The compelling case for decarbonisation

Mining in a low-emissions economy

Report collaborators

This work reflects the specialist focus areas of the CEFC and MRIWA, and our shared commitment to the growth and development of the Australian mining sector as part of our clean energy transition. We thank specialist consultants ENGIE Impact for their detailed insights and analysis.

CEFC investing to achieve net zero emissions

The CEFC is a specialist investor at the centre of efforts to help deliver on Australia's ambitions for a thriving, low emissions future. With a strong investment track record, we are committed to accelerating our transition to net zero emissions by 2050. In addressing some of our toughest emissions challenges, we are filling market gaps and collaborating with investors, innovators and industry leaders to spur substantial new investment where it will have the greatest impact. The CEFC invests on behalf of the Australian Government, with a strong commitment to deliver a positive return for taxpayers across our portfolio.

MRIWA and the *Net Zero Emission Mining Challenge*

With the global shift towards decarbonisation, the need for mineral resources to support the energy transition places Western Australia at the forefront of a significant economic opportunity. The Minerals Research Institute of Western Australia (MRIWA), a WA State Government statutory body, fosters and promotes minerals research for the benefit of WA. Through its ***Net Zero Emission Mining Challenge***, MRIWA is working across the sector to showcase innovation and help capture the benefits of net zero emission mining.

ENGIE Impact and the sustainability transformation

ENGIE Impact is the consulting arm of the global ENGIE Group, the world's largest independent power company. ENGIE Impact works with organisations to embed sustainability in their operational strategies, capturing the economic value of sustainability commitments to lift long-term competitiveness. It applies data analytics, multi-disciplinary expertise and global reach, developing tailored roadmaps to help organisations establish and achieve their sustainability goals, across energy, water, waste and carbon.

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A message from the CEOs

For a century or more, Australia's economic growth has been inextricably linked to our mining sector, whether in terms of regional development, export markets, investment, technology or revenue.

The low-emissions economy of the future inherently relies on what our mining sector produces – not least because of an abundance of critical minerals. In turn, mining businesses can benefit from the operational efficiencies and low-cost energy solutions underpinning the transition to net zero emissions.

It is an exciting future, presenting the sector with the potential to shape our economic growth in the coming century.

But if we are to capture the benefits and make meaningful contributions to emissions reduction, it is past time to turn planning into action – what we need is substantial investment, innovative market development and accelerated emissions ambitions.

To that end, the Clean Energy Finance Corporation (CEFC) and the Minerals Research Institute of Western Australia (MRIWA), are pleased to present this practical analysis of the exciting trends, opportunities and challenges ahead for the mining sector in a net zero economy.

The CEFC and mining

Mining is considered a hard-to-abate sector, reflecting the high energy intensity of mining activities, the heavy reliance on emissions intensive fuels and the requirement for thermal energy in processing activities. This is reflected in the sector accounting for nearly 10 per cent of Australia's national emissions.

The geographic location of mines, at edge-of-grid or off-grid areas, also shapes the operating emissions profile. The CEFC is making investment commitments across these areas, working with miners to accelerate improvements in their operational emissions footprint.

We are also focused on opportunities to exploit the development of new mineral commodities, especially those essential to the development of renewable energy, energy storage and electrification.

Growing demand for these minerals is driven by market participants seeking to capture the economic benefits of the emissions transition, as well as delivering on their decarbonisation commitments by reducing Scope 3 emissions via a low-emissions supply chain.

“Our goal has been to provide practical information and insights for mining executives, operational leads and sustainability teams to accelerate efforts in achieving net zero emissions, both as mineral producers and mining operators.”

Ian Learmonth and Nicole Roocke,
CEO, CEFC and CEO, MRIWA

MRIWA and net zero emissions

With a global shift towards decarbonisation, the need for various commodities to support the energy transition places Western Australia at the forefront of a significant economic opportunity.

Western Australia supplies the minerals used for wind and solar energy generation, electric vehicles and battery storage which will enable the international community to achieve the Paris Agreement goals of net zero emissions by 2050.

With this opportunity also comes a challenge – to ensure new and increased demand for these minerals meets rising environmental, social and governance expectations, and does not negatively impact on the competitiveness of the mining sector.

Innovation is also needed for our mining sector to capture this opportunity, develop new ways of working and transform how energy is generated and used. The lead time to new technology development and installation means preparation needs to start now.

MRIWA is working across sectors to challenge what is possible, showcase innovation and provide support to advance net zero emission mining through a targeted program of minerals research.

The goal is to reduce the carbon footprint, lower overall energy costs and improve the energy efficiency and competitiveness of the Western Australian mining sector, harnessing collective efforts to enable decarbonisation to become a growth opportunity for the sector.

