transition of mines to a post-mining land use where mines have complex geotechnical or geochemical attributes, or where governments have not provided significant subsidies to develop those post-mining land uses, as has occurred in European lignite mining areas.

The conventional approach to the mine life cycle is to extract the resource, potentially do some progressive rehabilitation along the way and then complete the majority of rehabilitation after operations have ceased. Mined land is then presented to the regulator for surrender. The track record of successful mine transitions in Australia would suggest this paradigm is not delivering optimal transitions to post-mining futures.

Given very little in the literature has canvassed the views of mine rehabilitation experts on this situation, an expert elicitation survey was undertaken to assess what barriers to post-mining land uses being deployed earlier in the mining cycle experts thought might exist. These experts are grappling with the challenges of mine transitions and are well-placed to provide guidance. Specifically, the experts were asked to consider the likelihood and severity of potential barriers to post-mining land uses being dovetailed onto operational mines.

This paper summarises the main areas of consensus and divergence in expert views and reports back on a process commenced with delegates to Mine Closure 2023 in Reno, Nevada, United States. The results of this research provide some early insights into opportunities to remove critical barriers to more and earlier beneficial uses of mined lands.

Keywords: *Post-mining land use, expert elicitation survey, mine rehabilitation, mine transitions*

1 Introduction

Earlier in 2026 we published a paper called ‘Barriers to introducing non-mining land uses onto operational mines as perceived and experienced by experts In Australia’ (Purtill et al. 2026). The research was prompted by the relatively low levels of successful transitions (Measham et al. 2024) of geotechnically or geochemically complex mines to sustainable post-mining land uses (PMLUs) in the absence of significant government or philanthropic subsidies. The argument ran that if these mines cannot readily surrender their mining and environmental licences, is there a need for PMLUs to be transitioned onto long-lived operational mines. Thus we sought to answer, in part, the question: ‘What are the barriers, perceived and actual, to the introduction of non-mining land uses earlier in the life cycle of multidecadal mines?’ (Measham et al. 2024)

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The paper outlined the paucity of research in the literature seeking to better understand how PMLUs might be introduced onto operational mines, particularly as a mechanism to 'dovetail' PMLUs onto mines to minimise the hiatus between mining operations and some form of beneficial use of rehabilitated mine lands. The research demonstrated that the linear approach to closure (i.e. extended periods of mining, limited progressive rehabilitation, completion of rehabilitation and transition to PMLUs) requires very long lead times, after which significant human, social and economic capital has likely exited the mining region.

We undertook a novel meta-study of the (mostly) grey literature, carefully curating sources including proceedings of mine closure conferences to identify potential actual and perceived barriers to PMLUs being introduced into the mining life cycle earlier than the conventional model of the status quo. Eleven barrier themes were identified for further investigation.

In the absence of empirical research upon which to examine this possible approach to mine transitions, an expert elicitation survey was chosen, based on the United States Environmental Protection Agency's (EPA's) draft Expert Elicitation Task Force White Paper (2009). This approach emphasises that, in the absence of quantitative data, seeking the views of a (preferably large) group of subject matter experts can assist in elucidating areas of consensus and differences to develop a more informed position. We canvassed the views of 54 experts in mine rehabilitation, drawn from industry, consultants and specialist non-government organisation consultants, government and academia, to identify and prioritise actual and perceived barriers to progressive rehabilitation on operational mines to accelerate transition to a post-mining land use. The registration of interested experts commenced at the Mine Closure 2023 conference in Reno, Nevada, US, and this paper builds on the analysis and interpretation presented in Purtill et al. (2026) for Mine Closure 2026.

2 What actual and perceived barriers were investigated?

An extensive meta-study of the literature was undertaken to identify perceived and actual barriers to PMLUs being introduced onto operational mines. The review involved both peer-reviewed research and grey literature, given the relative paucity of published research focused on this aspect of mine transitions. The review focused on those barriers that were external to the commercial decisions of mine operators, rather than the external barriers that might thwart orderly transitions. Eleven potential barriers were identified for further elicitation and Table 1 (Purtill et al. 2026) provides a summary of the eleven barriers investigated.

