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Closure in Design: a framework for embedding closure considerations early in mine development

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Abstract

Traditionally, mining has focused on short-term costs and operational efficiency, often at the expense of long-term closure considerations.

Rio Tinto Iron Ore's Closure in Design Framework changes that approach by embedding closure considerations from the very beginning of mine development, guided by 10 principles which support informed, value-based decision-making. This ensures decisions relating to mine layout, sequencing and landforms are made with long-term cultural heritage and environmental outcomes in mind.

Recent implementation of the framework has demonstrated improved closure and operational outcomes for Rio Tinto Pilbara iron ore mines, highlighting the value of closure-conscious mine planning. At one site, waste rock previously scheduled for placement in 2 large ex-pit waste dumps was redirected to backfill mined-out pits. This redesign removed hundreds of hectares from the overall disturbance footprint, reduced operational haulage costs, and improved present and future cultural heritage and environmental outcomes. The Closure in Design Framework demonstrates how early, structured consideration of closure can enable reduced-impact mining while supporting enduring environmental, cultural and social outcomes.

The Closure in Design Framework is adaptable across commodities and geographies, with flexibility to address unique project needs. The framework establishes a practical and repeatable benchmark for integrated and forward-thinking closure solutions.

Keywords: *closure strategy, mine development, decision-making, stakeholders, governance*

1 Introduction

Rio Tinto Iron Ore (RTIO) is a major miner in Western Australia's Pilbara region, with operations spanning more than 6 decades. As mining portfolios mature and societal expectations evolve, the complexity of mine closure has increased significantly. Closure is not a phase to be considered late in a mine's life; it is a defining component of responsible resource development that must address regulatory compliance, environmental performance, cultural heritage protection and long-term social value.

Recognising these challenges, RTIO has developed and implemented a Closure in Design (CiD) Framework – a structured, scalable and values-based approach that embeds closure considerations from the earliest stages of mine planning and study development. The framework fundamentally reshapes how closure risk, cost and opportunity are identified, assessed and managed across the project life cycle, enabling reduced-impact mining and improved closure outcomes.

2 The challenge

International and industry guidance is clear that mine closure must be considered from the earliest stages of mine development and embedded into mine design and planning, rather than treated as a discrete end of

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operational life activity. The International Council on Mining and Metals (ICMM) (2025) defines integrated mine closure as a 'dynamic and iterative process that considers environmental, social and economic aspects at an early stage of mine development and throughout the life of an asset', and emphasises that closure should be considered 'an integral part of the mine operations' core business'. ICMM (2025) further notes that a closure approach 'fully incorporated into mine planning activities' supports improved health, safety, environmental, social and governance outcomes, including the early identification of risks, more accurate closure cost estimates and a progressive reduction of liabilities.

Similarly, the Global Acid Rock Drainage (GARD) Guide developed by the International Network for Acid Prevention (INAP) (2024) says that 'planning for closure should begin as early as possible in the project life cycle, preferably during the project design phase,' recognising that 'design decisions made early in the mine life can significantly influence the long-term stability, performance and cost of mine closure' (see Figure 1). The GARD Guide further emphasises that designing for closure focuses on preventing long-term environmental and safety liabilities through upfront design decisions rather than relying on management or treatment measures after closure, and supports early and continuous closure planning to facilitate progressive rehabilitation and reduce the creation of long-term liabilities.

While this guidance establishes clear principles, translating them into consistent, study-level design decisions across large and diverse portfolios remains a practical challenge. Often these challenges relating to mine closure are amplified by:

- a large and diverse portfolio of operational and development mine assets
- continuously evolving closure expectations from regulators, traditional owners and local communities
- operations located within or adjacent to areas of high cultural, heritage and environmental significance
- legacy closure risks associated with historic planning decisions.

Recent closure studies have highlighted the consequences of limited early state closure considerations, prompting a shift towards a more systematic and standardised approach. Senior leadership challenged the organisation to develop a proactive, standardised framework capable of embedding closure considerations consistently across all study phases.