The opportunity for industry leadership

In developing the *Mining in a low-emissions economy series*, our goal has been to provide practical information and insights for mining executives, operational leads and sustainability teams to accelerate efforts in achieving net zero emissions, both as mineral producers and mining operators.

There is no question the transition to a net zero emissions economy is a mighty task, requiring new operating models and increasing transparency about emissions.

Equally, it is a mighty opportunity, and one that gives us every confidence about the continued positive impact of the mining sector for Australia.

Ian Learmonth
CEO

Clean Energy Finance Corporation

Nicole Roocke
CEO

Minerals Research Institute of Western Australia

About Mining in a low-emissions economy

Australia's mining and resources sector has a critical role to play in the transition to net zero emissions by 2050. The potential is enormous, as are the benefits.

But where are the opportunities? What should be prioritised? And how do we turn ambition into action?

These questions are addressed in this practical analysis, developed by the Clean Energy Finance Corporation (CEFC) and the Minerals Research Institute of Western Australia (MRIWA), drawing on the expertise and insights of specialist consultants, ENGIE Impact.

The information is applicable to mining executives, operational leads and sustainability teams. It is presented in a package of three interlinked documents.

Mining in a low-emissions economy

Essential information for junior and mid-tier mining companies seeking to capture the economic and sustainability benefits of our low-emissions future, available in three practical and up-to-date documents.

01 

The compelling case for decarbonisation
The next frontier of sector growth, for industry leaders and executives.

02 

Technology solutions for decarbonisation
Comparative analysis of proven and emerging technology options.

03 

Roadmap to decarbonisation
Understanding what to prioritise, drawing on a simulated mining operation.

Download all three documents via:
cefc.com.au or **mriwa.wa.gov.au**

01
The compelling case for decarbonisation

The compelling case for decarbonisation

The case for addressing decarbonisation is clear. Momentum is building, technologies for immediate action exist, and the commercial case is strengthening. Within Australia, the demand for low-emissions energy minerals and the decarbonisation of mining presents the greatest opportunity in a generation to diversify and grow the resources sector.

While pressure to decarbonise was historically driven by stakeholder interest and Environmental, Social, and Governance (ESG) expectations, the implications of the historic Paris Agreement have filtered down to commercial operations (1).

Access to cheaper capital and the mitigation of risks associated with corporate social responsibility and carbon liability are some of the opportunities decarbonisation can provide. Mining industry executives are seeing this and acting to deliver stakeholder and commercial competitive advantages. Those seen lagging behind are likely to suffer reduced competitiveness and risk their long-term sustainability.

While change is difficult, new sources of revenue, sustainability focused business models, investor appetite and new markets will drive change.

Mineral production is central to the world economy and its decarbonisation is a crucial step towards achieving sustainable climate action.

The mining sector is an enduring cornerstone of the Australian economy. Today, there are about 350 operating mines, and mining contributes more than 10 per cent to national gross domestic product (GDP). Resource and energy export earnings in 2021-22 are forecast to reach a record $425 billion (2).

Australia is among the top producers of the world's key mineral commodities, many of which are crucial to the low-emissions economy of the future, including lithium, tantalum, bauxite, ilmenite, manganese, copper and nickel (3). With almost all renewable energy technologies relying heavily on mineral commodities, decarbonising mining is a compelling opportunity to align financial and sustainability goals for competitive advantage, both now and in the longer term.

Addressing the complexities of climate change challenges how every sector of the global economy operates. It requires comprehensive change across many areas of economic activity – from energy production to infrastructure, manufacturing, transport, agriculture and waste, to name a few.

Mining and mineral processing intersects with these industries, presenting a broadscale opportunity to drive diversification and growth on the back of the shifting demand for new low-emissions minerals, while also capturing the economic and sustainability benefits of delivering net zero emissions across new and existing mining operations.

A decarbonised future presents a significant transition from business-as-usual (BaU) for Australian mining. De-risking key technologies, understanding the required development pathways, and demonstrating their applications in mining operations are crucial factors in the sector's transition to net zero emissions.

- **Momentum is building**: Global markets have created an imperative to decarbonise. While delaying action may lead to greater scrutiny from investors, customers, communities and regulators, the energy transition presents a clear opportunity for proactive mining companies to establish competitive advantage. This global energy transition is putting a focus on sustainable supply chains, driving significant new demand for minerals and metals, of which Australia has a comparatively large share. Those that embrace decarbonisation will be well-positioned for this growing demand for cleaner supply chains and the related availability of capital.

