

Transformation for positive post mine futures

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Abstract

In 2020, we established the Cooperative Research Centre for Transformations in Mining Economies. Our CRC seeks reposition closure as a valued cornerstone for post mine economies and the mining industry, building enduring benefit for all Australians. We bring together over 70 partners from across diverse stakeholder groups to help reimagine and dramatically transform Australian mine closure outcomes. In the first two years of operation, we invested AUD 4.9M in 22 foundational projects to explore these themes, identify key barriers to success and identify points at which to focus to achieve change. This paper explores various themes and opportunities for change identified by this foundational research.

We need new frames and tools that can integrate repurposing opportunities at an individual site and integrate planning at regional scales to deliver net benefits beyond the mine (considering both towns and the broader regions in transition).

We recognise this requires the mining industry and governments to connect with sectors driving post mine development, from conservation to tourism, agriculture and energy and the critical role First Nations people play in land stewardship. This is why our aim is to work with stakeholders to help define a new vision and measures success in mine closure and post mine transitions.

Without a new-shared understanding of success, we will continue to see opportunities missed and conflicts emerge – undermining the sector, policy and improved outcomes. Australia is incredibly fortunate to have an environment in which diverse stakeholders can come together and explore solutions. A program such as the Australian Governments Cooperative Research Centre Program that can enable this to occur.

Of course, a new definition of success has significant implications for how we plan, execute and regulate mines as well as broader community and regional planning and development. The CRC is working with our partners to identify, develop and share new ways to incorporate short and long-term, tangible and intangible risk and opportunities in decision-making. This will help deliver increased confidence in the forecast and prediction of residual risk and decisions are made before a mine starts and through out its life, better positioning for a positive post mine transition. This brings important consideration of how all stakeholders consider mine closure through a ‘whole of government’ lens. The CRC is fortunate to be working with policy makers from across government portfolios and multiple national jurisdictions to inform new frameworks and standards that can enable these transitions.

Another piece of the puzzle is driving innovation in our technology to ensure we have capability to execute these visions. We need to re-frame and ensure our focus on technology directly addresses the key areas of risk and opportunity identified to in the delivery of new models for success in post mine transitions. This requires integration of water, landform and ecosystem design tools, delivery mechanisms that are cost-effective, scaleable and fit for purpose and takes advantage of remote monitoring technologies that identify progress and inform future trajectories. With a mine closure ‘boom’ forecast over coming decades, the CRC platform will enable piloting and commercialisation of these technologies will ensure Australia’s mining equipment, technology and services supply chains are ready to meet domestic needs and positioned to capitalise on an emerging global marketplace.

Keywords: *mine closure, post mine transitions, policy, repurposing, regional planning, technological innovation, CRC TiME*

1 Introduction

Mining resources continues to be an important global economic activity, providing the materials required for the products underpinning modern life while also driving industry, employment and investment. However, thousands of mines around the world will cease production over the coming decade and many will close. The end of the mine lifecycle has to date, been considerably less scrutinised by industry, regulators and investors. It currently offers little in the way of return on investment and in many cases, considerable direct and indirect costs as mining companies and investors withdraw from mine sites and turn their attention to the next prospective venture. Globally, landscapes are littered with abandoned mines and unusable land due to poor or no mine rehabilitation. Enabling mine closure and relinquishment is a national priority for the resource sector and regional communities, with over 4,000 operating mines in Australia, 400 due to close in the next decade. However, there are few examples of successfully relinquished mines. At the same time, growing demand for the minerals required for ongoing human development as well as decarbonisation will lead the development of new operations – each with mine closure regulatory conditions to be established.

While social license have long been recognised as important, recent challenges experienced by the sector, coupled with broader social and investor expectations regarding environmental, social and governance (ESG) - indicate these could be some of the most significant business risks companies' face (EY 2022). Public confidence in the ability to minimise the net social and environment impact and deliver enduring value is critical. Confidence in the ability to close, relinquish and transition mines and their communities is central to social license.

What's more, this is having broad effects: ESG considerations are increasingly a focus of investors in the sector and our ability to recruit the next generation depends on sustainability credibility. Transforming the sector to one that not only generates wealth during the operating life of a mine but one that leaves a positive legacy will be critical in attracting and building the workforce of the future.

Australia has experienced a mining boom and it is inevitable that this will be followed by an increase in the numbers of mines going through closure over coming decades. While many new mines are likely to come onto market, addressing the challenges of mine closures creates significant opportunity for innovation and an expanded view of how we conceptualise the mine closure supply and value chains.

