Mine Closure 2024 – AB Fourie, M Tibbett & G Boggs (eds)

doi:10.36487/ACG_repo/2415_90

Circular economy strategy for repurposing coal seam overburden as construction sand in the mining industry

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Abstract

This paper presents a circular economy strategy for the repurposing of coal seam overburden (CSOB) material as construction sand in the mining industry. The study focuses on the technical and economic feasibility of extracting sand from CSOB and its potential as a sustainable alternative to natural sands in various construction applications.

The paper highlights the current challenges in the mining industry regarding the management of mine overburden, which is traditionally considered a waste product. It emphasises the need for a circular economy approach to eliminate waste and re-use materials, with a specific focus on CSOB as a valuable resource.

The technical performance of CSOB sand is evaluated through existing examples from India, where CSOB sand has been successfully used as a partial substitute for natural sands in concrete production. The study demonstrates that CSOB sand can meet the specifications set in AS 2758.1-2014 for fine aggregate in Australia.

Also discussed is the environmental impact of CSOB sand extraction when used in combination with manufactured sand and natural sands in residual form to reduce the ecological destruction caused by over-dredging of marine sands. By utilising CSOB sand, the mining industry can contribute to the sustainable sourcing of construction materials and reduce the ecological footprint associated with sand extraction.

Market proximity is examined to assess the feasibility of transporting CSOB sand from remote mining sites to consumer locations. Existing mining infrastructure, such as rail lines, can facilitate transportation and provide a cost-effective and environmentally efficient mode of delivery.

Regulatory barriers are identified as a major obstacle to circularisation of the mining industry. The paper calls for changes in current regulations to allow for the processing of non-mineral residual assets, such as CSOB-sand, within Australian mining leases.

The potential financial benefits of re-using CSOB as sand are discussed, including the reduction of liability in handling mine overburden and the potential for sustainable regional enterprises. Commercial viability, markets and the need for regulatory changes to enable this circular economy initiative within the mining industry require further work.

Keywords: *circular economy, sand extraction, coal mine overburden*

1 Introduction

Mine overburden has traditionally been viewed as a waste product and been termed ‘waste rock’, having ‘intrinsically no value’ (Li et al. 2012). In this study, mine overburden has been referred to as a residual mine asset (RMA) to reflect its potential value. The Australian mining industry is a significant producer of waste in the form of overburden and tailings as a product of the mining life cycle. Waste quantities throughout the

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mining industry will likely increase with future mining demands and diminishing ore grades. For Australian metallurgical coal mines, rising strip ratios, by definition, generate more waste (Gorringe 2023).

Implementing the circular economy in the mining industry is important in working towards local (state-wide) goals as well as the Australian Critical Minerals Strategy 2023-2030 which emphasizes the need for progressing circular economy initiatives as part of improving environmental, social and governance credentials within the resources industry (Australian Government Department of Industry, Science and Resources 2023).

The circular economy works on three principles which can be described as eliminating waste, circulating waste material at a high value and restoring to nature (Ellen Macarthur Foundation 2024). This paper focuses on an application of the circular economy within the mining industry and investigates its potential value and viability as a strategy to be implemented in the Australian mining context.

The value of eliminating and/or re-using mining waste with a view to indefinite re-use of byproducts from metals mining has the potential to create a resource-efficient system while reducing the footprint of disturbed natural environments where those products (sand, gravel and rock) are currently extracted. In Australia, the circularity rate of all raw materials is around 4% (half of the global average). Of the total raw virgin materials extracted from Australia in 2019 (2,587 million tonnes), 371 million tonnes became gangue (waste rock) and tailings. This suggests that there is a sizeable economy in Australia for circularity in mining waste (Miatto et al. 2024).

The re-use of mining waste materials has already been implemented as part of some tailings management strategies. For example, in Minas Gerais, Brazil, sand for construction purposes has been extracted from treated iron ore tailings. This is an example of a circular economy initiative that provides several benefits, including the reduction of tailings material which presents safety and environmental risks, as well the provision of a secondary source of construction sand in place of riverine sands (Golev et al. 2022).

Mine overburden can also be extracted for other purposes. In Australia, EQ Resources is processing low-grade stockpiles to extract tungsten from mine waste and is stockpiling oversized material from Mt Carbine Quarry for quarry sale. This is an example of a regenerative strategy for mine waste that is economically feasible (EQ Resources 2024).