Table 1 Potential barriers investigated

Potential barrier	Description of each barrier provided to experts
The requirement for rehabilitated mined land to sustain a post-mining land use	Societal expectations for the rehabilitation of mined lands have evolved to include the requirement that miners identify and develop mines such that the rehabilitated lands can sustain a nominated post-mining land use(s) (e.g. Beer et al. 2022; CSIRO 2023; Keenan & Holcombe 2021)
Responsibility for health and safety	In Queensland, the site senior executive holds ultimate responsibility for the health and safety of all personnel on site. This includes potential exposure to industrial manslaughter legislation (Oliver & Whittle 2024; Roth 2024)
Rehabilitation as a 'mining activity'	In Queensland, the legislated definition of mining includes mine rehabilitation as a mining activity. Mining health and safety legislation provides some exceptions (e.g. 'pastoral activities'). Without such an exemption, post-mining land uses introduced into an operational mine would be considered a mining activity. Alternatively, post-mining land uses may be deemed inconsistent with the right to access mineral resources and thus be deemed impermissible (Minerals Council of NSW 2024; Standing Committee on State Development 2025)
Uncertainty pertaining to residual risk	Tiemann et al. (2002) state residual risk poses a 'major impediment' to relinquishment. In the context of the survey, recipients were requested to consider the issue of residual risk as it pertains to decisions to transition rehabilitated mined lands to a post-mining land use (International Network for Acid Prevention 2009; Maybee et al. 2024; Boggs et al. 2025)
Stakeholder rights and interests in the post-mining land use	The Queensland Resources Council (2020) queried the role of underlying landholders in providing consent to the post-mining land use and the potential need to amend access and compensation agreements (in their case for renewable energy projects). Native title may also be a rights-based barrier (Bainton & Holcombe 2018; Foran et al. 2022)
Local government planning approvals	In some jurisdictions, local government planning approvals for non-mining activities would need to be approved by local government in those instances (Cheshire et al. 2014; Dzakpata et al. 2021)
Uncertainty around closure acceptance criteria	Tiemann et al. (2022) cite the lack of clarity regarding acceptable closure criteria as an impediment to relinquishment. This concern may hold for decisions regarding operational sites committing to progressive rehabilitation to a post-mining land use (see also Blommerde et al. 2015; Manero et al. 2021)
Operational restrictions on third-party access	In addition to health and safety issues, logistical and operational issues such as non-operational voids used for water storage, linear infrastructure and trafficability etc. may be barriers (EY 2023)
Rehabilitated land may contain residual resource to be re-mined at a later date	Rehabilitated land may contain residual resource that could be extracted at a later date. Numerous examples of rehabilitated areas being 'dehab'd' due to commodity price changes, new winning technologies etc. may impede lands being 'given up' to a post-mining land use during operations (BHP 2018; Van der Ent et al. 2020)
Apportionment of liability regarding mixtures of activities	Should post-mining land uses introduce additional environmental impacts, or rehabilitated lands retain some residual liability for the miner, how liability is apportioned may cause barriers. This potential barrier is not that which is negotiated commercially, but rather the views of the regulator (Bocking 2010; Maybee et al. 2014)
Limited post-mining land use options	Rehabilitated mined land may limit the range of post-mining land uses available where, for example, cover systems may be disrupted by the post-mining land use (Wilson et al. 2003; Hancock et al. 2025)

For each of these 11 barrier themes, experts were asked:

Do you perceive this to be a barrier to rehabilitated lands progressively transitioning to a post-mining land use during operations?

If so, how severe do you believe the barrier to be, and how likely is it to occur on the sites you are familiar with?

For the second question, participants were asked to rate the barrier's severity and likelihood of occurrence using Garvey & Lansdowne's risk assessment matrix (1998), a common tool in risk assessment methodologies, as follows:

- the severity of the barrier
  - a complete barrier with no envisaged path forward
  - a significant barrier that would require policy shift and legislative amendment
  - a medium barrier that would require policy shift or significant cultural, attitudinal or administrative change
  - a minor barrier that would require modest cultural, attitudinal or administrative change
  - insignificant as not a barrier in any interpretation.
- the likelihood of this barrier occurring
  - virtually certain and likely to occur > 99% of the time
  - likely to occur > 66% of the time
  - about as likely and possible to occur as not (33–66%)
  - unlikely: likely to occur < 33% of the time
  - exceptionally unlikely (likely to occur < 1% of the time).

Experts' responses were then 'bundled' into 'minor', medium' and major' consequence categories as depicted in Figure 1. Participants were then asked to provide free text responses to elaborate on their assessments of each potential barrier.