While mine rehabilitation is not a new topic, it is one that is usually underpinned by a shared belief that after a mine finishes, it should be returned to a state that closely resembles what was there before. This belief has underpinned public policy development, mine planning and associated investment through the life-of-mine and has become tightly connected to community's social license for the sector. This approach fails to recognise that as mines develop, they build infrastructure, capability and assets and radically change and become part of a broader region. If we are to change from this 'single path', we will need a new way of thinking and ensure we have the skills, knowledge, technology, business settings and policy environment that will best enable a new vision of success in mine rehabilitation and closure. Globally, society is demanding that the mine lifecycle and its attendant assets, including land, water, people and the communities nearby, are properly valued from beginning to end of the cycle and appropriately prepared for other, sustainable post-mining uses (International Council on Mining and Metals [ICMM] 2019; Minerals Council of Australia 2018; OECD 2022).

In 2020, the Cooperative Research Centre for Transformation in Mining Economies (CRC TiME) was formed to support a step change over the coming decade in mine closure and post mine transitions that will deliver enduring value. Australia's unique, government funded Cooperative Research Centre Program, provides the framework and governance model that brings shared financial and human resources together to transform and fast track innovation. It provides and is a valuable platform to drive transformation in this multi-layered, socially, environmentally and technically complex mine closure and post-mining sector.

In the first two years of the CRCs operation, we invested \$4.9M of these resources into 22 foundational projects that explored key areas for innovation across CRC TiMEs key focus areas in regional economic development, risk, valuation and decisions, operational solutions and data and knowledge integration. This paper will explore the key drivers underpinning the next decade of transformation in mining economies towards positive closure and post mine transitions and highlight key findings from the CRC TiME Foundation Portfolio.

2 About CRC TiME

The Cooperative Research Centre for Transformations in Mining Economies (CRC TiME) is an Australian consortium for undertaking a globally leading research and impact agenda. Our investments will provide the evidence base, tools and connections to enable industry, governments and communities to work together to improve post-mining outcomes.

It commenced in mid-2020 with a total 10-year investment of about AUD 130M and brings together over 70 leading mining and mining service companies, regional development organisations, government departments and research partners (CRC TiME 2022).

CRC TiME provides a platform that is independent, collaborative, solutions focused and brings together a unique partnership of stakeholders required to inform, deliver and use innovative solutions to achieve enduring value through mine closure and post mine transitions. The governance, management, planning, and investment structures established within CRC TiME have been established with this one purpose in mind and form the start of a decade of innovative transformation. CRC TiME will deliver a transdisciplinary and collaborative research program that will address eight research priorities (Figure 1).

CRC TiME's vision, mission and goals are:

Our Vision: Closure as a valued cornerstone for post mine economies and the mining industry, building enduring benefit for all Australians.

Our Mission: Bring together diverse stakeholders to help reimagine and dramatically transform Australian mine closure outcomes.

Our Strategic Goals:

- Comprehensively broadened approach to the mining cycle.
- Access to new commercial opportunities.
- Thriving and resilient regions and natural systems.
- Diversified and more equitable post-mining economies.
- Continued investment in Australian resources.
- Increased certainty for all stakeholders.
- Fewer abandoned sites.

CRC TiME will achieve this vision by working with our partners to invest in activities that generate new knowledge and understanding, build enabling platforms, create scaleable and business ready technology and support the education and training of the new workforce required to create change.