- **Low-risk technology exists**: There are a range of low-risk technology investment options which can be made in the short term to accelerate decarbonisation of mining operations. Many renewable energy technologies[1] are technically mature and commercially viable, providing immediate opportunities to reduce greenhouse gas emissions and operating costs. Early movers have an opportunity to differentiate their greener products to the market.
- **The economics stack up**: In Australia, zero-carbon or net zero mining is becoming the expected goal as the business case continues to improve, even for assets with complex decarbonisation challenges. Abundant and cheap renewable energy provides favourable economics over traditional fossil fuel energy systems. In many cases, despite additional capital requirements, the financial case to decarbonise is positive without consideration of emission reduction benefits. Access to lower costs of capital[2], and the potential to charge higher premiums for low-carbon products, further reinforce the business case.

1. Refer to the 'Stationary energy' section of 'Technology solutions for decarbonisation: Mining in a low-emissions economy'.
2. See Newmont example, Case study R within 'Technology solutions for decarbonisation: Mining in a low-emissions economy'.

Decarbonisation in action
Ark Energy hydrogen trucks support green zinc

The CEFC has committed up to $12.5 million to Ark Energy Corporation to finance the production of green hydrogen at the Townsville SunHQ H2 hydrogen hub, through the Advancing Hydrogen Fund (4).

The investment supports the construction of hydrogen production and refuelling infrastructure for the Sun Metals zinc refinery, with green hydrogen produced from an electrolyser powered by the Sun Metals solar farm. It will also finance five purpose-built, zero-emissions, ultra-heavy duty Hyzon hydrogen trucks (Figure 1).

The hydrogen fuel-cell electric trucks will deliver zinc ore from Townsville Port to the Sun Metals zinc refinery where they will refuel with green hydrogen before transporting the refined zinc ingots to port in a 30 km clean-energy round trip.

Figure 1
Hyzon motors road train similar to those to be used for Ark Energy.

The demand upside

The energy transition is driving new demand in a range of sectors and minerals. Commodities such as lithium, graphite, cobalt and nickel are expected to benefit from significant tailwinds driven by increasing battery demand, more than offsetting the headwinds posed by declining demand for high emitting fossil fuels.

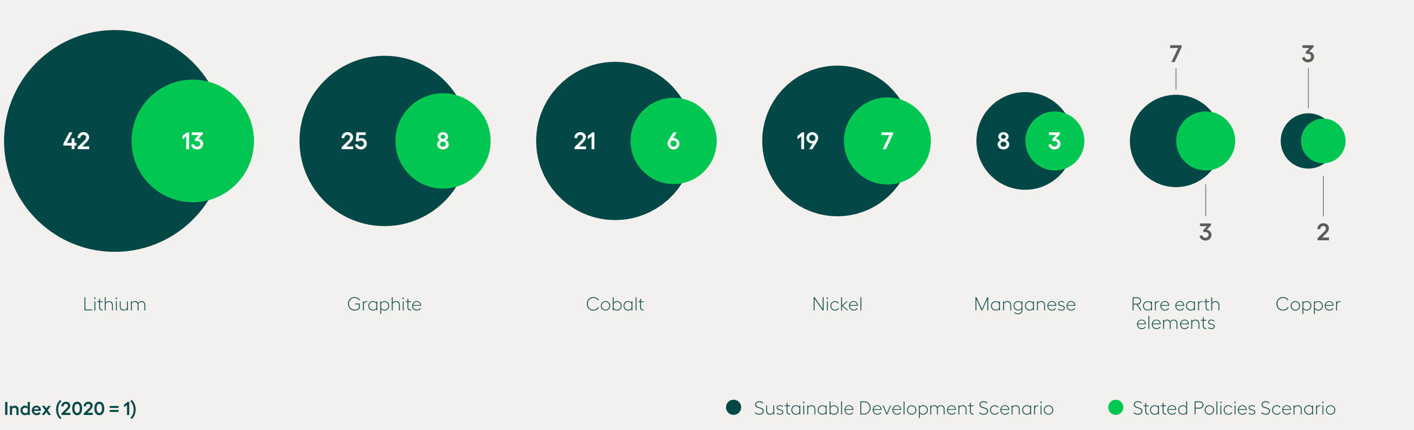
- Iron ore, bauxite, lead, chromium and manganese demand will grow, with increased recycling rates moderating demand for raw materials.
- Nickel, cobalt, lithium and rare earths will experience a surge in demand as the electrification of transport and battery storage accelerates.
- Copper growth will reflect demand for wind turbines, solar panels, transport and battery storage, with increased recycling rates again moderating demand for raw materials.