A total of 54 respondents provided whole or partially written responses to the survey, with 5 follow up interviews undertaken. Experts nominated their jurisdictions as multinational (10), Australian national (6), or state or provincial (31), with 23 Queensland focused, and the balance did not nominate. As such, much of our discussion is centred on Queensland regulation, and its relevance to other jurisdictions would benefit from a broader field of experts to test the applicability of the results in a wider context.

Participants responded to the major commodity types they worked with: all commodities (24), coal (25), base and precious metals (17), bulk commodities (9) and others (5). A total of 80 responses were recorded, given that some participants nominated a number of categories.

3 What did the experts think?

Figure 1, adapted from Purtill et al. (2026), shows the results of expert ratings of the 11 barrier themes. The likelihood and severity ratings were moderated to provide a consequence score for each. The relative size of each circle provides the relative level of consensus amongst experts – the larger the circle the more experts rating that barrier. Colours were used as a visual aid to identify the groupings of barriers in consequence ratings.

Purtill et al. (2026) discussed each of the results in detail. They also highlighted that the strong consensus that 'responsibility for health and safety was not of high consequence' was likely a result of the expert cohort being divided on the intent of this question regarding these obligations and therefore the barrier was

considered of low consequence, while others interpreted the introduction of a PMLU as the potential barrier. Further clarification would be required before dismissing this barrier as immaterial.

This paper specifically focuses on the major-consequence barrier responses and the anomalous feedback regarding mine health and safety responsibilities, and discusses how each might be better managed to deliver a more orderly pathway to transition for long-lived mining operations.

