# Circular Economy Approach in Bauxite Mine Closure Planning

## Concept Paper

Developed with ASI's Circularity Working Group

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# 1. Introduction

For bauxite mine closure, the introduction of a circular economy (CE) approach would be not merely innovative; it would be a transformative shift that has the potential to redefine industry standards and the stewardship of natural resources.

Based on ISO 59004, a CE is an economic system that adopts a systematic approach to maintaining a circular flow of resources by recovering, retaining, or adding to their value, all while contributing to sustainable development (ISO, 2024). In contrast to a linear model—where materials are extracted, used, and discarded—the circular model strives for resource input minimisation and waste, emission, and energy leakage mitigation. It is an approach that should be harmonious with the laws of nature, where nothing is wasted, and everything serves a purpose in a continuous cycle.

By applying CE principles to bauxite mine closure, the aim is to create a positive post-mining legacy. ISO 59004 enlists six principles which underpin CE, and which thus need to be aligned with whole-of-mine-life practices. These principles are:

- Systems Thinking: Mining interconnections and life cycle impacts must be understood. A mine should be seen as part of an ecosystem, with closure as an integral part of its lifecycle, not an afterthought.
- Value Creation: The objective is to create value beyond the primary purpose of mining. Mines should leave more than remediated or rehabilitated landscapes; they should provide socio-economic and environmental assets for future generations.
- Value Sharing: Involving stakeholders in the value chain ensures mine closure benefits the local community and beyond. Equitable value sharing promotes community well-being and collaborative efforts to create sustainable post-mining futures.
- Resource Stewardship: Good resource governance requires efficient and respectful use of all materials, including pre-mine natural resources such as forests or agricultural landscapes.
- Resource Traceability: Resource flows (and stocks) must be tracked for responsible sourcing and waste management. This traceability ensures CE's accountability and transparency.
- Ecosystem Resilience: Mining operations must foster the development of new ecosystems by creating optimal conditions for local flora and fauna, which deliver essential ecosystem services to communities. The closure process should enhance existing ecosystems not directly (or less) impacted by mining operations and the resilience of emerging ecosystems in mine rehabilitation areas against environmental stresses and changes.

Using these principles in mine closure planning shifts the focus from ending operations to redesigning the mine's lifecycle. Resource optimisation strategies can be implemented by repurposing mine infrastructure for new economic activities, thereby retaining value. Re-use, repurposing, and resource recovery can transform remaining materials and spaces into new lifecycles, potentially turning what would be a closure cost into an economic opportunity. This paper explores CE concepts for bauxite mine closure as part of the ASI Circularity Working Group's exploration of future standards criteria.

## 2. Circular Design Strategies in Mine Rehabilitation

The circular economy model in mine closure and ecological rehabilitation involves proactive resource recovery and innovative (re-)use of both mineral and non-mineral resources, enhancing ecological restoration instead of mere extraction, disposal and minimisation. This shift reduces environmental impact and maximises resource value throughout the materials' lifecycle (Section 2.1) and land rehabilitation (Section 2.2). Strategies under the "10 Rs" framework—Refuse, Rethink, Redistribute, Reduce, Reuse, Repair, Repurpose, Recycle, Regenerate, and Reclaim—can be applied to preserving biodiversity and supporting the delivery of ecosystem services by incorporating organic matter, vegetation, and soil fauna, while also ensuring the efficient use of recovered materials for ongoing industrial and community applications (Figure 1).