Commodities aligned with clean energy technologies appear likely to see the greatest economic opportunities, driven by compounding growth and demand intensity (Figure 2). Since 2010, the average amount of minerals required to deliver a new unit of power generation has risen 50 per cent as renewable energy capacity has grown (5). The increase in demand is driven by market participants looking to capture the economic benefits of the energy transition, as well as delivering their decarbonisation commitments, including reducing Scope 3 emissions[3].

There will likely be differentiation, based on carbon intensity, within the production of each commodity. The ability to ride the growth of demand in each commodity will partly be determined by the sustainability of production processes and the relation to technologies such as electro-chemical batteries and renewable energy generation.

Australia is well placed to benefit from this growth in demand through raw materials and, potentially, refined products. The country's stable investment environment and governance arrangements make it an attractive choice for providing secure mineral supply that is responsibly produced (6). Australia currently holds significant portions of both global mine production and economically demonstrated resources (EDR) for key commodities (Figure 3).

Figure 2
Example of growth in critical energy minerals demand from 2020 to 2040. Data from IEA 2021 (5).

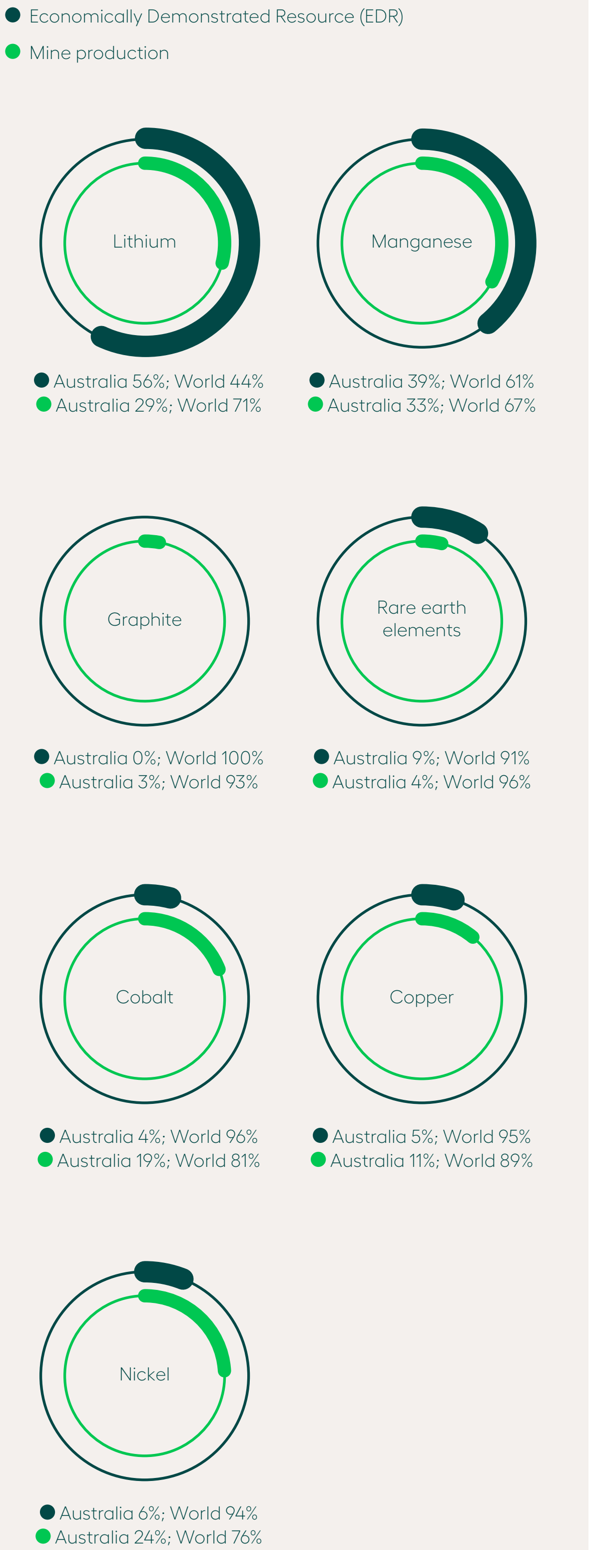


3. Scope 1 greenhouse gas emissions are the emissions released to the atmosphere as a direct result of an activity. Scope 2 are the emissions released to the atmosphere from the indirect consumption, for example consuming electricity generated from a fossil fuel source. Scope 1 and 2 emissions are generally within an organisation's operational control. Scope 3 emissions occur as a consequence of the activities of a facility, but are indirect and from sources not owned or controlled by that facility's business. For example, emissions from the extraction and production of purchased materials or the use of sold products and services. Scope 3 emissions are increasingly considered in corporate target setting and by those evaluating emissions performance.