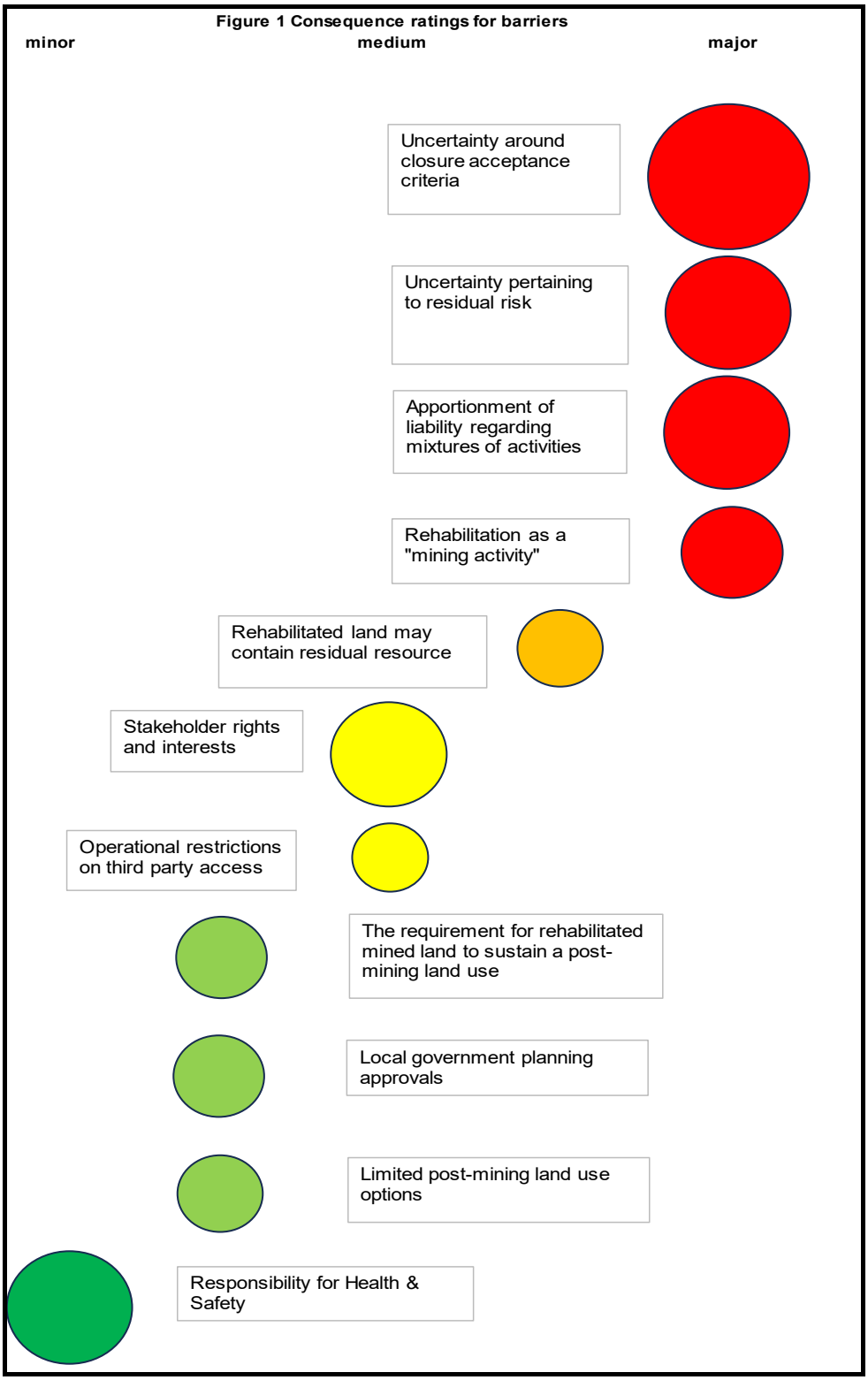

Figure 1 Consequence ratings for barriers

3.1 Barrier 1 – Uncertainty around closure acceptance criteria

> *'Setting clear and measurable closure criteria can be surprisingly difficult. In the absence of such criteria, it is difficult to obtain regulatory certification that all closure goals have been achieved with the potential to delay the transition to post-closure land uses.' (Industry expert response)*

In Queensland, Australia, for example, miners are required to rehabilitate mined land to a condition that is safe for humans and wildlife, geotechnically and geochemically stable, non-polluting and able to sustain a post-mining land use [s111A *Environmental Protection Act 1994* (EP Act)].

Each of these criteria in its own right has inherent challenges. For example, a waste rock dump must be geotechnically stable. However, how long that 'stability' must persist remains contested. As a case in point, capping for the waste returned to the pit at the Ranger uranium mine in the Northern Territory, Australia, is required to cover hostile materials for 10,000 years (Commonwealth of Australia 1999). Were the regulator to prescribe measurable criteria for this stability, it likely would fall foul of the site-specific idiosyncrasies of each mine.

The requirement for mined land to sustain a PMLU stretches the remit of the EP Act even further. To achieve an approved life of mine plan for Queensland's 200 largest operations, miners must nominate their PMLUs as part of those closure acceptance criteria. The Utah Mining Company commenced Blackwater mine operations in Queensland in 1967 (Whitehaven Coal n.d.). Blackwater's progressive rehabilitation and closure plan application (p.32) proposes mining to continue until 2113. Had Utah Mining been required to articulate the PMLU almost 150 years into the future, such a requirement is self-evidently challenging and practically meaningless. It is therefore of little surprise that the vast majority of nominated PMLUs to date consist of returning mined lands to grazing or native ecosystems; relatively simple land use outcomes but with limited economic value.

3.2 Barrier 2 – Uncertainty pertaining to residual risk

> *'…residual risks are the remaining risks once controllable and known mitigatable [sic] risks have been mitigated or managed.' (Anderson 2026)*

While residual risk specifically pertains to post-closure transfer, the 'spectre' of uncertainty regarding any PMLU introduced earlier in the mine life cycle may influence any decision to support earlier transitions. While not specifically tested with experts, the uncertainty of how residual risk would be considered before landforms had demonstrated sufficient stability to be surrendered may also impact on residual risk as a barrier. Introducing PMLUs onto land that has not achieved a stable equilibrium may ignore the technical risks involved. The difficulty in apportioning residual risk is considered under barrier 3.

The Saskatchewan (Canada) Government's Institutional Control Program (ICP) is a leading example of a provincial government establishing a clear policy framework for the relinquishment of responsibilities for rehabilitated mine lands. The 2025 register records 50 individual sites enrolled on the ICP program. These consist of a small number of mines with associated satellite deposits and ancillary infrastructure areas, some of which had not hosted mining, which have been successfully returned to the province under the ICP. Two funds established hold a modest capital base. One of these funds, the Unforeseen Events Fund, is tantamount to a residual risk fund, and held CAD 381,500 in 2024 (Ministry of Energy and Resources 2024)

In 2018 the Queensland Government released its discussion paper Managing Residual Risks in Queensland (Queensland Government 2018). Figure 2 reproduces the residual risk model depicted in that paper.