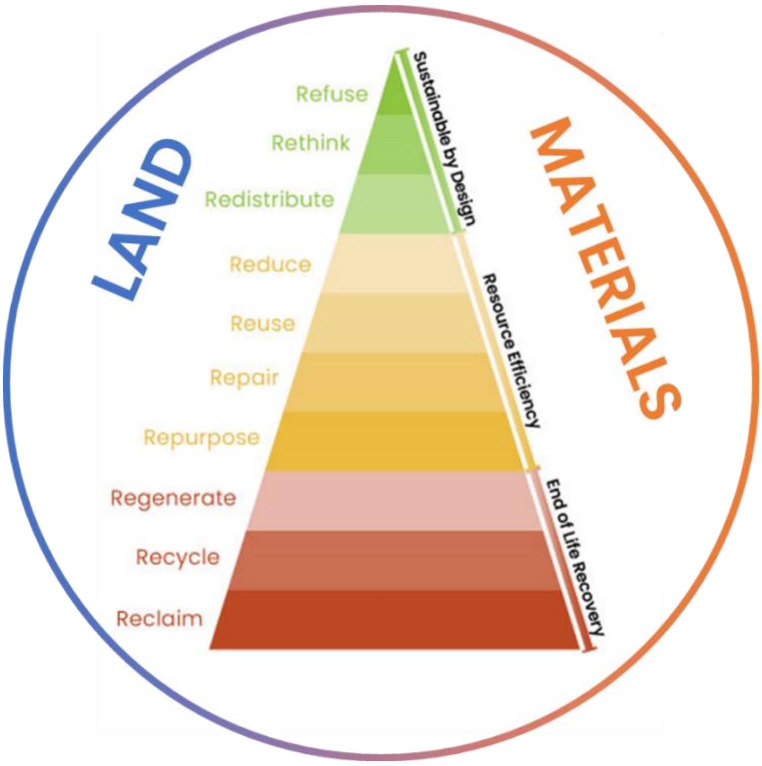


*Figure 1. R strategies for material and land management*

In the following sections, we first address strategies for materials, focusing on sustainable management, recovery, and repurposing. Following this, we explore land management techniques aimed at effective post-mining land use. While some strategies might be applicable to both materials and land, this distinction helps to organise the content. The separation ensures that each area is discussed thoroughly, though there may be overlap where strategies complement one another in both contexts. This structure allows for a comprehensive review of how circular economy principles can be adapted to different aspects of mine closure.

## 2.1. Circular Design Strategies for Materials in Mine Closure

Mine closures are an opportunity for sustainable material management, benefiting the economy and environment by rethinking how all natural resources and materials are used, recovering and repurposing, and maximising best use values.

### 2.1.1. Sustainable by Design for Materials (Refuse, Rethink and Redistribute)

Sustainable by Design strategies involve informed material and process choices, particularly at the mining project feasibility stage, drawing on a comprehensive impact assessment to establish an initial baseline of environmental, economic, and social conditions. This involves evaluating both potential adverse and beneficial impacts, assessing measures to **refuse** or minimise adverse effects—including direct, indirect, and cumulative impacts—and considering alternative project methods to reduce these impacts.

Involving governance structures, local NGOs, Indigenous peoples, and other stakeholders is vital for well-rounded decision-making. Where Indigenous Peoples are involved, Free Prior and Informed Consent (FPIC) should be implemented to ensure their active participation in decisions about infrastructure use, its **(re)distribution**, and mine rehabilitation outcomes. This collaborative approach helps regulators and authorities make decisions that are informed by the comprehensive results of impact assessments and the contributions of all stakeholders.

Choosing materials involves internalising costs and prioritising those with the greatest lifecycle value and post-closure repurposing potential, such as post-mine use of haul roads. This decision-making process should evaluate materials for recyclability and durability to ensure that mining infrastructure can continue to provide value after the mine's life. To inform these decisions, at the mine design stage, post-mine land uses should be discussed by all relevant stakeholders.

To further refine this approach, several initiatives can be implemented to **rethink** resource use in mining operations, including:

- Electric or hybrid machinery to reduce emissions
- Mining processes that use less water and explosives
- Renewable energy installations to replace fossil fuel power sources
- Mine waste facilities situated in safer locations with future reuse potential
- Modular designs and the use of recycled aluminium to improve the flexibility and sustainability of mining infrastructure (see for example Spantech, 2024)
- Temporary buildings such as modular offices and accommodation units designed to be easily disassembled and transported: after independent valuation, these can be relocated and reused as school classrooms or community centres
- Conveyor belts could be repurposed for agricultural use or general manufacturing, emphasising cost-effective design for disassembly and reassembly (see for example Kelly, 2018; Lenmark, 2023).

When considering the repurposing of infrastructure and equipment from closing mines, comprehensive risk assessments focused on potential uses of and life of assets, impacts on environment, health, and safety need to be considered to prevent harm or liability shifting to stakeholders. This includes managing risks associated with hazardous materials such as asbestos, contaminated soils and mine wastes, ensuring proper decontamination processes are followed, safeguarding both the environment and community health.

When a closing bauxite mine has infrastructure deemed viable for future use after a risk assessment, decisions must be made on whether to use it for other mining operations, for local community needs, or industrial applications (Pavloudakis et al., 2024). For example, to support post-mining livelihoods, (some) mine haul roads could be maintained to access ongoing ecosystem management, forestry plantations and/or fire protection. Non-essential offices and furniture from administration buildings could be donated to schools, hospitals, and community, improving public services. Governance arrangements are essential to ensure that repurposed infrastructure does not become a liability requiring unaffordable maintenance or upgrades by communities. This strategic approach not only reduces waste but also fosters economic development by repurposing resources that are no longer needed for mining, thus minimising the demand for new resource expenditures (Finucane and Tarnowy, 2019).

### 2.1.2. Resource Efficiency for Materials (Reduce, Reuse, Repair and Repurpose)

A central resource efficiency focus for a mine is the ore being extracted. Precision mining involves using advanced technologies such as aerial surveys, 3D GPS mapping, real-time data analytics, which when combined with high-quality drilling data can enhance the accuracy of resource estimates and extraction planning, siting of mine infrastructure and locating areas with high ecological, biodiversity and or cultural values that must be protected. These methods **reduce** waste and impact by optimising resource utilisation and minimising overburden extraction and unnecessary land disturbance (Greenwood, 2015). However, it is important to note that the effective application of these technologies still depends heavily on the availability of closely spaced, high-quality drilling data, as current advancements have not yet eliminated the need for such detailed groundwork in mine planning.