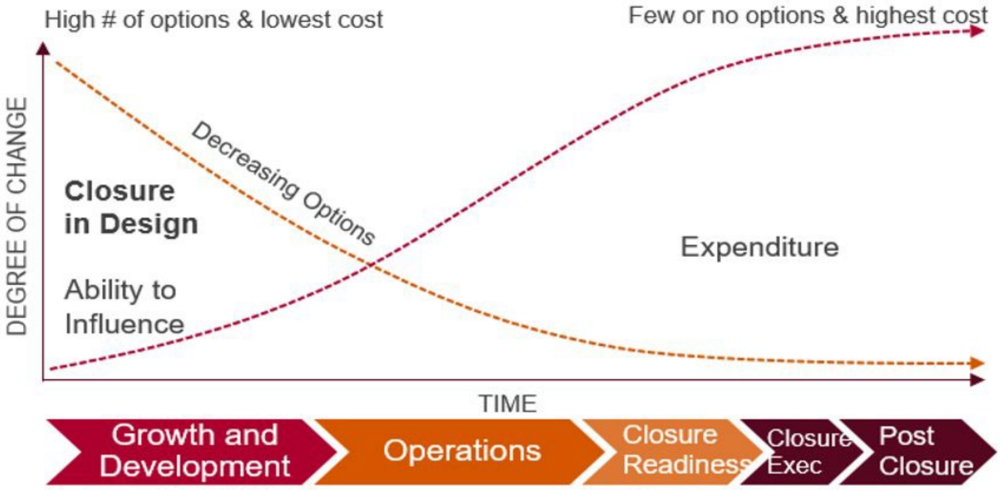

Figure 1 Opportunity to influence closure outcomes over time

3 The opportunity

The greatest opportunity to influence closure risk, liability and outcomes exists at the front end of mine planning and decision-making (Kemp & Olds 2017).

The CiD Framework ensures closure considerations are integrated from the outset of mine development, enabling earlier identification of risks and opportunities and supporting more informed design trade-offs.

The CiD Framework embeds closure from the earliest planning phases, guided by 10 core principles, enabling:

- consideration of closure decisions from project inception, directly influencing mine design, sequencing and landform planning
- reduction of the disturbance footprint through prioritised operational backfilling and the minimisation of ex-pit landforms
- characterisation and management of both problematic and beneficial materials
- avoidance of long-term legacy risks, including problematic pit lakes and unmanaged hazardous materials
- construction of rehabilitation-ready landforms during operations to support progressive rehabilitation
- early and ongoing stakeholder engagement to align mine design with cultural heritage and environmental values.

To address variability in closure capability and influence across studies, the CiD Framework provides a standardised methodology for integrating closure across all RTIO mines. The framework spans key themes including strategy, stakeholders, pit voids, waste rock landforms including land bridges, tailings storage facilities, water management and beneficial materials.

3.1 Closure in Design principles

Ten principles underpin the framework and support informed, values-based decision-making grounded in a comprehensive understanding of closure implications and stakeholder expectations (see Figure 2).

The principles are classified as either:

- core requirements: mandatory principles applied to all studies
- trade-off principles: assessed on a study-specific basis using defined minimum requirements.

Core Requirements			
Fill First	The study evaluates a scenario, whereby sequencing is optimised to eliminate external waste landforms and pit lakes through operational backfill.	Rehabilitation Ready	Operational construction of landforms to be ready for rehabilitation, including early construction of abandonment bunds.
Stakeholder Engagement	Key stakeholders are consulted early and regularly regarding proposed closure strategies, rehabilitation standard and post-closure access.	Integrated Closure	The study integrates closure requirements across the entire asset and mine life to deliver reduced impact mining practices and enable cost-effective closure.

Trade-offs			
Waste Landforms	External waste landforms are minimised through operational backfill to enable alternative landform designs on smaller waste dumps.	Tailings Storage Facilities	Eliminate ex-pit facilities where reasonably practicable, and ensure compliance with GISTM and D5 Standard.
Water	Surface water and groundwater hydrological regimes supporting significant receptors are maintained or fully reinstated.	Problematic Materials	Problematic materials (PAF, fibrous, or highly erodible waste) are avoided, prioritised for pit backfill or encapsulated sufficiently during operations.
Pit Voids & Pit Lakes	The creation of problematic pit voids or pit lakes are avoided through strategic mine planning and sequencing.	Beneficial Materials	Segregation and stockpile of beneficial materials in the area intended for final use occurs during operations.

Figure 2 Closure in Design principles

3.2 Minimum requirements

Clear minimum requirements ensure that trade-off principles represent meaningful thresholds rather than discretionary guidelines. These requirements define the minimum acceptable closure performance expected within mine development studies and provide transparency and consistency in decision-making (Figure 3).