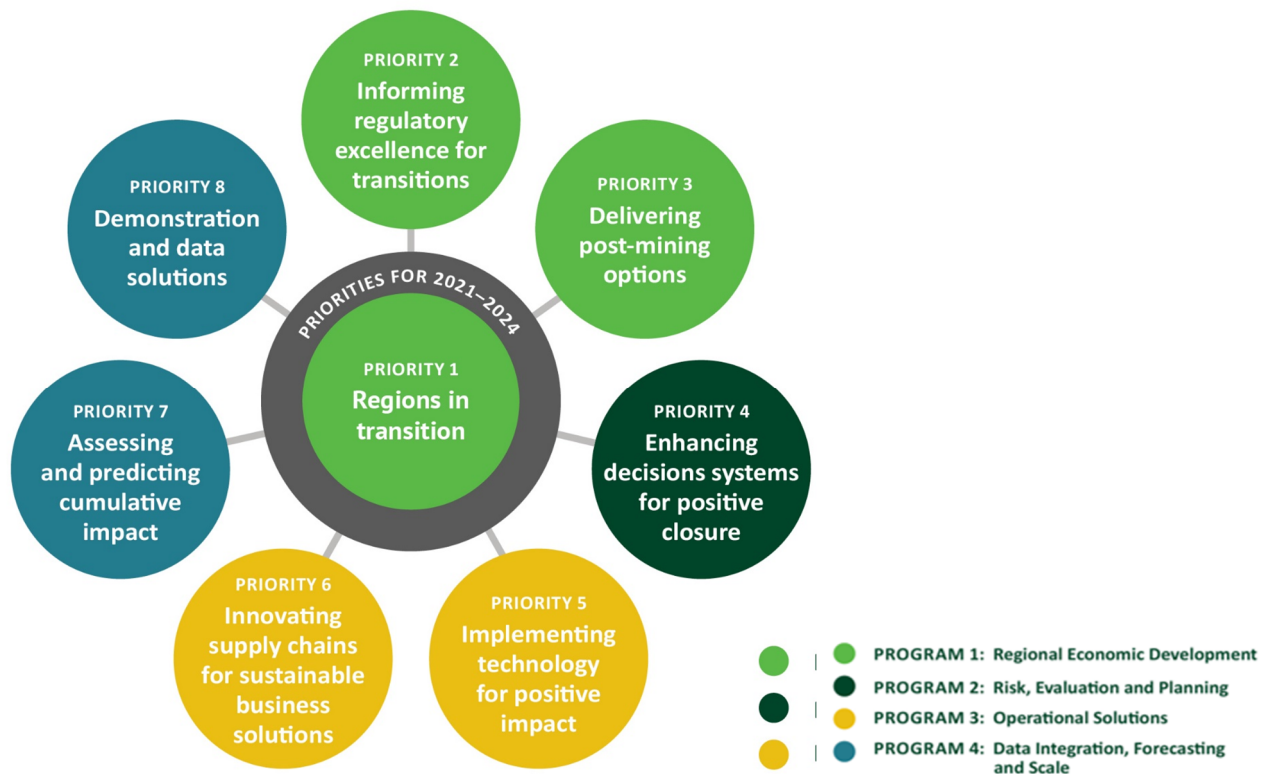


Figure 1 CRC TiME Research Priorities (CRC TiME 2021)

3 Towards 2030 and the decade of transformation

A question that has been asked frequently since we began the journey to form our organisation ‘is why now’? Mine rehabilitation is not a new concept, with many decades of research and work across industry and government to ensure landscapes are left in safe, stable, non-polluting and self-sustaining manner. At the same time, we see little evidence of successful mine closure, relinquishment and post mine transitions at a National and Global scale. The decade ahead will see transformation across the sector with a number of key global and local drivers of this change emerging over recent years.

Growing investment trends are driving transformation in ESG and demands for projects that demonstrate value additional to simple measures of return on investment. Since 2012, there has been an exponential increase in sustainable investment. The US SIF Foundation's Report on US Sustainable and Impact Investing Trends identified \$17.1 trillion in total assets under management at the end of 2019 using one or more sustainable investing strategies, a 42 percent increase from the \$12.0 trillion identified two years prior. This is underpinning a rapid increase in the level of accountability tied with what have traditionally hard to quantify or monitor environment, social and governance factors. Critically, this is also seeing major investors coming together to develop and agree on frameworks to be used across industry, such as the recently released beta version of Taskforce of Nature Related Risk and Opportunity Management and Disclosure Framework. This will drive sector wide transformation.

In Australia, and other jurisdictions such as Canada, the mining sector is maturing and bringing a degree of focus to mine closure as more mines approach end of life. The University of Queensland has brought together data from the S&P Global Market Intelligence database (<https://www.spglobal.com/marketintelligence/en/>) to map expected mine closures over coming decades. This indicates more than 400 will occur over the next decade and this will only increase with time. The scale of closures occurring over the next decade are also larger than many before, with a number of projects going through closure over the coming decade expected to cost over \$1B bring the realities and true cost of closure and post mine transitions to the fore for many companies and their shareholders.

Community expectations for the sector continue to grow. The 2022 EY top business risks and opportunities for mining and metals identified environment and social issues, decarbonisation and social license as their top three risks. The legacy of mining and community consideration of the whole of life risks and benefits of a project are critical to retaining support for the industry. As we move into another growth phase for the sector, new projects are being asked to demonstrate how they will deliver a net-positive legacy and ensure this is integrated into decisions made across the life of the mine.

At the same, a new wave of projects is expected to meet increasing demand for minerals underpinning ongoing industrialisation and improved living standards. This will be buoyed by significant demand for critical and other minerals required to enable decarbonisation. With foundational mine closure planning required to be undertaken before a project is given regulatory approval, future options for post-mining land use and economies in these areas will also likely be shaped in the near term.