Another specific technique employed is selective mining. This involves differentiating between high-grade and low-grade bauxite ore during the mining process (Orzechowski, 2017) to enable production and resource efficiency to be enhanced through blending of mined ore. While focusing on high-grade areas can maximise the yield from extracted material and reduce the volume of ore that needs to be processed (**reducing** associated waste), it is important to manage this approach carefully. Selective high-grade mining can lead to the sterilisation of resources if not strategically planned, as grade values and their economic viability can vary over time. Historical practices in older bauxite mines in Australia have shown that ore previously left unmined due to being considered uneconomical can later become economically viable due to advancements in technology and/or increased market value for lower grade ore. This revisiting of sites can disrupt rehabilitated areas, potentially degrading soil properties and resulting in suboptimal rehabilitation outcomes. To mitigate this, miners should integrate rehabilitation into mine planning, to ensure consideration of the long-term implications of ore extraction sequencing.

Additionally, adopting automated and remotely operated equipment can contribute to operational efficiencies, including **reducing** material use and labour costs associated with FIFO (Fly-In, Fly-Out) operations (Rio Tinto, 2024). Such technologies have an opportunity to allow for more precise handling and cutting of the ore. Automated systems can be programmed to follow exact specifications, which can help in streamlining the extraction process and potentially lowering the unit cost of ore extraction.

Equipment, consumables and infrastructure used in mining are another area of resource efficiency opportunity. Routine maintenance, refurbishment, and remanufacture of mining equipment, consumables and infrastructure helps extend the lifespan of these assets, thereby reducing the demand and reducing waste generation (Barabady and Kumar, 2008). Implementing maintenance routines of all plant, equipment and associated infrastructure for the full life of mining operations including lubrication, replacing worn parts like belts and bearings, and performing diagnostic checks can significantly extend their operational life (AggNet, 2022). These measures not only enhance machine efficiency but also mitigates environmental risks, such as preventing hazardous liquid spills e.g. hydrocarbons, from deteriorating components.

Remanufacture involves the rebuilding of equipment to the specifications of the original manufactured product using a combination of **reused, repaired**, and new parts. It often results in the performance of the remanufactured equipment being comparable to new equipment. This could involve disassembling and rebuilding a mining truck diesel engine with new emissions-reducing and fuel-efficient technologies (Aramine, 2024). Mining companies can also create local jobs and enhance community skills by investing in **repair**, **refurbishment**, and **remanufacturing** skills and technologies, accompanied by targeted training and education programmes to empower indigenous communities.

Waste definitions should encompass all potential resource uses, including **repurposing**, turning typically discarded resources into valuable products for other industries. This enhances resource utilisation and generates economic value from what has historically been described as waste. Examples include:

- Using forest resources growing on bauxite reserves for forestry enterprise and/or community needs such as housing infrastructure.
- **Repurposing** bauxite tailings from beneficiation or screening fines as a supplementary cementitious material in concrete, reacting with calcium hydroxide to form new compounds, thereby enriching the concrete mixture (de Azevedo et al., 2022). Geochemical studies are necessary to confirm tailings' suitability, so as to make informed decisions, ensuring no risk of contaminants that may leach from the concrete.

### 2.1.3. End of Life (EoL) Applications for Materials (Recycling, Regenerate, Reclaim)

Recycling systematically recovers waste and scrap materials, reintroducing them into new production cycles. For example:

- **Recovered** by-products like silica can be used in construction or to produce high-strength concrete (Alelweet and Pavia, 2022).
- Bauxite beneficiation water is generally **recycled** as part of the beneficiation process therefore maximising process water reuse by using advanced water treatment technologies like returning tailings dam decant water to beneficiation plants. This approach reduces fresh groundwater and surface water requirements, reducing costs, minimising impacts on other water users and wastewater discharge (IAI, 2022).

- Bauxite tailings, are a byproduct of ore beneficiation and include a number of minerals, the composition of which vary depending on the bauxite geology and generally include silica, iron oxides, titanium, gallium and residual alumina. (Abedini and Calagari, 2014; Qi et al., 2023). These elements can be **recovered** using technologies such as separation or advanced flotation, for example to separate and concentrate titanium minerals from tailings. This **reclaimed** titanium can be used in paint, pigment, and aerospace manufacturing.
- Large industrial tyres from mining machinery, often stockpiled indefinitely due to recycling challenges, require innovative **recycling** solutions to address this persistent issue.

For related strategies on the rehabilitation of land for biodiversity and ecosystem services, see section 2.2.3.