Trade-off Principle		Minimum CiD Requirement
Waste Landforms	External waste landforms are minimised through operational backfill to enable alternative landform designs on smaller waste dumps.	Contribute to the Pilbara-wide average of 60% of non-beneficial waste being scheduled for backfill during operations.
Tailings Storage Facilities	Eliminate ex-pit facilities where reasonably practicable, and ensure compliance with GISTM.	In-pit TSFs are adopted, where seepage does not impact receptors, to eliminate geotechnical risks.
Pit Voids & Pit Lakes	The creation of problematic pit voids or pit lakes are avoided through strategic mine planning and sequencing.	Eliminate problematic pit lakes through operational backfill to nominal height above the pre-mining water table.
Water	Surface water and groundwater hydrological regimes supporting significant receptors are maintained or fully reinstated.	Impacts to water dependent ecosystems are temporary and can be managed through engineered mitigation measures.
Problematic Materials	Problematic materials (PAF, fibrous, or highly erodible waste) are avoided, prioritised for pit backfill or encapsulated sufficiently during operations.	Hazardous materials are encapsulated during operations within fewer "hazardous" dumps. High erodibility waste is prioritised for backfill.
Beneficial Materials	Segregation and stockpile of beneficial materials in the area intended for final use occurs during operations.	Volumes of beneficial materials are separately stockpiled for closure activities within the mine site.

Figure 3 Trade-off principles' minimum requirements (CID = Closure in Design; PAF = potentially acid forming; TSF = tailings storage facility; GISTM = Global Industry Standard on Tailings Management)

4 The framework

The CiD Framework has been developed with a strong focus on usability and consistency across mine-development studies regardless of the subject matter experts' closure experiences. It establishes the regulatory and technical context, provides guidance to users and includes supporting references to underpin closure-related decisions.

Key features of the MS Excel-based Framework tool include (see Figure 4):

- adaptability to the study context, scale and complexity
- evaluation of only those closure principles relevant to the study scope
- application at the level of individual pit voids, waste rock landforms and tailings storage facilities
- embedded guidance to support subject matter experts
- an automated scorecard to enhance transparency
- clear summary of closure principle status at the completion of each study phase
- tracking of closure maturity across successive study phases.

Waste Landforms - Dumps, Landbridges, Low-grade stockpiles, ROM pads										
No.	CID Element	Discipline(s) responsible	Addressed	Study Actions	Outcome by Feature					Comment
					WD1	WD2	WD3	WD4	LB1	
4.0 Overview										
4.0.1	Waste landform development (dumps, landbridges, low-grade stockpiles, ROM pads) is within the Study scope	Closure	Yes	Address all relevant items for each waste landform						
4.1 Post-closure heritage and environmental interactions - Refer to *Landform Closure Guideline* and *Surface Water Closure Guideline*										
4.1.1	Waste landform rehabilitation footprint will: - remove access to a cultural heritage site or value - intersect with the buffer of a: - cultural heritage site or value, or - sensitive environmental receptor	Mine Planning, Heritage and Closure	Yes	Provide details in the Study report and document approach for each waste landform: - PREVENT: operational footprint revised to avoid restricted access and/or interaction by the rehabilitation footprint - OPS ACTION: fleet allocated for scheduled operational rehandle (partial / full) to reinstate access / avoid interaction by the rehabilitation footprint - CLOSURE ACTION: rehandle (partial / full) to reinstate access / avoid interaction by the rehabilitation footprint at closure - RESIDUAL RISK: restricted access and/or interaction with a sensitive receptor will not be managed through study options	Prevent	Ops action	Ops action	Prevent	Closure action	*Landbridge will be rehandled at closure*
4.2 Landform visual amenity										
4.2.1	Waste landform location and rehabilitation design has addressed visual amenity from areas of high cultural heritage significance *(Note: this could be a condition of the Ministerial Statement)*	Mine Planning, Approvals, CSP	No	This knowledge gap needs to be addressed before finalisation of the FS Study						*Will be addressed in the PFS phase. Noted as a knowledge gap*

Figure 4 Closure in Design Framework hypothetical example (CID = Closure in Design; OOM = order of magnitude; PFS = prefeasibility; FS = feasibility; ROM = run of mine; CSP = communities and social performance)

4.1 Scorecard

The scorecard is a core output of the framework; it summarises how closure principles have been addressed within the current study phase and enables comparison across study phases to demonstrate improving closure maturity over time (Figure 5). It provides a summary of the overall closure maturity of the study in a single table.