Figure 3

Economically demonstrated resource (EDR) and mine production: Australia vs world in 2019.

Source: GeoScience Australia 2020 (7).



Decarbonisation in action

WA mine sees greener future with lithium ore

The CEFC has committed ~$50m to Pilbara Minerals to support the development of the Pilgangoora Project, which includes two processing plants (8). Pilgangoora, 120 km from Port Hedland in WA's resource-rich Pilbara region, is one of the largest hard rock lithium deposits in the world and is considered strategically important within the global lithium supply chain.

The scale and quality of the Pilgangoora Project provide Pilbara Minerals the ability to expand its operations to meet the growing demand for lithium raw materials to support the rapid adoption of clean energy technologies globally. As part of the CEFC investment, Pilbara Minerals is implementing additional sustainability targets at Pilgangoora, which are expected to set important new low-emissions benchmarks in the mining sector. These include installing renewable energy, completion of a lifecycle assessment to understand Scope 3 emissions up to the point of lithium hydroxide production, and planning a pathway to achieve net zero emissions in its operations. Pilbara Minerals will also adopt external reporting in line with the Task Force on Climate-related Financial Disclosures (TCFD).

Figure 4

Pilgangoora Lithium Mine.

Carbon context

The mining industry will have a significant role to play for Australia to achieve its stated goal of net zero emissions by 2050.

Mining is considered a hard-to-abate sector, reflecting the high energy intensity of mining activities, the heavy reliance on emissions intensive fuels and the requirement for thermal energy in processing activities not easily provided by renewable energy generation. The geographic location of mines, in edge-of-grid or off-grid areas, also shapes operating emissions profiles.

In 2019, mining represented 6.2 per cent (Figure 5) of Australia's energy demand and 9.5 per cent of greenhouse gas (GHG) emissions (Figure 6). While ranking behind transport, electricity supply and manufacturing in terms of total energy consumption, the average annual growth rate in energy consumption in the mining sector was 8.6 per cent over the past 10 years, far outstripping growth in other sectors. (9) While transport demand increased 0.5 per cent on average over the same 10 years, consumption fell 2.8 per cent in manufacturing and one per cent in electricity supply on average.

Similarly, the growth in mining-related emissions outpaced that of other sectors from 1990 to 2019. (10) Direct emissions from mining increased 115.6 per cent or 53.5 $MtCo_2$-e over the period, almost double that of the services, construction and transport sectors – collectively up 64.3 per cent or 24.4 $MtCo_2$-e. Direct emissions from the residential sector were up 31.5 per cent or 15.7 $MtCo_2$-e over the same period, ahead of electricity, gas, water and waste, which saw a 24.0 per cent increase, or 36.1 $MtCo_2$-e.

The energy profile comprising overall demand varies considerably from one mine to another, driven by the type of activities and equipment requirements, variation in operational characteristics and expected mine life (Figure 7 and Figure 8). Major sources of emissions generally arise from the core activities of material movement, in-mine operations, energy generation and processing. Mining diesel, in this context, is generally mobile diesel used in material movement, in-mine operations, and non-power generation.

As Australia exports a substantial proportion of its mined production as ores and concentrates, the associated transportation emissions, especially from shipping, are substantial and harder to address. One way of reducing these emissions is through supply chain carbon optimisation, and further processing and beneficiating of mined products in Australia.

This reduces the carbon footprint of the final product through reduced shipping of 'waste' associated with the shipment of low-grade ores and concentrates. This will ultimately require substantial restructuring within supply chains to minimise emissions.[4] The *Mining in a low-emissions economy* reports do not focus on such initiatives, but on the practical approaches that existing and planned mines can take to improve operational emissions profiles.

Figure 5
Net energy consumption in Australia by industry in 2019. Source: DISER 2021 (9).

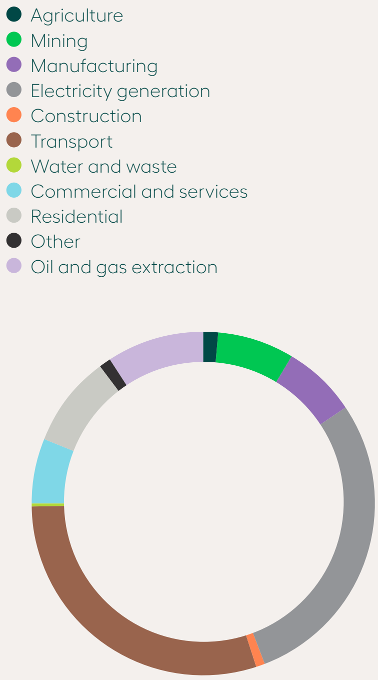
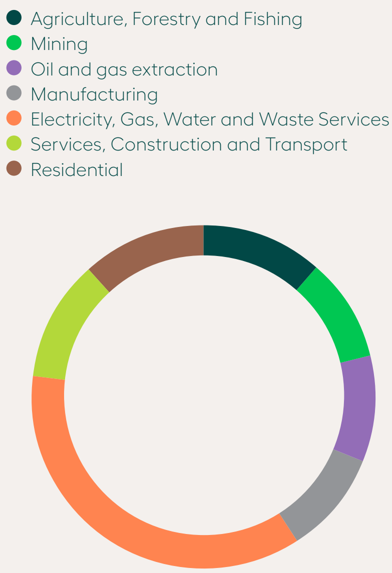