## 2.2. Circular Design Strategies for Land in Mine Closure

### 2.2.1. Sustainable by Design for Land (Refuse, Rethink and Redistribute)

In the context of mine closure planning, the decision to initiate mining operations should consider more than just ore quality, processing costs, and infrastructure; it must also integrate circular economy principles from the outset. Evaluating the cumulative impacts, potential disruptions to local communities, Indigenous peoples, and ecosystems is crucial, particularly in terms of how these factors will influence post-mining land use and community well-being (Haddaway et al., 2019). By focusing on circular economy strategies during the feasibility phase, this approach ensures that any proceeding mining operation will aim to minimise its ecological footprint and positively enhance local ecosystems and communities.

**Refusing** harmful land management practices means actively avoiding both pre- and post-mining landscape degradation.

Excessive deforestation increases GHG emissions, cultural and social impacts, soil erosion, and biodiversity loss, and impacts on the hydrological cycle, which may cause water scarcity and pollution (Berglund and Johansson, 2004). A selective, minimal-clearance approach can be used for mining instead of clearing large areas of forests or other pre-mine land uses. All mine clearing operations should include full utilisation of pre-mine natural resources including timber, traditionally used food and medicine plants, native bees and other fauna. This approach eliminates waste and reduces disturbance and impacts on biodiversity, ecosystem services, socioeconomic and cultural impacts. Additionally, measures should be implemented to control access to mining concession areas for management of impacts from poaching, further protecting local wildlife and maintaining biodiversity.

**Rethinking** post-mine land use requires inclusive planning, implementing an FPIC process with Indigenous communities, and well informed mine rehabilitation and land management practices. Post-mine land use options need to mitigate additional environmental impacts i.e. soil protection, weed control; that they demonstrate an appreciation of natural resource values; consider the values as identified by the pre-mine landowners or rightsholders, which may include Indigenous peoples or local communities; and increase the land's value and utilisation for the community and environment (Finucane and Tarnowy, 2019).

In an ideal situation, after a bauxite mining operation ends, the mine closure plan will have been implemented for years to meet agreed land use and land relinquishment criteria that may include land uses such agricultural, forestry, aquaculture, or food security projects, supports a diversity of ecosystem services including cultural, biodiversity, sequesters carbon, whilst supporting a diversity of livelihoods. Conservation areas that promote, strengthen, and/or recover biodiversity and teach about local wildlife and ecosystems are another option. Lifecyle thinking begins at the start of the mining project to integrate necessary measures and strategies through sustainable design.

Sustainable by design strategies are also relevant for rehabilitation, by selecting vegetation that meets the agreed closure land use options to stabilise post-mining soil conditions that support post-mine livelihood opportunities. This approach helps restore pre-mine livelihoods and cultural practices and the mining site's ecology, including biodiversity. When livelihood opportunities are tailored to the needs and preferences of Indigenous peoples and local communities in mine rehabilitation areas, for example through an FPIC process where communities are actively involved, it not only facilitates their return to the land but also promotes long-term stewardship (de Souza Barbosa et al., 2022).

*For a detailed exploration of Pre-Mining Considerations and Planning for Closure, ASI has developed an extensive guide that focuses on early integration of sustainability practices. This guide thoroughly discusses environmental impact assessments, community engagement including the FPIC process, and strategic approaches to ensuring robust mine rehabilitation. For more in-depth information and practical guidelines, please refer to ASI's publication on the* ***5 Key Steps to Mine Rehabilitation*** *available here.*

### 2.2.2. Resource Efficiency for Land (Reduce, Reuse, Repair and Repurpose)

**Reducing** the use of land involves strategic planning to limit the extent of the area disturbed by mining activities. As outlined in section 2.1.2, this includes using more precise mining methods and equipment to extract bauxite from smaller areas or methods with less secondary or tertiary environmental impact. The design of haul roads and other infrastructure are important to mitigate impacts, reduce habitat fragmentation, and minimise the risks associated with weeds, feral animals, and fire spreading across the landscape. **Reusing** mining-displaced topsoil and subsoils requires careful management of these fragile resources to maximise mine rehabilitation outcomes. It is important to acknowledge that topsoil is a limited and valuable resource.

Additional **reuse** strategy would use the mine's infrastructure and layout to benefit the community or post-mine industry options, including haul road, energy production, water availability and mining village infrastructure where the community has identified such assets as useful. After mining ends, in some regions bauxite mine open pits can be turned into water reservoirs or recreational lakes, using their inherent structural features for community use (Lund and Blanchette, 2023). Continuous monitoring and adaptive management strategies for any post mine land uses need to consider the biophysical limitations to ensure the long-term land use viability, safety and sustainability of proposed repurposed sites.