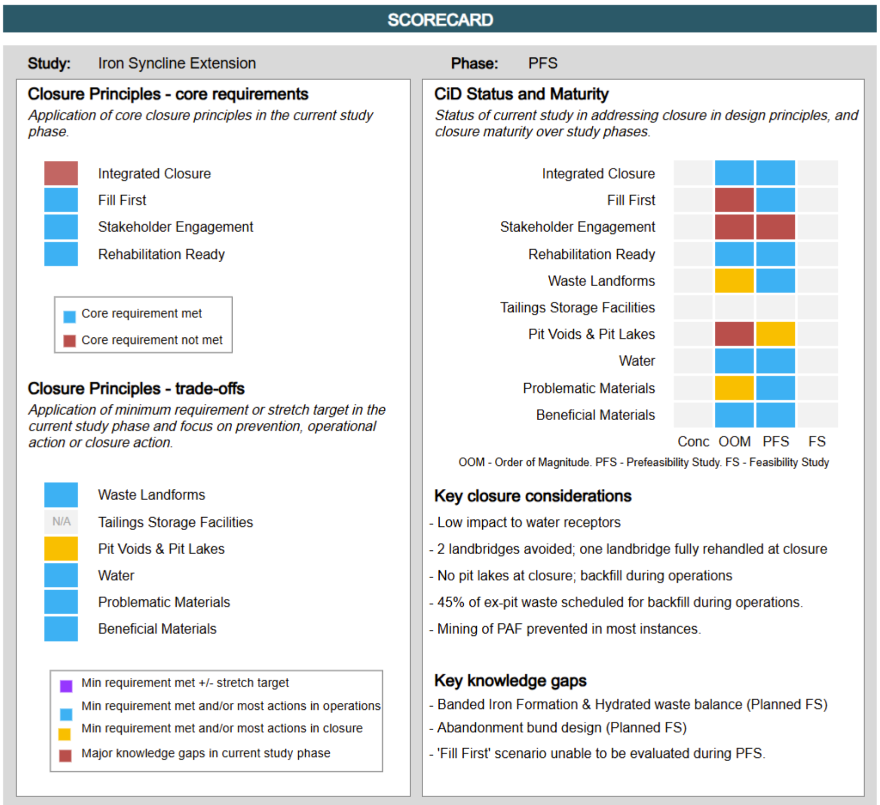

Figure 5 Scorecard hypothetical example (CID = Closure in Design; PAF = potentially acid forming)

5 Demonstrated outcomes

The CiD Framework was piloted across several RTIO mine development studies during 2025, during which time measurable improvements in closure outcomes were realised and clearly demonstrated the benefits of the framework.

5.1 Case study 1: Pilbara development site A

The framework was piloted on a pre-feasibility (PFS) development study, demonstrating how early integration of closure considerations can influence mine layout, sequencing and infrastructure choices, all of which materially reduce closure risks and costs while preserving operational flexibility. Application of the framework supported improved closure outcomes as summarised in Table 1.

Table 1 Application and integration of Closure in Design principles – case study 1

Closure in Design principle	Study outcome
Waste landforms	Fill first scenario resulted in optimisation of in-pit backfilling to minimise disturbance; one small ex-pit waste landform remains (see Figure 6). All backfill obligations will be met through operational backfill Mine waste from early stages of development hauled longer distance to neighbouring operations to minimise external clearing and large ex-pit waste landforms
Tailings storage facilities (TSF)	Initial utilisation of neighbouring operations' TSF to deposit tailings, instead of new TSF constructed Facilities capped where possible during operations. Later stages of mining utilise in-pit TSF facilities
Pit voids and pit lakes	Whilst below watertable mining will occur, operational backfill will prevent pit lake formation at closure No additional backfill currently required at closure
Water	Natural flow paths maintained No reliance on engineered control structures at closure
Problematic materials	Problematic materials prioritised for pit backfill/capping No potentially acid forming materials anticipated to be exposed through mining
Beneficial materials	Non-beneficial materials prioritised for backfill and tailings capping Soil types stockpiled separately (e.g. alluvial versus plains soil) and outside 1% annual exceedance probability floodplain. Total soil volumes calculated to ensure adequate volumes