Figure 6
Scope 1 & 2 carbon emissions in Australia by economic sector in 2019. Source: DISER 2021 (10).



4. Comminution is a form of physical processing where ore is sized down through processes of crushing, screening and other processes.

Figure 7

Energy profile of various open pit mines. Source: Engeco 2021 (11).

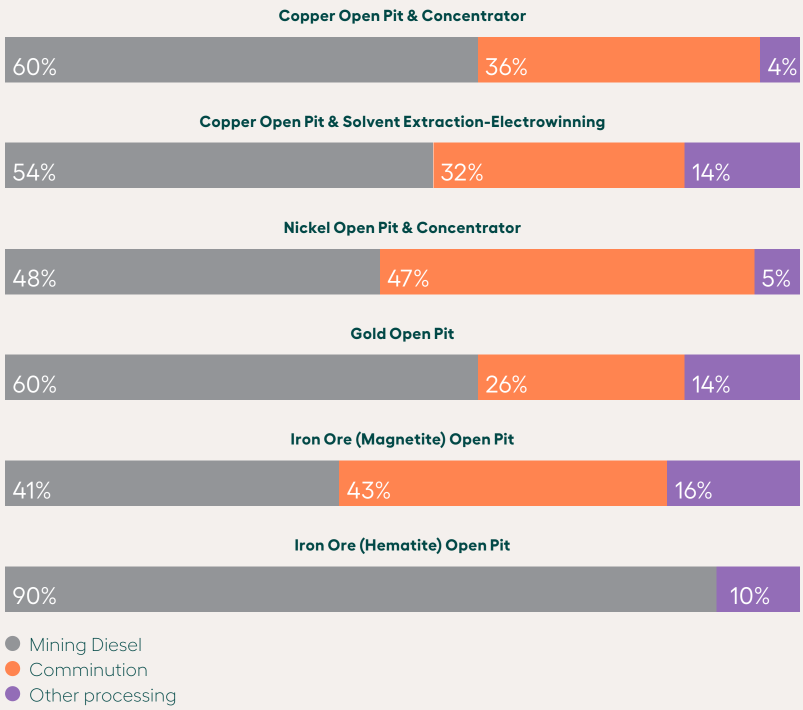
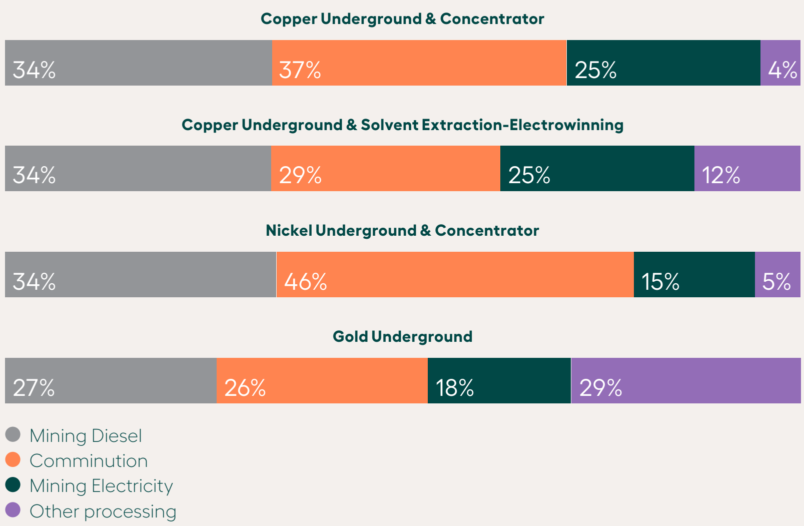


Figure 8

Energy profile of various underground mines. Source: Engeco 2021 (11).



Decarbonisation in action

Leveraging of green-capital – Newmont

In March 2021, Newmont Corp was able to convert its US$3B debt facility to an ESG-linked facility by linking the interest payable under the facility to its corporate ESG performance. The debt facility was restructured such that Newmont is rewarded/penalised with a lower/higher interest rate based on its ESG performance (12).