If approved through an FPIC process, reclaimed mining areas can be **repaired** and **repurposed** to benefit the communities and provide a range of environmental benefits. Solar or wind farms could be built on these lands in suitable climates and terrain (CSIRO, 2023) if there is a market for the energy produced. These sorts of initiatives have the potential to provide a diversity of benefits, at the local community level, for the environment, local energy needs, and to support post-mining economic development opportunities.

### 2.2.3. End of Life (EoL) Applications for Land (Recycling, Regenerate, Reclaim)

A "Recycle" land management strategy reuses mine site materials to improve land functions afterward, either on or off the site. Overburden, crushed rock, and other inert bauxite mining materials are often used as aggregates for local road and construction projects. Reclaiming these materials reduces environmental impact and virgin material extraction.

Mine closure planning includes detailed assessment to determine best post-mine land use options. An inclusive approach integrates both traditional ecological knowledge and land management practices with western science. Examples of innovative end of life approaches include:

- Some areas may be more suited to rehabilitate as wetlands in areas where ore was extracted down to the seasonal or permanent water table levels, therefore providing a habitat for a diversity of species and providing support for additional ecosystem services.
- Establishing corridors of native vegetation between areas not cleared for mining operations (buffer zones, protected areas and areas with no bauxite), as part of the mine rehabilitation and mine closure program, supports connection of isolated patches of habitat and potential for some animal populations to migrate from buffer zones into mine rehabilitation areas, thus reestablishing some ecosystem services, maintaining genetic diversity, and supporting ecosystem resilience.
- Buffer zones on mining leases that are not directly affected by mining operations can be managed to maintain their ecosystem services, which can be further enhanced through progressive mine rehabilitation to maximise protection of environmental assets as part of a mine closure plan. Biodiversity and other ecosystem services from buffer zones can then be reestablished to speed the rehabilitation of specific habitat for key animal and plant populations.
- Reintegrating dried bauxite tailings directly back into previously mined areas could actively contribute to the land's ecological restoration (Hydro, 2021). Instead of requiring separate, permanent disposal areas, the tailings are used to refill excavated sites. These sites are then prepared for rehabilitation preferably with native species, but care must be taken to address issues such as soil crusting, poor water retention, and potential erosion, which can hinder successful mine rehabilitation. Note: the use of tailings in mine pits to date have not proved successful in reaching optimal mine rehabilitation outcomes. At site level, an applied research approach is required to investigate the use of tailings achieves the desired final landform, and can be made to support the long-term sustainability and relevance of rehabilitation efforts.

# 3. Stakeholder Engagement

Table 1 lists the main stakeholders in circular economy mine closure. As listed below, each stakeholder group has distinct roles, perspectives, and goals in line with a sustainable post-mining future.

*Table 1. Circular economy outcomes for mining closure planning*

| STAKEHOLDER | DESCRIPTION | CIRCULAR ECONOMY OUTCOMES |
|---|---|---|
| Miners | Operators and practitioners focused on integrating circular economy strategies into the ongoing mine operations closure process, aiming to create sustainable post-mining ecosystems. | • Employ circular design in closure planning to ensure material reuse and sustainable mine rehabilitation outcomes.<br>• Achieve resource efficiency to eliminate waste through applied initiatives and innovative technology.<br>• Realise the transition of mine sites to new circular business models.<br>• Apply a risk-based approach to mine closure process.<br>• Associate local stakeholders to the mine closure process, creating ownership for Indigenous peoples and local communities (including local NGOs) |
| Communities | Local Communities and Indigenous populations affected by mining operations, with a strong interest in sustainable development and the long-term stewardship of their environment. | • Engage in co-creation of land use plans that align with circular economy values, through an FPCI process.<br>• Promote local community-led initiatives for post-mining land use options, based on traditional ecological knowledge and western based science, that foster local economies and support livelihoods.<br>• Create conditions that foster the development of ecosystem services.<br>• Acknowledge traditional knowledge systems and land management practices of Indigenous peoples and local communities.<br>• Participate in governance and management of land- and water resources of closed mines |
| Governments | Regulatory bodies and policymakers promoting the circular economy to improve mine closure outcomes and long term sustainable resource management. | • Set and implement regulations that incentivise circular approaches to mine closure.<br>• Support research and development in sustainable mining technologies.<br>• Monitoring, evaluation and review<br>• Facilitate the transition of closed mine sites to serve long term community purposes and reduce risk.<br>• Strengthen the mandate and capacity of local management structures to ensure institutional sustainability, recognising participatory institutions of governance and management of old mines |
| Other Industries | Sectors interested in the potential of closed mine sites for new circular economy business opportunities, such as renewable energy or agriculture. | • Explore opportunities repurpose mine sites for renewable energy projects, management through emerging payment of services for ecosystem services (through an FPIC process as applicable).<br>• Collaborate with mining companies to develop new materials from historically identified mine waste.<br>• Use closed mine sites where identified through an |