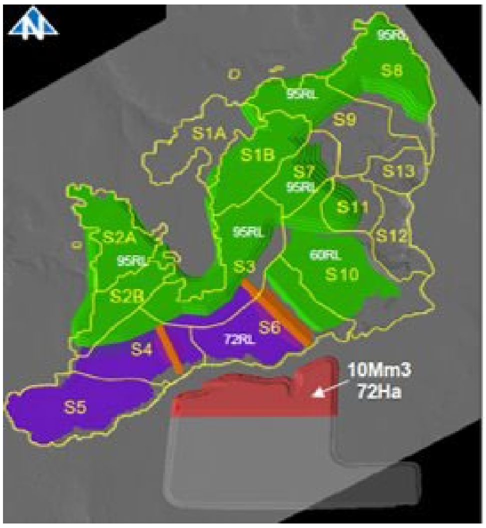

Figure 6 Reduced dump footprint through increased progressive backfill

5.2 Case study 2: Pilbara development site B

A second case study involved another PFS level development study. This study was originally designed with multiple large ex-pit waste landforms and several pit voids requiring backfill under approval conditions. Application of the CiD Framework supported the realisation of the following design outcomes:

- removal of external waste landforms. Two large external waste landforms were completely removed from the development scenario. The revised design reduced the surface disturbance footprint by approximately 435 hectares
- increased progressive backfill. Approximately 193 Mm^3 of waste rock will be redirected from external waste landforms to pit backfill during operations
- cultural heritage outcomes. Potential impact on 29 cultural heritage sites was avoided and removed from the proposed disturbance footprint.

5.3 Case study 3 – Pilbara development site C

The third case study involved an order of magnitude study for a site with potential complex closure risks relating to pit voids, below-watertable mining and close proximity to sensitive areas. CiD principles were applied to test early design interventions aimed at avoiding long-term pit void and safety risks (see Table 2).

Table 2 Application and integration of Closure in Design principles – case study 3

Closure in Design principle	Study outcome
Waste landforms	Fill first scenario run, with optimisation of in-pit backfilling to minimise the footprint of ex-pit waste landforms 50% of waste is currently scheduled for backfill during operations, with further optimisation planned during the PFS Footprints of waste landforms revised to protect cultural heritage sites
Problematic materials	Mining of potentially acid forming and fibrous minerals materials was prevented in most instances or, where exposed, backfilled to cover scheduled during operations

6 Our commitment

RTIO has commenced implementation of the CiD Framework across all new mine development studies from 2026, with iterative application through subsequent study phases. This commitment is supported by:

- endorsement from RTIO senior leadership and the global closure team
- integration of CiD requirements into the internal study definition guidance
- mandatory consideration of CiD principles during study scoping and execution planning
- targeted training for closure practitioners and study leads.

The framework has driven a measurable maturing of closure culture across technical disciplines, embedding closure accountability beyond specialist closure teams and into core mine planning functions.

7 Influence on industry

The CiD Framework is intentionally adaptable, enabling application across commodities, geographies and project types while acknowledging that trade-offs are inherently site-specific and closure outcomes must be balanced against preserving optionality for potential mine life extension. The principles-based structure allows flexibility while maintaining clear minimum standards.

Externally, RTIO has shared the framework with:

- other Rio Tinto product groups seeking to address similar challenges
- Pilbara mining peers through the Pilbara Rehabilitation Group
- Western Australian regulators, including the Department of Mines, Petroleum and Exploration, the Department of Water and Environmental Regulation, the Department of Biodiversity, Conservation and Attractions, and the Department of Energy and Economic Diversification.

Feedback from industry and regulators has been positive, recognising the framework's potential to drive a broader shift toward proactive, integrated closure planning and reduced-impact mining practices. The CiD Framework was a finalist in the 2025 Department of Mines, Petroleum and Exploration Golden Gecko Awards, which recognise excellence in environmental management within the Western Australian resource sector, celebrating innovation and leading practices.

8 Conclusion

The Closure in Design Framework represents a fundamental shift in how closure considerations are integrated into mine development decision-making within Rio Tinto Iron Ore (RTIO). By embedding closure considerations from the earliest stages of mine planning, RTIO has demonstrated that it is possible to reduce long-term closure risk and liability while enhancing cultural, environmental and social outcomes.

As the mining industry faces ever increasing expectations around responsible mining, approaches such as Closure in Design offer a scalable and defensible pathway to improved performance and a potential reduction in closure liability. The framework sets a new benchmark for integrated closure planning and reinforces the importance of designing mines today with closure in mind from the outset.

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