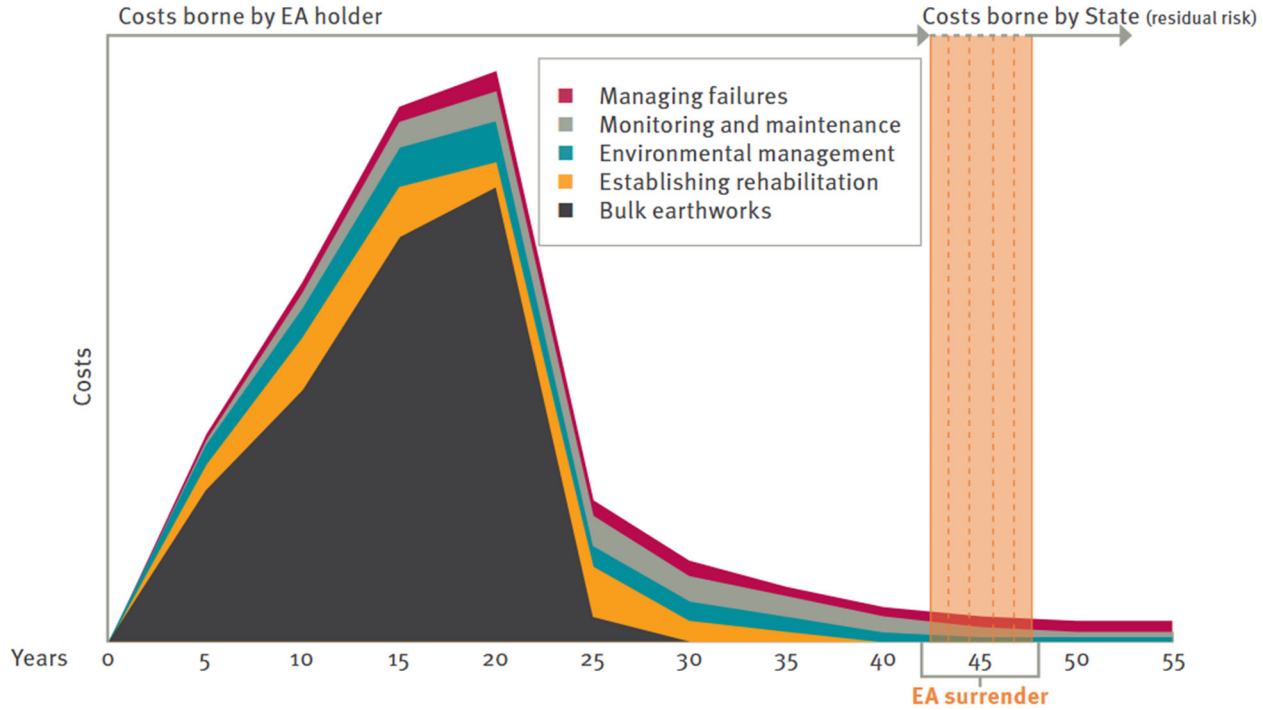

Figure 2 Residual risk model (Queensland Government 2018)

The model proposed that the residual risk payment required paying to the government would be nominal, given the rehabilitation work required to meet closure acceptance criteria would require all but the most rudimentary ongoing maintenance to be provisioned for. Erroneously, the model also suggested that ongoing costs would be borne by the state – residual risk payments are designed to ensure the costs are borne by the industry.

Queensland developed a residual risk cost calculator in 2019 (Cramer et al. 2023) and published an interim guideline in 2020 (Queensland Government 2022). The Queensland Government has recommenced stakeholder consultation on a potential release of the calculator, likely to occur before Mine Closure 2026 is convened. Some preliminary estimates of residual risk payments suggest that the envisaged nominal costs will be more substantial. A large residual risk payment may prompt miners to hold exhausted assets.

Successful transitioning of residual risk requires the ability to partition residual risks not only by domain but by post-mining land use. This requires a clear understanding of not only the nature and magnitude of residual risks, but also where the liability must be shared and the principles for partitioning these risks appropriately. The principles of risk partitioning are unclear, resulting in a significant stumbling block in the Australian context (Anderson 2026).