There is no one-size-fits-all approach to re-using mine waste, and it is becoming more evident that there are several strategies for mine waste regeneration.

This paper focuses on the re-use of coal seam overburden (CSOB) for construction materials as an example of a circular economy strategy that could be implemented within the Australian mining industry. It discusses its potential value and limiting factors both in its technical and economic feasibility, as well as the broader challenges in implementing this in the Australian context.

In doing so, this paper aims to outline the importance of a circular economy in mining and the factors preventing it. A significant barrier to its uptake in Queensland, Australia, is the current *Mineral Resources Act 1989* (Section 5) (Government of Queensland 1989d). Within this legislation, currently, under a mining lease, companies cannot process a non-mineral RMA separately to mining activity. This essentially encourages greater waste production.

This paper also aims to challenge the current thinking about residual asset material and post-mine land use strategies that stem from current regulation. The re-use of CSOB as construction sand could be feasible both technically and economically. There are several site-specific factors that will affect the potential production and consumer costs of extracting sand from CSOB. Although the extraction of sand from CSOB may be possible, current Queensland statutes effectively preclude it.

1.1 Coal seam overburden as construction sand

The extraction of construction sand from CSOB has already been carried out in countries such as India where companies have re-used the sandstone overburden in response to issues posed by illegal sand mining

(Rentier & Cammeraat 2022). This is not currently a practice in the Australian market, where CSOB is seen as having little residual value. However, existing developments in India demonstrate that there is value in the overburden where there are market shortages (India Times 2023). In response to the sand shortage crisis in India, investigations regarding the feasibility of extracting CSOB have been carried out to address existing data gaps. In the Maharashtra state, pilot studies in collaboration with academic researchers and industry professionals have been carried out to assess the economic and technical feasibility of such. The studies determined several benefits of using sand from overburden, including it being a source of cheaper sand as well as a provision of a sustainable alternative to riverine sand extraction (Dod et al. 2024).

Other RMAs may include cobbles and boulders, inert ore sands, claystone and secondary minerals within tailings. While not included in the scope of this study, gravel supplies face similar supply shortages and ecological disruption (United Nations Environment Programme 2022). Furthermore, in Queensland, extracting gravel from mining sites is effectively precluded from a mining lease.

The United Nations highlights that there are five major factors in determining a material's suitability as an alternative to naturally occurring sand and gravel. In this study, these have been used as framework criteria to assess CSOB within the Australian landscape (United Nations Environment Programme 2022). The five factors are outlined in Figure 1, with the CSOB application for each described.

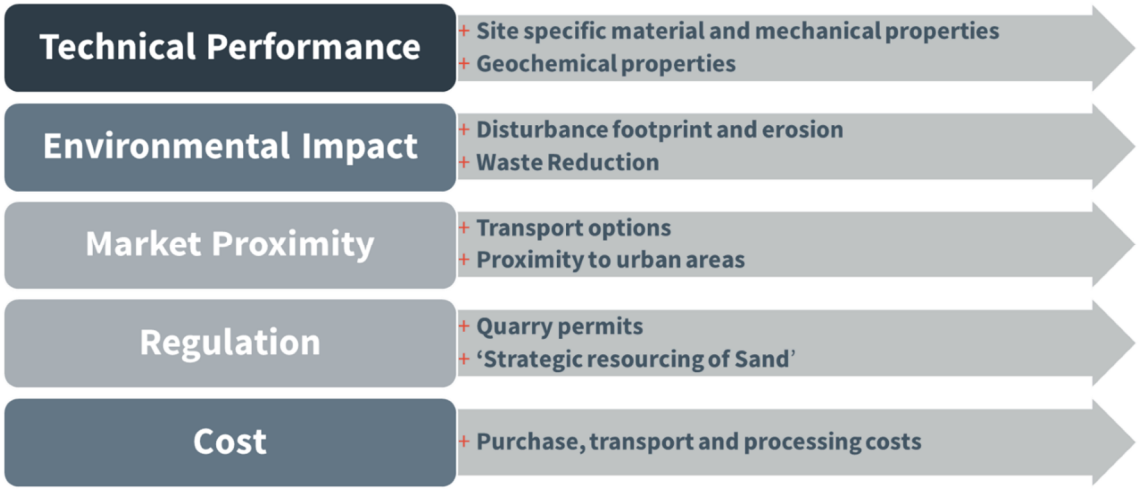

Figure 1 Criteria framework for alternative sources of sand

2 Technical performance

The feasibility of CSOB sand is very much site-specific. The nature of overburden will not only dictate the production capacity of CSOB sand but also its grade. The aim in extracting CSOB sand should be as a partial replacement of natural sands in commercial and industrial uses. However, for this to occur, site-specific testing would need to take place; particularly for its use in construction, the primary consumer of sand (Rentier & Cammeraat 2022).