The massive consequences of information and communication technology on our lives is not yet fully understood. Automation, machine learning and digital communications continue to increase productivity and efficiency in the way we work and affect the nature of jobs and skills. This will change how we mine and manage the risk and opportunities associated with mine closure. Less known are the long-term consequences of digitally enabled relationships on culture and the nature of family, conflict, and the political economy. These issues will affect the manner in which people can participate economically in post-mining land use, the skills required to participate and the aspirations of the regional communities and First Nations communities looking to make their future on the formerly mined land.

Finally, circular economy concepts have led to a massive focus on technology and supply chain innovation that re-use and re-purpose waste products and the continual safe use of natural resources. According to the World Economic Forum, the circular economy can yield up to \$4.5 trillion in economic benefits to 2030 (World Economic Forum 2022). Combined with the decarbonisation agenda and drive to net zero, these concepts are changing how waste is managed through the mine life and mining assets at closure are being viewed through a lens of their potential value. This challenges the long standing notion that return to pre-existing state is the most valued outcome for closing mines and as we broaden our concepts of value, is demanding the examination of all assets at closure (land, community and infrastructure).

4 Building foundations for the transformation

Over the first 18 months of CRC TiME, a portfolio of foundational projects was established to identify the gaps and barriers for orderly mine closure and relinquishment and the enablers for ongoing regional development. The portfolio represented a \$4.9M investment in 22 projects that had been scoped through a six month consultation process across the CRC partnership. The projects involved over 400 people directly in their delivery and governance structure. The portfolio projects were highly connected and recognised the challenge of mine closure and post mine transitions as a complex issue. The role of these projects was:

- Baselining and benchmarking the current state of knowledge.
- Sharing data and knowledge from existing initiatives with partners.
- Roadmapping gaps, priorities and future research directions.
- Short-term field or modelling studies as driven by end-users.
- Establishing collaborative infrastructure to underpin future use within CRC TiME.

They have also been identified as critical topics for enabling the CRC to move beyond business as usual considerations in its long-term research strategy and informing the development of a high impact organisation. The projects were structured into five theme areas including regional economic development, risk, evaluation and planning, operational solutions, collaborative infrastructure and strategy solutions (Table 1).

Table 1 CRC TiME Foundation Project portfolio

Theme area	ID	Research project
Regional economic development Over the next 25 years 50% of Australia's mines are expected to close and a stream of post mine land use transitions are proposed. These mine closures and potential transitions will have major environmental, economic, and social impacts, particularly in regional and Indigenous communities where mining activities have been dominant. This research program seeks to optimise the regional economic development potential of the relinquished mining assets through prescient planning and the harnessing of local knowledge.	1.1	Towards a framework for cumulative regional impact assessment (Sinclair et al. 2022)
	1.2	Post-mining land use (Beer et al. 2022)
	1.3	Mapping the regulation of mine closure (Hamblin et al. 2022)
Risk, evaluation and planning The risk, evaluation and planning program is to carefully examine the assumption that mine closure planning is not sufficiently well connected to operational activity to promote effective mine closure and relinquishment. This requires understanding how decisions are made in the face of uncertainties that can be spread over long timelines. The post mine land use options and the necessary steps to achieve a shared understanding of how the transition from mining to other uses can be achieved and implemented will be interrogated.	2.1	Understanding stakeholder values in post-mining economies (Foran et al. 2022)
	2.2	Exploring the issues in mine closure planning (Dzakupata et al. 2021)
	2.3	Current tools, techniques and gaps in evaluating mine closure (Lilford et al. 2022)
	2.4	Quantifying risks and opportunities from mine closure (Holloway 2023)
Operational solutions The foundation projects in the Operational Solutions program are enabling CRC TiME to move beyond 'business as usual' research on individual topics. There is an extensive knowledge base and leading practice in issues such as tailings, landform stability and water management. CRC TiME is aiming to transform practice by looking at operations, closure and post-closure as an integrated system.	3.1	Integration of biophysical aspects of mine closure planning (Cote et al. 2022)
	3.2	Transforming disparate approaches to remote sensing and monitoring to industry best practice (Hernandez Santin et al. 2022)
	3.3	Mine site water: options for extracting value from open pits (Cook et al. 2022)
	3.4	Returning ecosystem resilience
	3.5	Mined landform stability for regional benefit (Williams et al. 2022)
	3.6	Barriers to reducing acid and metalliferous drainage (AMD) risk (Singh et al. 2022)
	3.7	Comparative Closure: assessing the biophysical closure challenges of different mining methods (Sellers et al. 2022)
Collaborative infrastructure The projects within the collaborative infrastructure program are developing the platforms for CRC TiME as it develops research over 10 years. The focus is on establishing systems for capturing and networking the knowledge, data and site assets available to CRC partners including: a network of demonstration sites (both operational and abandoned); a knowledge and data hub; and a one stop shop portal into available material on different aspects of the post-closure transition.	4.1	Dynamically transforming environmental assessment through a shared analytics framework (Cote et al. 2022)
	4.2	Mine Rehabilitation Trials Online (MRTO)
	4.3	Network of demonstration and testing sites (Bekele & Davis 2021)
	4.4	CRC TiME Knowledge Hub (e-library) (Desai et al. 2022)
	4.5	Abandoned mines in Australia (Salmi et al. 2022)
Strategy solutions Some challenge areas are critical right across the CRC TiME portfolio. Theses strategic themes are explored through strategy solution projects, ensuring programs are connecting with whole of industry challenges and opportunities, and informing development of the CRCs long-term strategy.	5.1	Defining our path to impact (Foran & Yuen 2021)
	5.2	Foundations for Indigenous inclusion (Miller-Sabbioni et al. 2022)
	5.3	Transitions and climate change (Maher et al. 2022)