| STAKEHOLDER | DESCRIPTION | CIRCULAR ECONOMY OUTCOMES |
|---|---|---|
| | | FPIC process for community-driven, sustainable projects such as agriculture, forestry and other land uses. |
| Environmental and social NGOs | Organisations focused on conservation and sustainable management of natural resources, maintenance of ecosystem services and advocating for closed-loop systems in mine rehabilitation. | • Partner in the development of biodiversity action plans post-closure.<br>• Ensure that mine closures enhance ecosystem services.<br>• Advocate for the management of ecosystem services including biodiversity, and cultural services. |
| Investors and Shareholders | Financial stakeholders interested in the long-term value creation and risk management associated with circular economy practices in mine closure. | • Encourage investments in circular economy innovations for mine closure.<br>• Assess and mitigate financial risks by supporting sustainable mine closure plans.<br>• Promote transparency and accountability in the use of resources and post-closure plans.<br>• Adopt FPIC principles in investment decisions.<br>• Make financial assurances to fund mine closure. |
| Research and Academic Institutions | Entities that study and provide scientific input on the efficacy of circular economy practices, contributing to sustainable closure strategies. | • Provide evidence-based research on circular mine closure practices.<br>• Collaborate on pilot projects to test new circular technologies in mine rehabilitation and mine closure opportunities.<br>• Train the next generation of mine closure specialists with a focus on circular economy principles.<br>• Include Indigenous traditional ecological knowledge and other aspects into evidence-based research. |
| Circular Economy Advocates | Specialists in circular economy principles applied to mine closure and beyond, including waste minimisation, resource recovery, and lifecycle thinking. | • Develop and implement innovative practices for resource recovery and waste reduction.<br>• Advocate for systemic changes that extend the lifecycle of materials.<br>• Influence policy towards circular economy incentives. |
| Communication and education, the media | Promote equity in partnerships among all stakeholders through education, training, and awareness initiatives facilitated by media and communication. | • Capacity building of local stakeholders to effectively participate in the process<br>• Raising alertness on socio/environmental interests and the impacts thereon. |

Adapted from: (CSIRO, 2023)

## 3.1. Strategies for Engagement

The stakeholder engagement approach is reshaped by circular economy principles, which promote sustainability and rehabilitation throughout mine closure. These strategies aim to balance the diverse interests of all parties, making closed mine sites safe, compliant, and hubs of long-term value creation and community development. Based on to Everingham et al. (2020), these engagement strategies can include the following:

1. Formation of Consultative Groups

Community reference groups or external closure review teams, supported by independent technical specialists if requested, allow affected parties to share information and provide feedback, ensuring transparency and effective participation in decision-making and negotiation. After closure, these circular economy-inspired groups can innovate material reuse, job creation, and local economic development solutions. They can help turn circular economy principles into community- and environmental-friendly actions.

2. Local and Indigenous Knowledge Panels

In addition to general and potentially more broadly based Consultative Groups, dedicated panels can incorporate traditional wisdom and technical insights into mine closure community reference groups, closure planning, and diverse knowledge systems. Framed panels allow access to traditional ecological knowledge and practices needed to design scientifically sound and culturally relevant circular closure processes. They must also respect Indigenous intellectual property and keep cultural knowledge safe. Understanding and respecting Indigenous wisdom can optimise mine closure plans for resource recovery, livelihoods, ecosystem services restoration, and conservation, aligning with the circular economy's focus on biodiversity and sustainable resource management.

3. Community Visioning

Communities can articulate their desired future and shape mine closure strategies and management requirements to meet sustainable development goals by participating in a visioning process. This strategy is based on the circular economy's value creation and sharing. Communities can create a sustainable development plan beyond the mine's life by envisioning circular land use for agriculture, conservation, or renewable energy.

4. Impact Assessments (IA)

Conducting IAs during closure help identify and manage environmental, social, cultural, and economic impacts, integrating community perspectives and mine development implications. In a circular economy, IAs must consider both mine closure impacts and mine site repurposing and rehabilitation. The *Indigenous Peoples led Cumulative Impact Assessment* methodology developed by the Sami peoples in Norway supports a holistic and collaborative approach to impacts (ASI, 2023). IAs show how closure activities can boost the post-mining economy and ecosystem, integrating social systems with ecological cycles and following the circular economy's systemic approach.

5. Participatory Monitoring and Evaluation

Stakeholder participation in monitoring processes, especially environmental rehabilitation as an integrated approach with community development, improves accountability and ensures that closure activities benefit the ecosystem and community. This collaborative approach involves all stakeholders, especially local communities and Indigenous peoples, in tracking mine closure progress and intervening to address mine rehabilitation development shortfalls and circular objectives. Participatory monitoring promotes transparency, trust, and knowledge sharing. It ensures that mine closure outcomes, such as cultural protection, livelihoods development, water quality, and land rehabilitation, contribute to the circular flow of natural and economic resources and benefit the community and the environment over the long term.