2.1 Coal seam overburden re-use case study: India

Currently some developments are being undertaken in India due to the country's sudden sand shortage crisis, including Coal India (IANS 2023; Beiser 2019). Studies from India have shown that not only can CSOB sand be a viable partial substitute for natural sands in concrete but that concrete strength can in fact increase with CSOB sand. A concrete mix with CSOB sand accounting for 60% of fine aggregate and natural sand accounting for the remaining 40% produced the best results (Jena et al. 2024).

In India, sandstone CSOB sand has also been shown to be mineralogically, mechanically and durably similar to natural fine aggregates (Mishra et al. 2023). The lithology and characteristics of overburden material will dictate such results. Therefore, a replication of testing should be conducted on CSOB spoil material from a Queensland coal mine as a pilot site study.

2.2 Australian construction sand requirements

For CSOB sand to be used in Australia as fine aggregate it will have to meet technical specifications to ensure both the quality of the used material and its safety for re-use. Australian Standard AS 2758.1-2014: Aggregates and Rocks for Engineering Purposes sets out specifications regarding sulphate and fines content within fine-grained aggregate (Standards Australia 2014).

Strength parameters are also important but vary with the application of concrete as highlighted by the Department of Transport and Main Roads Guideline: Quarry assessment of "manufactured sand" crushed fine aggregate sources (Department of Transport and Main Roads n.d). It should be noted that CSOB sand is a residual asset, not a byproduct, and therefore requires secondary processing from mining operations.

There are several applications of construction sand aside from concrete use, including general construction fill and landscaping. Therefore, if a specific sites overburden is not suitable for concrete use, value may be found elsewhere.

3 Environmental impact

There are several environmental benefits for the development of CSOB sand. While Australia has a large supply of natural sands it is not immune to the ecological destruction caused by over-dredging and hard rock construction sand supply. The Brisbane River, for example, while originally dredged for navigation purposes, was also dredged to supply 33.2 million m^3 of construction aggregate from 1900–1991 (Erskine 1996). This resulted in permanently changed the river's tidal hydraulics, increasing bank erosion, turbidity and salinity.

Therefore, developing supplies of construction sand that are sustainably sourced is important to protect Australia's river systems. Rather than replacing river sand, manufactured sands can bridge the gap between demand for construction materials and natural replenishment rates.

Manufactured sand has been produced in Australia as a byproduct of quarry activity. However, as Australia continues to urbanise, the demand for sand will continue to rapidly grow. The result will be greater land disturbance as more and larger quarries will need to be developed to sustain this demand. Finding alternative supplies of manufactured sand is a proactive approach to sustaining Australia's urban development and reducing the associated ecological footprint.

Simultaneously, Australian coal mines have been steadily increasing strip ratios (Gorringe 2023). This means that larger quantities of overburden are excavated, and while the majority of this is used to progressively backfill pits, some is inevitably stockpiled in spoil piles. By processing overburden into manufactured sand, mining waste volumes can be reduced.

There is also a potential for reduced liability and risk in the storage of mining overburden. Loosely compacted spoil is susceptible to erosion, potentially leading to increased sedimentation in waterways. Spoil is also susceptible to high rates of settlement, cracking, gullying and tunnelling (commensurate with its fines content and cationic balance). Thus, waste reduction is vital in creating stable landforms that enable post-mining land use.

The extraction of construction materials from CSOB therefore presents an opportunity to provide a singular solution that can address several environmental issues.

4 Market proximity

In Australia, major mines are typically located in rural regions, meaning that there could be logistical and cost challenges in sustainably transporting material from remote sites to consumer locations in urban areas. However, it should be noted that there is existing infrastructure in place to allow for the transport of primary material mined.

For almost all Queensland regions, the demand for sand is expected to substantially increase over the course of the next decade and beyond (Oxford Economics Australia 2023). This is a result of significant investments

in major infrastructure projects and residential upturn. As a result, by 2039–2040 Greater Brisbane and Townsville regions are expected to see depletions of –69% and –52% of sand reserves, respectively (Oxford Economics Australia 2023). Furthermore, there is uncertainty whether current quarry operations can meet the simultaneous increase in demand for sand throughout Queensland; thus providing an opportunity for Queensland's coal mines to meet this increase in demand.