5 What did we learn?

5.1 Key areas for policy innovation for transitions

Currently in Australia, there are no single legislative or regulatory frameworks that specifically address mine repurposing or relinquishment. The CRC TiME Foundation Project review, limited to law and policy that directly examines mine closure in three Australian state jurisdictions (Western Australia, Victoria and Queensland), showed that mining and environmental laws intersect not only with water resources and land use planning laws, but also with a diverse cross-section of native title, heritage, corporate, tax, health, labour relations, and local government legislation, among others (Hamblin et al. 2022). Mine rehabilitation and closure are also inevitably affected by extra-legal influences, both national and international, including a growing role for international soft law standards adopted by the mining industry; for example, the ICMM and IGF.

One of the key challenges identified from the research was the inconsistent definitions and usages of several core concepts that are central to the discussion of mine closure. For example, ‘rehabilitation’, ‘restoration’, ‘remediation’, ‘relinquishment’ and ‘residual risk’ are not used consistently in legislation and in some industry and government commentary and grey literature. Consistency in meaning and use of these definitions and concepts across all Australian jurisdictions would assist in improving mine closure outcomes. The research also found that, similarly, the terminology applied to various forms of resource tenures and regulatory authorisations should be consistent to more effectively implement core legal concepts for mine closure. Critically for CRC TiME’s vision, the report indicates a recognition of evolving concepts of ‘transformation and transition’ associated with the environmental, economic and social changes effected through mine closure. These provide the context for two significant new concepts that have arisen but lack clear regulatory guidance: *repurposing* of mine assets and land forms and social transitions in communities where mine closure greatly impacts levels and types of employment opportunities and social services.

Critical to these concepts of positive post mine transition is the integration of stakeholder views and re-framing of goals for ‘success’ in mine closure. In particular, the research found that while all three states examined are developing principles of progressive rehabilitation and closure of mines and securing financial provisioning to ensure effective mine closure, reform could seek to ascertain what importance lies in the clear statutory expression of goals pertaining to mine closure. The reports also highlighted the robustness and clarity of opportunities for community engagement and influence in the mine closure process vary across states, particularly where some states relegate community engagement to lease holder responsibility with merely bureaucratic oversight. One of the goals of CRC TiME is to work with stakeholders towards developing a National Framework to support best practice across jurisdictions.

Finally, there is a gap in the explicit legislative framework for repurposing of mining assets in the transition to closure and tenure relinquishment. For example, the Victorian provisions use only the language of land rehabilitation whereas the Queensland provisions contemplate outcomes that are consistent with land use planning schemes, which arguably provide more legal room for repurposing solutions. However, the legislation and guidelines are generally quiet on the terms for repurposing, perhaps because those ideas have emerged more lately in the mine closure conversation and are acted on more in the latter stages of operations, closure and rehabilitation. Western Australia on the other hand has some specific procedures, spelled out in statutory and non-statutory guidelines, but their efficacy has been queried due to high levels of uncertainty for industry, community and even government, with gaps and ill-defined authority for implementation (Hamblin et al. 2022).

5.2 Moving from site to regional scale assessment

Mine closures and regional transitions to post-mining economies have major environmental, economic, and social impacts, particularly in rural and First Nation communities. Despite recognition of the need for coordinated, regional scale approaches to the assessment and management of the cumulative impacts of mine closure, the Foundation Project report by Sinclair et al. (2022) found there is little in the way of

frameworks or guidance for this purpose. There is, however, considerable guidance on cumulative impact assessment and management more generally, as well as literature and guidance on regional planning and other related topics.