The facility references the ESG ratings of Newmont from MSCI and S&P Global. MSCI ESG ratings measure a company's management of financially relevant ESG risks and opportunities. It uses a rules-based methodology to identify industry leaders and laggards according to their ESG risks and compares their performance against peers. MSCI ESG Ratings range from leader (AAA, AA), average (A, BBB, BB) to laggard (B, CCC).

Similarly, S&P Global Ratings' ESG Evaluations assesses a company's ESG strategy and ability to prepare for potential future risks and opportunities. Once S&P Global Ratings has determined the company's ESG profile and preparedness, they are combined to produce a relative overall ESG Evaluation score on a 100-point scale.

Under the Newmont debt facility, if Newmont achieves an ESG rating of AAA from MSCI (or above 90 from S&P), Newmont will receive a 0.05 per cent reduction in interest on its drawn balances. For an ESG rating of AA from MSCI (or 88-89 from S&P) the interest rate will reduce by 0.025 per cent. However, if its ESG performance drops to BBB or below BB from MSCI (or 81-82 or below 80 from S&P), the interest on its drawn balances will increase by 0.025 per cent or 0.05 per cent respectively (12).

While this Sustainability Linked Loan (SLL) structure was the first of its kind for the mining sector, there are clear indications across the finance sector that these type of facilities and loan covenants are going to become the norm (13) (14).

The evolving financial landscape

- **Access to capital**: Financial institutions are rewarding decarbonisation with access to both equity investment and debt finance. For ambitious decarbonisation, relatively cheaper finance may be available, such as through green bonds or SLLs as shown by Newmont and others. In Australia, the CEFC is playing a leading role in catalysing investment to accelerate decarbonisation through project finance, debt market solutions such as green bonds, and equity instruments.
- **Emerging carbon instruments**: Instruments such as high-integrity carbon offsets may be used to manage residual emissions from hard-to-abate activities, where low-emissions technologies have not reached commercial readiness or where a company has been unable to put in place other measures to effectively reduce emissions in line with a zero-emissions goal. High-integrity carbon offsets are generated by emissions reduction projects that either absorb or avoid CO_2, contributing to abatement outcomes in line with the ambitions of the Paris Agreement. High-integrity offsets also deliver co-benefits such as biodiversity outcomes, regional employment outcomes and social benefits.
- The Australian Government regularly reviews the credibility of carbon offsets, and eligible offsets need to meet integrity requirements under the Climate Active Carbon Neutral Standard to ensure they represent genuine abatement (15). The Climate Change Authority is conducting a review of international carbon markets and will provide advice on the future use of international offsets. (16) In July 2022, the Government announced that Professor Ian Chubb is reviewing Australian Carbon Credit Units (ACCUs) and the carbon market on behalf of the Government. (17) The recommendations are to be submitted to the Minister by 31 December 2022. Best practice offset usage is not mutually exclusive with abatement on the mine site. A successful decarbonisation strategy will usually factor in the commodity pricing of carbon and will ideally use carbon instruments solely to manage residual risk. In the future, it is expected interest will increase in the co-benefits arising from carbon instruments, assisting companies to achieve other ESG aims.
- **The risk of carbon border taxes**: Carbon border taxes are a policy instrument being proposed to support the transition away from fossil fuels by Australia's major trading partners (18), such as the European Union Carbon Border Adjustment Mechanism. These taxes aim to counter 'carbon leakage', where businesses opportunistically source cheaper commodities from countries with less stringent emissions regulations. Australian mining companies who do not move forward with decarbonisation but produce commodities tied to export markets, may experience the negative financial impact of carbon border taxes.
- **Product pricing premiums**: Discussion of the emergence of pricing premiums for clean, low-carbon products has been building in recent years. The European aluminium market illustrates this development with S&P Global Platts quoting evidence of a $US59/t premium for a long-term, low-carbon aluminium contract in 2021, an increase over the commonly held $US10-15/t view (19). Leading investors have expressed the view that commodities would increasingly be priced according to how they were produced, with some expecting a green premium for aluminium of up to $US350/t in the longer term (20). Similarly, premiums are expected to emerge in battery minerals before 2030, making carbon an emerging competitive issue for miners.