### 3.2. Guidance on Designing Acceptance Criteria

Stakeholder engagement involves developing clear acceptance criteria; these benchmarks or standards help judge the adequacy of mine closure activities (Hawley, 2017). Establishing these criteria is essential for aligning stakeholder expectations with the outcomes of mine closure. As a fundamental aspect of mine closure discussions, these criteria ensure that closure activities adhere to agreed-upon environmental and social standards. To support this, the guidance provided should set clear, measurable goals tailored to the unique environmental, social, and economic contexts of bauxite mining projects. Regular review meetings, stakeholder surveys, and iterative document updates are crucial to incorporate stakeholder feedback effectively. The criteria must also address several key components as outlined by Young et al. (2019):

1. Selection of post-mining land uses (PMLUs): Define potential, future circular economy land uses like sustainable community development or ecological rehabilitation.
2. Aspects and closure objectives: Identify environmental, economic and social/cultural and institutional issues that closure activities should address to promote resource conservation and community well-being.
3. Selection of references: Choose benchmarks or models from previous successful closures that reflect best practices, including circular economy applications.
4. Selection of attributes and risk-based prioritisation: Clearly define specific mine closure attributes, such as soil stability, water quality, presence of key-biodiversity (e.g. red-listed species), and community impact, and prioritise actions based on a detailed risk assessment that considers both potential hazards and opportunities for circular economy outcomes.
5. Development of completion criteria: Set clear, achievable closure activity criteria, such as soil health benchmarks, vegetation cover targets, and water quality standards, to ensure all actions support PMLUs and circular economy targets.
6. Monitoring: Establish a comprehensive monitoring plan to evaluate the mine closure against circular economy-based completion criteria.

By embedding this approach early in the engagement process, the outcomes will align with mine closure strategic objectives and have sufficient stakeholder support. This ensures that closure plans meet environmental standards and support sustainable development.

## 4. Monitoring, Reporting, and Continuous Improvement

Continuous improvement in mine rehabilitation is guided by circular economy principles, such as material and resource efficiency and waste and environmental degradation reduction. Circularity indicators (such as ISO 59020) evaluate rehabilitation interventions' efficacy and efficiency. Table 2 lists strategies, from refusing unnecessary materials to recovering valuable elements from waste, to ensure sustainable material handling. Monitoring these strategies ensures best practices and reporting brings transparency and accountability.

*Table 2. Monitoring and Reporting of Circular Economy Strategies for Materials Management in Bauxite Mining Closure*

| Strategy (Rs) | Monitoring | Reporting |
|---|---|---|
| Refuse | Track decisions to refuse the use of non-essential and unsustainable materials through procurement records and policy adherence checks. Indicate key areas of ecological and cultural importance that should not be affected by the exploitations | Document cases where environmentally harmful materials were avoided, and describe the alternatives used, highlighting the environmental benefits achieved. |
| Rethink | Engage with all stakeholders in an FPIC process to assess the lifecycle of materials and the environmental impact of current practices to identify opportunities for improvement. | Report on initiatives and design changes that reduce the environmental impact, showcasing innovative practices and their benefits including integration of traditional ecological knowledge. |
| Redistribute | Monitor the distribution of excess or reusable materials to ensure those benefiting are not disproportionately impacted by mining activities. | Provide details of opportunities on how redistributed materials can be used in new contexts, including benefits to the community or environment. |
| Reduce | Measure reductions in material usage through inventory management systems and efficiency assessments undertaken in partnership with local stakeholders. | Provide data on material savings and reductions in waste generation, comparing baseline and current usage metrics. |
| Reuse | Keep records of equipment and materials that are repurposed within the mining site or donated for external use. | List reused items, identify their new applications, and specify who is using them, applications, both within and outside of the mining operations. |
| Repair | Log maintenance and repair activities, tracking the extension of equipment and infrastructure lifespan. | Summarise repair activities and their role in reducing the need for new materials, highlighting cost savings and environmental impacts. |
| Repurpose | Track the repurposing of materials and infrastructure for alternative uses. | Provide examples of how repurposed materials have been integrated into new projects, detailing the environmental and community benefits. |
| Recycle | Monitor the quantities of materials sent to recycling facilities versus those disposed of as waste. | Report recycling rates and the impact on resource conservation, detailing specific materials that were recycled and their subsequent uses. |
| Rehabilitate | Assess the effectiveness of using mining by-products in rehabilitating ecosystems or contributing to soil health. | Report on rehabilitation projects, providing details on the ecological outcomes and how these contribute to sustainable land management and other goals agreed as part of the mine closure plan. |
| Reclaim | Monitor the recovery of valuable elements from waste streams. | Detail the types of materials recovered, the processes used, and their reintroduction into production cycles. |

Table 3 lists circularity strategies and monitoring and reporting mechanisms. This framework ensures that mining companies follow regulations and demonstrate their commitment to environmental and community responsibility. This structured approach allows companies to demonstrate their sustainability and community engagement efforts during mining closure.