3.3 Barrier 3 – Apportionment of liability regarding mixtures of activities

The introduction of non-mining uses onto operational sites brings a variety of risks.

The responsibility for site health and safety (H&S) was canvassed as a separate barrier and is discussed in more detail below. However, H&S responsibilities and the assignment of a locus of control for site safety are among the concerns regarding how liability is allocated. The second area of liability risk lies in the environmental impacts of site activities. For example, how a secondary processing operation on a non-operational tailings storage facility may create new environmental impacts were of concern to respondents. This is despite numerous examples of commercial arrangements for waste disposal or tolling of product through joint-user facilities being routinely agreed upon by parties.

Overall, experts strongly agreed that how liabilities were to be apportioned could be a barrier to the PMLUs transitioning onto operational mines. While some precedents exist, such as the Good Samaritan laws in the US (United States of America 2024), they are restricted to abandoned mines and only 15 sites are permitted

during the 5-year trial period, which is designed to assess the efficacy of the program prior to wider implementation.

3.4 Barrier 4 – Rehabilitation as a 'mining activity'

Definitions of what constitutes a mining activity were considered by the expert cohort to be of high consequence. In Queensland, regardless of the underlying tenure, mine land rehabilitation remains under the auspices of Resources Safety and Health Queensland (RSHQ) (CEO RSHQ pers. comm.). The standards applied to the hazardous activities associated with mining may not sit comfortably on more benign non-mining land uses introduced onto operational mines. While areas can be annexed from the locus of control of the mine operator, there are cultural dimensions for large corporations allowing relatively smaller entities onto sites, risking safety incidents which may reflect back on the miner. In short, there is little incentive to host these activities, from a commercial or business risk perspective.

3.5 Barrier 5 – Resources industry standards of safety as a barrier

Five follow up interviews were held with experts to discuss results in greater depth. Of particular interest were the responses to the H&S-related barrier question. Despite sources supporting a concern that the responsibilities of the key management personnel for H&S (in Queensland, the senior site executive) may view non-mining activities as a barrier, the results suggested this was lowest consequence of all 11 barriers proffered. Unfortunately, experts interpreted the question differently. The intent of the question was to explore the concerns of the responsible officer to non-mining land uses coming under their locus of control. Many respondents interpreted the question to ask if the responsible officer was responsible for rehabilitation, which experts agreed was a legal requirement and therefore of little consequence as a barrier. Any supplementary research in this field would benefit from a re-caste question more explicitly outlining that the potential barrier is the responsibility for a non-mining activity being captured within the locus of control of a mining safety officer, who may not have the expertise to supervise those non-mining activities..

Remaining barriers were deemed of medium or low consequence and most had little unanimity across the expert cohort. One exception was any concern with stakeholders' rights and interests being of medium consequence, but with relatively strong alignment across the cohort. Follow up interviews suggested experts regard stakeholder views to be an essential component of good quality transitions to PMLUs.

4 Discussion

There is a fundamental shift globally in mine closure from a focus on simple rehabilitation ('make good') towards identifying and unlocking 'beneficial' values in post-mining landscapes (Measham et al. 2024).

The difficulty in successfully transitioning a complex, multidecadal mine to a beneficial post-mining land use prompted us to explore how PMLUs might transition to their post-mining land use earlier in the mine life cycle. Particularly for open cut coal mines and other shallow-mined bulk commodities such as bauxite, mineral sands and phosphate, non-operational areas lend themselves to an earlier transition. However, resource allocation and environmental regulations have not been designed for these transitions. The focus of regulation historically has been the efficient extraction of resources while minimising environmental harm. Regulators are now expecting mines to deliver sustainable post-mining land uses, bringing with it a recognition of the spatial complexity of mined land and assets and their temporal dynamics in the context of different post-mining land use transitions. A gap exists between regulatory expectations and the demonstrated performance of the industry to date. Without a 'circuit-breaker' such as transitioning PMLUs onto operational mines, mine lands will remain quarantined from beneficial economic opportunities for many years after mining has ceased.

The expert elicitation survey described in Purtill et al. (2026) is a modest early step to better understanding what barriers may impede a more orderly transition. Here we outline some preliminary thoughts on how some of the more consequential barriers as opined by experts may be reformed to better enable mines to successfully transition to sustainable PMLUs.