The cumulative impacts of mining and mine closure are the aggregated impacts from multiple developments often with different and sometimes competing owners, over time in a particular place or region (Sinclair et al. 2022). Cumulative impacts are described by Franks et al. (2010, p.1) as:

“The successive, incremental and combined impacts (both positive and negative) of an activity on society, the economy and the environment. They can arise from the compounding activities of a single operation or multiple mining and processing operations, as well as the interaction of mining impacts with other past, current and future activities that may not be related to mining.”

They may create both opportunities and limitations for future land use and development pathways. However, despite advances in regulation, technology, and methodologies for assessing cumulative impacts across Australian and International jurisdictions, there is no consistent, comprehensive framework or guidance for cumulative impact assessment (CIA) for mine closure at regional scales. It is now widely understood that post-closure environmental legacy issues requiring management are more complex than simply onsite soil stabilisation and rehabilitation of vegetation (Atlin & Gibson 2017; Unger et al. 2020). Current approaches to CIA mainly focus on either the project-proposal and environmental approval stage of mining, or on managing the cumulative impacts of specific industries (see for example: Franks et al. 2010).

Mine closure is a critical juncture for accurate and comprehensive CIA to be in place in order to manage and mitigate both the legacy impacts of the mining operations and the impacts of the process of closure itself or for planning next uses of the land. Arguably this may be the longest and most complex phase in the mining lifecycle (Beckett et al. 2020). The complexity is magnified when numerous mines within a region close, with associated cumulative impacts on the economy and social fabric of the region, underscoring the need for consistent frameworks and methodologies for managing the cumulative impacts of mine closure at a regional scale.

Perhaps most pressing in the Australian context is the paucity of documented cumulative impacts from mining on the Australian First Nations landholders and communities. Cultural dissonance can be exacerbated by the standard impact assessment approach, which is to commission separate studies of the environmental, social and economic components. This is a false demarcation for Indigenous groups, as they experience these components as an intersecting whole. The notion of ‘Country’ for Australian Aboriginal people is more than simply a geographical area and instead, can be understood as a “shorthand for all of the values, places, resources, stories and cultural obligations associated with a geographical area” (Smyth 1994 in Russell et al. 2020, p.4). Indigenous Land Use Agreements and Cultural Management Plans, which are usually part of the environmental and impact assessment process at the commencement of a project, are an opportunity for Indigenous group and knowledge holders to have input regarding predictive impacts however their level of ongoing importance can be diminished by inadequate or weak regulatory and policy frameworks. However, there increasingly resources, including Healthy Country Plans and cultural mapping technologies that can be harnessed for CIA.

5.3 Transitioning to post mine land uses

The transformation we wish to see is to deliver value through the mine closure process. The recognition of the process as a transition rather than closure as a single end point is critical to this. For a transition to occur, significant emphasis must be placed on the post mine stakeholders concepts of value. This moves the conversation from one focused solely on asset relinquishment to one driven by concepts of asset acquisition. Creating valued post mine land uses is important in this narrative, and several case study sites were examined by Beer et al. (2022) to identify barriers and enablers for that affect transition.

The lack of clarity of process and the piecemeal approach to the repurposing of mines suggests that each example of mine repurposing has been dealt with as a unique, ‘one off’ project, with consequent significant implementation costs. Not surprisingly, given the evidence outlined regarding the varied and variable government regulatory arrangements across Australia, which focus on harm minimisation and environmental rehabilitation, the importance of leadership, geography (local and regional nuances, place, people and time) and alternative market opportunities are minimised.

Importantly, in many developed economies the pathway to mine re-use is both time consuming and potentially influenced by a substantial number of hurdles. Essentially for a mine to be repurposed, the site needs to pass through a number of gateways all of which may undermine the viability of the proposed re-use. These barriers include regulations that may mandate particular outcomes – such as the rehabilitation rather than the re-use of sites; what is technologically feasible at this point in time; the economics of repurposing, including the possibility of needing to undertake significant remediation or reconfiguration of the site prior to re-use; and community attitudes and sentiments.

The ICMM (2019) Good Practice Guide 2nd Edition is highly influential but it is also limited by its universality and there is an inferred expectation that national, regional and local industries will adapt the guidelines to the capacities of local institutions, regulatory frameworks and expectations. To date, few, with the exception of Bainton & Holcome (2018) have integrated the community, regional and environmental perspectives.

Of the 11 mine repurposing case studies, some remain ‘works in progress’, with uncertain futures, shifting government priorities and a greater appreciation of the challenge as more becomes known in the repurposing transition process. The in-depth analysis identified a series of key enablers for repurposing:

- Community, industry, private sector, government leaders.
- Organisations and individuals acting as champions of change – often playing the most pivotal role to drive a repurposing agenda.
- Champions being able to articulate an agenda of change and positive outcomes.
- Existing infrastructure that may make otherwise impossible land uses possible.
- Collaboration across government tiers and private sector.
- Access to markets and the ability to monetise repurposing of sites within a short time frame.
- Early planning for post-mining land use.