*Table 3. Mining and Reporting of Circular Economy Strategies for Land Rehabilitation in Bauxite Mining Closure*

| Strategy (Rs) | Monitoring | Reporting |
|---|---|---|
| Refuse | Monitor land use decisions to ensure avoidance of practices that unnecessarily harm the post-mining landscape. Ensure an FPIC process is applied. | Document instances where harmful land management practices were avoided and detail alternative methods used. |
| Rethink | Evaluate land use plans using a participatory approach through an FPIC process to incorporate sustainable and multifunctional land uses that contribute to ecological and community recovery. | Report on the strategic planning processes and the envisioned benefits for land rehabilitation and community integration. Feedback to local and Indigenous communities |
| Redistribute | Track the allocation of land resources and rights to Indigenous peoples and or local communities through an FPIC process. | Provide updates on how land redistribution is consistent with pre mine communities (i.e. Indigenous peoples and or local communities) and supports agreed community development and environmental conservation, through an FPIC process. And recognise (co-) authority of Indigenous communities over the natural resources that they depend on for their well-being. |
| Reduce | Assess the extent of land (and water) disturbance and efforts to minimise it through efficient land use and mining practices by engaging with impacted communities through an FPIC process. | Provide metrics on land preserved and reduced disturbance, comparing planned versus actual disturbed areas. |
| Reuse | Track the conversion of mined land to new uses, ensuring these changes adhere to sustainable practices through an FPIC process. | Report on the previously agreed reutilisation of land, specifying the new purposes and their benefits to the community or environment. |
| Repair | Conduct regular assessments of rehabilitation measures aimed at restoring ecological functions through an FPIC process. | Summarise rehabilitation activities and their impacts on land recovery, detailing measures taken to enhance land health. |
| Repurpose | Through an FPIC process track the adaptation of reclaimed mining areas for alternative beneficial uses, such as community spaces or renewable energy projects. | Provide detailed and collaborative accounts with the local Indigenous peoples and or local communities of how repurposed lands are benefiting the |

| Strategy (Rs) | Monitoring | Reporting |
|---|---|---|
| | | community or environment, including specific project outcomes. |
| Recycle | Monitor the usage and effectiveness through an FPIC process, of recycled materials such as overburdens, crushed rock, and soils in construction and land rehabilitation projects. | Report on the applications and agreed benefits of using recycled mining materials in local construction and land restoration, through an FPIC process that highlight reductions in the use of virgin materials and improvements in ecological stability. |
| Rehabilitate | Assess rehabilitation efforts aimed at restoring the ecological functions of land, focusing on long-term sustainability. | With all local stakeholders report on rehabilitation projects, documenting the FPIC processes used and their effectiveness in establishing self-sustaining ecosystems. |
| Reclaim | With local stakeholders monitor the recovery of natural habitats and ecosystems on rehabilitated mining land.<br>Reclaim mined-out areas for sustainable productive land- and water uses to the benefit of local and indigenous communities | Detail and draft collaborative reports with local stakeholders the recovery processes, highlighting successful reintroduction of native species and rehabilitation of natural habitats.<br>Map these areas and make sure that they will be managed and governed with effective involvement of local stakeholders to the decision taking process. And recognise (co-)authority of Indigenous communities over the natural resources that they depend on for their well-being. |

For a detailed overview of monitoring, reporting, and continuous improvement processes essential for effective mine rehabilitation, ASI offers guidance in its publication **"5 Key Steps to Mine Rehabilitation"**. This resource outlines necessary evaluations to ensure plant species establishment, soil and water conservation, and ecosystem recovery align with sustainable closure practices. It also addresses adaptive management strategies for overcoming challenges such as plant survival and land use adaptation, ensuring that rehabilitation efforts comply with mine closure plan goals. For further guidance and methodologies, click here.

## 5. Final Remarks

This concept paper sets out a Circular Economy Approach in Bauxite Mine Closure Planning, outlining the opportunity to shift toward incorporating circular economy principles throughout the mining lifecycle, emphasising sustainable and beneficial outcomes post-mining. By implementing the "10 Rs" framework—Refuse, Rethink, Redistribute, Reduce, Reuse, Repair, Repurpose, Recycle, Regenerate, and Reclaim—this approach can redefine mine closure as an integral part of a broader and ongoing economy, with opportunities to enhance resource efficiency and reduce environmental impact.

Engaging stakeholders ensures they and their aspirations are at the forefront of closure plans. This approach not only aims to preserve ecological integrity but also to enhance social development and economic opportunities after mining. As these practices become more integrated globally, they establish a new standard for how mining operations can positively impact local communities and support broader sustainability goals.

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