In 2022 Australia was the second-largest global exporter of natural sand and Australian exports of sand were valued at $266 million in this year. While export markets primarily comprised East Asian nations, especially China, Australia also exported a sizeable amount of sand to European markets (Observatory of Economic Complexity 2023). Thus the transportation of sand at long distances *can* be viable.

Australia's coal mining operations do provide feasibility for the transportation of aggregate further distances. Firstly, the amount of sand that can be processed from large stockpiles of overburden material allows these operations to reach economies of scale. Secondly, mining infrastructure, particularly existing rail lines used to transport product coal, provide a more efficient, large-scale means of transportation that are more environmentally and cost-efficient than road transportation.

For ore sands (manufactured sands from ore processing) there is a market for one-third of mines within a 50 km radius of the mine site (Ievers & Franks 2022). Assuming a similar distribution for a nearby market can be applied to coal mines, depending on their geographical proximity to other industry and developments, this indicates that there is potentially an available market for sand recovered from CSOB.

5 Regulation

Regulation is a major obstacle in

the mining industry. Part 1 (a) of Section 276 of the Queensland Mineral Resources Act 1989 states:

> *'… a condition that the holder shall use the area of the mining lease bona fide for the purpose for which the mining lease was granted and in accordance with this Act and the conditions of the mining lease and for no other purpose …'* (Government of Queensland 1989a).

Furthermore, in Section 234:

> *'(1) The Minister may grant to an eligible person or persons, a mining lease for all or any of the following purposes—*
>
> (a) *to mine the mineral or minerals specified in the lease and for all purposes necessary to effectually carry on that mining …'* (Government of Queensland 1989b).

The Mineral Resources Act 1989 Section 6 excludes soil, sand, gravel and rock as minerals (Government of Queensland 1989c). Therefore, CSOB sand, or any other non-mineral residual construction material, cannot be processed through a mining lease. Rather, a separate quarry permit, largely regulated by local governments under the '*Queensland Planning Act 2016'*, would be needed (Business Queensland 2022).

Therefore, current legislation doesn't encourage circularising the mining industry but rather discourages it. Minimising the disturbance footprint from mining requires maximising inputs from necessarily disturbed land and minimising waste production.

In the current situation there is little incentive for mining companies to capitalise on non-mineral residual assets as they require further processing which, in turn, requires further investment and higher start-up costs. Adding further regulation through a quarrying permit, regulated at a different government level, produces a domain in which sourcing non-mineral RMAs may become unfeasible. Revenue from CSOB sand is likely to be financially insignificant relative to the mined coal. For mining companies its financial benefit becomes larger as liability reduction. However, this presents an opportunity for subcontractors to take

advantage, or for an additional mining tenure for secondary mining activities. This can be facilitated, and risks can be managed, through changes in regional and state regulations.

Considering the United Nations' call for sand and, by extension, gravel to be regarded as strategic resources, it becomes evident that governments need to update their regulatory framework (United Nations Environment Programme 2022). CSOB sand and other non-mineral RMAs provide a more sustainable alternative for construction materials. These materials reduce mine waste and, by increasing supply, place downward pressure on the cost of construction materials.

6 Financial benefit

There are several financial benefits that could be achieved from re-using CSOB as sand.

There is a financial benefit in reducing the liability in handling mine overburden and rehabilitation. Managing overburden material is a costly operation due to erosion, geochemical processes, seepage and mine pit backfilling. One way to potentially offset these costs is to minimise the volume of overburden stored in spoil piles. This may provide a steady stream of revenue compared to the variability in commodity prices.

The cost of sand has been increasing as demand for sand has drained regional supplies, resulting in increased transportation costs (Murphy & Hargreaves 2022). Greater levels of urbanisation and the need for more construction materials, combined with the anthropogenically finite nature of riverine sand, will only propel this trend. For example, there are already growing concerns that the simultaneous increase in demand for sand and quarry products throughout Queensland may result in heightened costs and procurement delays (Oxford Economics Australia 2023)

Utilising existing infrastructure constructed for mining (e.g. rail or port) can provide another mode of transport to on-road hauling. In addition, expanding the sand market in Australia and the number of suppliers will likely improve competition and assist in driving sand prices lower (Pienmunne & Whitehouse 2001).