Conceptually, there is a compelling rationale from industry that the acceptable criteria that must be met for successful surrender of resource authorities be explicitly stated by the regulator. In Queensland, for example, the requirement for mined land to be rendered safe, stable, non-polluting and able to sustain a PMLU is seemingly straightforward. However, nuanced discussions around safety, stability and duration remain missing. Given the expense of land rehabilitation, rehabilitating to an end point that is no longer acceptable to the regulator is an existential risk. Conversely, the argument can be readily surmised to be an excuse for inaction. More explicit regulatory prescriptions may stifle innovation. Articulating clear closure acceptance criteria beyond the conceptual remains a wicked problem. Possibly an alternative approach, whereby the negotiated closure criteria are made transparent and there is an ability to pivot should emerging issues arise, may help better manage the problem. Whether the community (either locally or at large) has sufficient trust in the industry to allow such a process remains open to debate.

Transitioning a PMLU onto mine lands prior to complete surrender and 'full' rehabilitation introduces more risk to the miner and to the PMLU proponent than no PMLU occurring on site at all. However, if we don't find a 'circuit-breaker', jurisdictions may perpetuate the boom and bust nature of mining. Few, if any, examples of early transitions exist and few complex mines have been successfully surrendered. While the physical disturbance area of the industry is relatively small, the significant capital investment in infrastructure by the resources industry may be laid waste if new ways to utilise that infrastructure are not found.

Jurisdiction over resources is the sole remit of states in Australia. The federal government has little involvement apart from pre-competitive geoscience, marketing and offshore/territorial areas. However, the federal government can play a substantive role. Federal entities such as the Net Zero Economy Authority and the Australian Renewable Energy Authority, for example, could partially or completely underwrite the financial assurance and residual risk payments of the PMLU entity coming onto mine lands. Criteria could be established such that the PMLUs accredited were of strategic importance to the nation as a whole, such as renewable energy, storage systems, and research and manufacturing facilities. If mechanisms to better manage both the apportionment of liability and the cost of residual risks can be found, more orderly transitions may ensue.

Restrictions imposed to ensure the safe and efficient extraction of mineral resources are a necessary and desirable element of the resource industry. As we expand the ambition of what is expected of an exhausted mine and seek new ways to evolve sites to a PMLU and effectively utilise the power, telecommunications, water, transport and other infrastructure invested in these sites, our definition of mining activities needs to change. Already we see innovative tenure arrangements emerging. In Western Australia, the Diversification Lease has been introduced to allow new activities on the large proportion of the state under Crown lease. In Queensland, the government has committed to developing a new mineral reprocessing tenure. There is potential for new tenure systems or new regulatory settings that allow a civil works approach to activities that are no longer associated with mining other than being located on an active mining operation.

Conclusion

This qualitative meta-study, using an expert elicitation process, was an initial investigation into 11 potential barriers to post-mining land uses (PMLUs) being introduced onto operating mines. The study did not attempt to investigate the barriers that may exist within companies' corporate decision-making, but rather the externalities that might work against the orderly introduction of PMLUs. The need for earlier introduction of PMLUs is prompted by the global paucity of successful mine transitions on complex mines in the absence of large externally funded subsidies, and the very long lead times between the cessation of mining and surrender of licences, if at all.

The results of this study provide a basis for wider exposition of factors creating inertia in the mine transition process. They also provide a useful starting point to explore opportunities for public policy reform, where governance arrangements can be adjusted to respond to the emerging need to drive non-mining futures for resource communities as they evolve from operational mining.

Industry and regulators must find common ground to address these barriers if society demands that mine lands be sufficiently and safely rehabilitated to not only ensure geochemical and geotechnical stability but also to host new, non-mining uses. The sector must also recognise the roles of third parties, including rights holders or key parties interested in further developing post-mining land uses. Presuming a key objective is to sustain economic opportunities for resource communities beyond mining itself, then greater clarity on closure criteria, apportionment of liability between parties, provisioning for residual risks and identification of when rehabilitation activities are no longer constrained by mining industry standards will enable a more meaningful conversation on the timing of PMLUs on operational mines. The pathway to better management of post-mining futures must ensure all parties that benefit from resource extraction play their role. Ultimately, however, industry and governments are the key players. Whichever pathways are ultimately chosen for individual sites or jurisdictions, the impacts of resource extraction must be funded by the industry; however, the long-term post-mining land use management must transfer to other parties at some realisable point in time.

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