It is critical that we move from opportunistic cases of success, and work to transform our systems in such a way that recognises, values and creates opportunities for the enablers identified above to become standard practice.

5.4 Integrating risk and evaluation into mine closure decision-making

As we move to a system that enables transitions that deliver net benefit, it will require a change in how we recognise both the tangible and intangible post-closure values, how these are integrated into annual planning cycles within our mining operations and their connection with mine closure planning processes driven through regulation. Knowledge of what people value, how these change over time and the diversity of values can assist decision-makers in producing policies that work towards delivering environmental and socio-economic outcomes that have broad acceptance (Lechner et al. 2017).

A key finding in the foundation study by Measham et al. (2022) was that changes in mining economies accompanying mine lifecycle transitions – notably mine closure – do not follow a uniform pathway. Many factors in the local context explain this variability including the social setting in which a lifecycle transition occurs as well as motivations for engaging with proposed options for post-mining economies. This is because major economic transformations require the support and active participation of stakeholders including government at different levels, trade unions, industry and business, civil society, and academia. These

different actors and social groups may hold a diversity of views about the most desirable development trajectories and transition options for mining regions. We need to develop systems able to respond to the dynamic nature of changing values for post mine transitions.

The other key finding in I wanted to highlight here was that levels of power and influence also vary considerably, meaning that some values may have a greater impact on decisions about mine rehabilitation and closure and the transition to a post-closure economy. For instance, the post-mining transitions may threaten the economic positions and business models of some stakeholders. If these are the largest and the most powerful stakeholders, they are likely to protect their vested interests and contest the need for, and speed of, transitions. As well, competing values may be resolved by win-lose compromises that favour the majority but increase the marginalisation of a minority. Hence, values often lie at the root of contestation and conflict and require understanding of power and influence (Measham et al. 2022)

Research on values conducted as part of the foundational projects emphasise the importance of place: regional contexts play an important role, such that values that underpin transition in Latrobe valley are different to those in Gove. However, it is possible to distil certain overarching themes that resonate at a higher level. One of these is that regional development outcomes should be net-positive, i.e. that positive effects of closure and transition outweigh the negative ones. To achieve such outcomes, it is crucial to focus on balance and a just distribution of responsibility between parties. A net-positive outcome is one that achieves mutually reinforcing benefits to a region and harnesses assets and opportunities while managing liabilities and risks (Foran et al. 2022).

The mine closure planning process has become the key connection point between mine operators and government regulators. We are finding that the mine closure planning process is changing to reflect a growing recognition of the dynamic nature and non-linearity of changes across the mine lifecycle. To identify the key closure planning challenges that prevent mine closure plans from being realised, the foundational study completed by Dzakpata et al. (2021) used two complex adaptive system viewpoints. What is clear from this work is that there are a number of challenges faced by both regulators and operators in the mine closure planning processes. Key from the regulators' perspective, was the diversity in regulatory focuses of main agencies, often causing lengthy processes with sometimes unconnected and complicated documentation. The lack of a consistent, clear, and unambiguous set of legal requirements, and the lack of flexibility in relation to regulatory integration and closure expectations of important stakeholders have all aggravated the situation. The study also highlighted the value of developing the regulatory knowledge base to draw on lessons learned and historic event triggers that can help determine which land use options are viable. These are key areas in which we believe the CRC can make a significant contribution.

From the mine operators' point of view, there are significant knowledge gaps for assessing (effectively and efficiently evaluating) novel alternative land uses. Historically, there have been gaps and an apparent lack of knowledge base that offers the mine operator a clear, concise approach to develop a mine closure plan that meets the mine regulator's requirements for approval without the need for external experts and consultants. When it comes to deciding a mine closure plan that favours a transition to an alternative mineral economy, the ultimate decision is determined by profitability and cost rather than the long-term viability of the post-mining option. Importantly, quantifying intangibles, such as the expenses of 'what ifs' or the consequences (lost opportunity) of not executing something effectively, is a double-edged sword that many mining (and mine closure planning managers) are grappling with on an ongoing basis.