As countries regulate sand supply due to ecological disturbance, and once sand is classified as a strategic resource, the financial benefits of CSOB can improve.

The actual benefits measured against the perceived benefits discussed above are dependent on several factors:

- the material properties of overburden — this is linked to the quantity of overburden sand that can be extracted and its suitability for its intended application
- the intended use of construction sand — the financial value of CSOB sand may vary depending on its grade and use; for example, as aggregate in concrete, general construction aggregate, landscaping or fill material
- processing costs — as overburden is a residual asset and not a byproduct of processing operations on mines, processing of the overburden is required to remove unwanted materials and extract sand. Overheads associated with additional processing and the additional management of overburden needs to be considered to determine if sand extraction is economical
- in addition to benefits attained from reprocessing existing overburden to extract sand as a financially viable asset there exists an opportunity to identify and separate overburden streams during operations to reduce the reworking of materials, resulting in easier and less-costly operations.

7 Conclusion

This study highlights the decision-making considerations for the re-use of CSOB as construction sand and the potential economic and environmental value that can come from it. This study found that there are several inhibiting and driving factors to the extraction of sand from CSOB.

The primary inhibiting factors are:

- regulatory uncertainty in Australia, limiting the extraction of material from mining waste for construction purposes
- uncertainty in the technical feasibility, requiring industry-driven pilot sites to assess the quantities that can be extracted
- further assessment being required to determine the financial benefits and costs associated with sand extraction from CSOB.

Despite these challenges, benefits that drive factors of the extraction of sand from CSOB were found to be:

- broad environmental benefits from improved overburden management and a sustainable sand source to address sand shortage concerns
- the potential to leverage existing mine transport infrastructure to minimise export costs and improve transport operations
- the potential for a secondary industry to be provided during mining operations and continued post mine closure.

Industry-driven research should be carried out to demonstrate the feasibility of a secondary market from CSOB sands. To analyse market trends and create initiatives for alternative sand sources, sand should be categorised as a 'strategic resource' to improve data collection and management. To this end, sand supply and security needs to move beyond a regional level.

Although this study assessed the extraction of sand from mine overburden as a specific scenario for a circular economy initiative in mining, the findings from this study are applicable to other circular strategies for mine waste, such as the re-use of gravel and rock for construction materials, which also undergo similar regulatory barriers. Lessons can be drawn from the implementation of mine overburden re-use for construction sand in India, and from joint industry and academic pilot studies to address gaps in data and demonstrate its feasibility. Pilot studies should be carried out to eliminate uncertainty in the feasibility of re-using RMAs and demonstrate its effectiveness. This can be extended to hard rock mines for supplying gravel, rock and boulder construction material.

The findings of this study should be considered in a broader context to draw attention to industry and regulatory actions required to enable the circular use of mine waste material. In addition, the benefits of re-using waste materials (sand, gravel and rock) in place of quarrying on greenfield areas should be recognised. Benefits such as the provision of a secondary economy from mining waste streams that may occur during mining operations as well as post mining is one that is necessary to ensure further economic opportunities exist for regional areas which may suffer a decline once mining activity ceases.

Circularising the mining industry creates post mine-life opportunities. The processing of RMA materials directly results in the reduction of mine waste and reducing these waste streams minimises the liability that they pose. It also provides an opportunity to design and develop post-mining land with value that utilises mining voids and shafts rather than overburden to infill pits as part of rehabilitation strategies.

In addition there is the potential to create an environmental positive from an industry that has been heavily scrutinised. By utilising RMAs, inputs from disturbed land can be maximised, thus preventing the need to disturb further land while also lessening the ecological disturbance footprint from quarrying activity.

Changing thinking towards sustainability in the mining industry requires cooperation between stakeholders, government and the industry to deliver the desired outcomes. The primary resisting factor to changing the landscape is often the current mining regulation, which inhibits this secondary land-use activity. Changing the current regulation is the first step in allowing the industry to invest in these valuable post-mining land use and circular economy initiatives so that mine operators can process non-mineral RMA. There are several drivers of regulatory change, including improved technical knowledge to reduce risk, demonstrated economic opportunity, and public awareness of the various economic and environmental benefits of re-using

mine overburden. Therefore, improvements in data from industry pilot sites and feasibility studies to de-risk these initiatives will start the process of enabling a circular economy in the mining sector's use of mine overburden.

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