One of the most important challenges our CRC is trying to address is integrating mine closure planning and post mine transitions into mine planning and key operational decision-making through financial planning. The Foundation study by Lilford et al. (2022) found that companies studied do this by compiling cash flow analyses, often culminating in the generation of a discounted cash flow (DCF) and also a net present value (NPV). There are two clearly stated pitfalls using the DCF NPV tool. The most commonly identified shortfall using this method is the fact that many of the ESG factors fall into the intangible basket, making them difficult to identify and even more difficult to quantify. These intangible factors are mostly associated with uncertainty, and less to do with risk (where uncertainty is typically related to risk). The second major shortfall

identified by the interviewed companies is the determination of an appropriate discount rate to be used in the NPV calculation. It can be generalised that the company practitioners are provided with a discount rate to use, and this rate is not determined using fundamental economic theory.

As noted, this is a critical area needing innovation, change and further development of practice if we are to transform mine closure outcomes, with interviewees in the study noting key gaps in the existing tools and techniques being used. Four consistent themes emerged from these responses and frame areas we can concentrate effort across the sector:

- Creating a framework to identify direct and indirect ESG factors, in order to develop tools to quantify these factors.
- Developing a road map to guide companies on how best to assist communities reach a sustainable solution once mining operations have ceased.
- Building appropriate tools to quantify mine closure assets and liabilities as a complement to the use of the DCF NPV method.
- Providing a framework and recommending a solution-based-processes for the identification and evaluation of intangible factors that contribute to risk and.

Addressing these gaps in knowledge and practice will be critical to addressing the disconnect between post mine aspirations and the short decisions that work against their actualisation. Promising signs in this area include the mining sector contributions into the Taskforce on Nature-related Financial Disclosures, Nature-Related Risk & Opportunity Management and Disclosure Framework and UN System of Environmental Economic Accounting.

5.5 Technical advances enabling us to build post mine landscapes

The greatest investment in mine closure R&D tends to focus on the technological innovation required to build safe, stable, non-polluting and self-sustaining post mine landscapes. As part of our CRC formation, we noted the lack of integration across disciplines and the largely bilateral relationships between companies and researchers limiting whole of sector advancement. Critically, our work looks to re-frame how we prioritise the development of technology to address the changing demands for post mine landscapes, driven by repurposing and post mine value optimisation models (cultural, social, environmental and economic).

The ‘technology solutions’ considered though CRC TiME for further study encompass a broad range of solutions from: 1) modelling, closure planning and design tools to identify pathways for positive post-mining land use; 2) instrumental technologies to measure and monitor closure and transition outcomes; and 3) new mining methods with the potential to more effectively deliver positive closure outcomes.

Foundational work by Cote et al. (2022) focused on the interconnections between the biophysical aspects of mine closure. These biophysical aspects comprised surface water and groundwater, geochemistry and water quality, biodiversity and ecosystem resilience, landform stability and re-establishment of self-sustaining ecosystems. The study noted that technical studies are not usually linked: they tend to progress in parallel, with the results from one providing information to the others. If one study is updated and produces different results, all studies require updating. This can be an inefficient process, with no obvious pathway with which to establish the feedback loops between the technical aspects. As our systems level understanding grows, and recognising this importance for post mine landscapes, there is a need to capture interdependencies and model relationships to avoid potentially conflicting approaches being implemented consider how they change over the life of the project and beyond. Moving to system based approaches will also require us to educate stakeholders about the nature of the technical approaches and ensure their application is based on a comprehensive understanding of the system.

Critically, the research reviewed several technology interventions for moving to post-mining land use including afforestation, sequestration, agriculture, bioenergy, renewable energy generation, biodiversity investments and the recreational use of pit lakes. Case studies illustrating these opportunities have been

compiled. Institutional arrangement, such as carbon markets, national biodiversity strategies and land use planning have a direct effect on the viability of different interventions as options leading to post-mining outcomes. For example, the re-establishment of vegetation corridors are unlikely to generate income in the current Australian economic system, recognising that this could change if carbon price mechanisms were re-introduced. Therefore, many biodiversity interventions are context specific.

6 Conclusion

The Cooperative Research Centre for Transformations in Mining Economies has been established to drive innovation in mine closure and post mine transitions to move to model that reduces the costs of closure, builds confidence in the management and transition of post mine risk. We focus on positive post mine transition through the optimisation of environment, social, cultural and economic values associated with post mine landscapes, repurposing of mining infrastructure for beneficial use and builds resilient communities. CRC TiME supports economic transition characterised by a just distribution of responsibility leading to net-positive outcomes. In the first two years of our 10 year journey we have delivered a Foundational Portfolio of research that is unique in its scope and delivers a number of key insights and directions for action across policy, planning, financial decision systems, risk management and technological platforms to deliver on this transformation. As we see a world in transformation driven by decarbonisation, ESG and social licence, there has never been a greater opportunity to affect the changes many working in the mine closure industry have been striving to achieve.

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