Focus on governance and risk

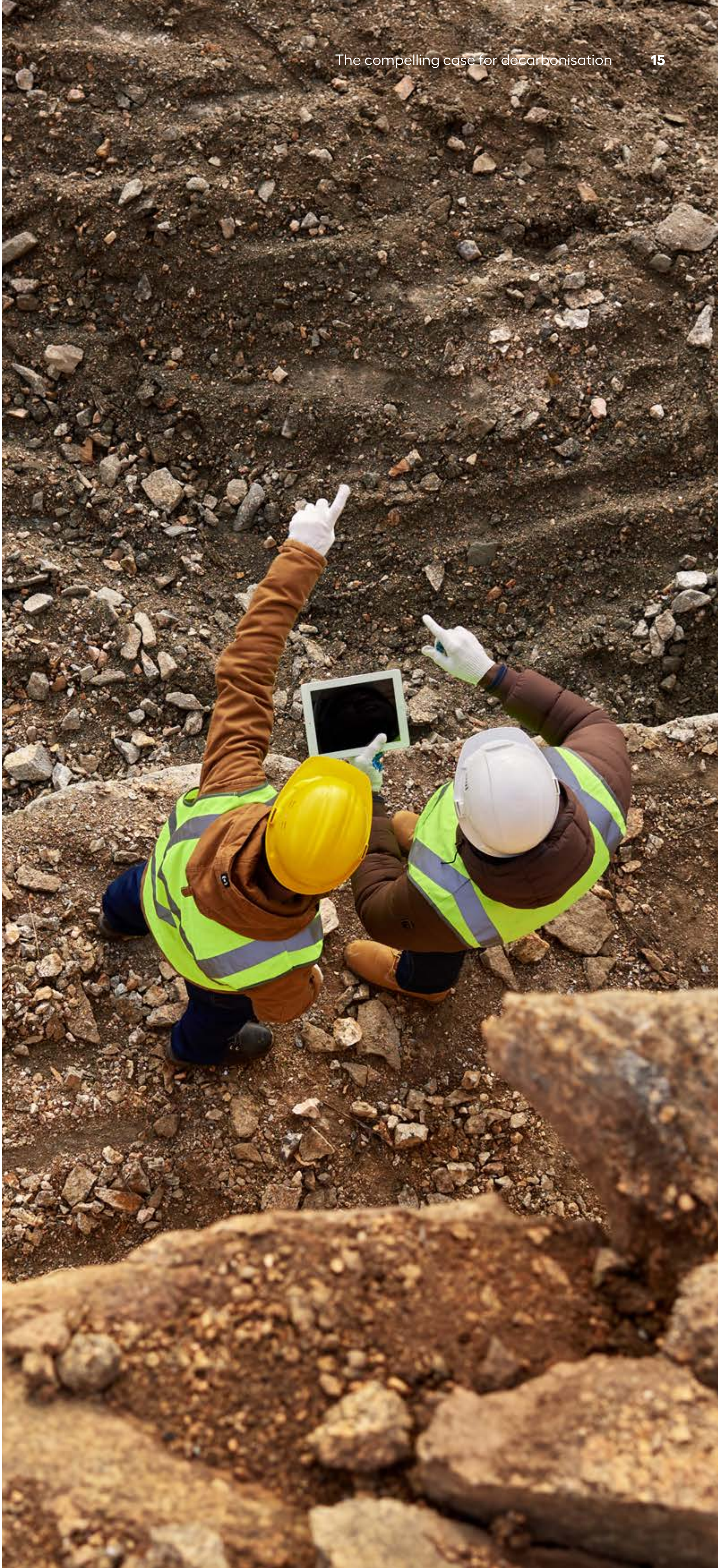
- **Investor scrutiny**: Investors are becoming more outspoken about the need for greater transparency on emissions reduction and the broader economic and environmental impacts of climate change. Australian mining companies are responding by leveraging frameworks such as the TCFD, the Carbon Disclosure Project and the United Nations Sustainable Development Goals to enhance their disclosure of climate-related risks and opportunities. The Investor Group on Climate Change has consolidated elements of these frameworks into useful guidance for companies developing climate transition plans (21).
- **Regulatory scrutiny**: Australian regulators have signalled their expectations for disclosure and management of climate risk. The Australian Securities and Investment Commission has emphasised the responsibility of company directors to ensure appropriate governance structures are in place, with reliable and useful information being disclosed while warning against so-called 'greenwashing' (22).
- The Australian Prudential Regulation Authority (APRA) has released a prudential practice guide on climate change financial risks, which is designed to assist banks, insurers and superannuation trustees to manage the financial risks of climate change (23). The APRA guide notes that a prudent institution will consider both the financial opportunities and the financial risks of climate change, and APRA-regulated entities are encouraged to use the guidance immediately.
- The Reserve Bank of Australia has also noted that "climate change is a first order risk for the financial system" (24).

- **Director scrutiny**: A ground-breaking legal opinion on climate risks and directors' duties, commissioned by the Centre for Policy Development in partnership with the Future Business Council, has elevated the conversation on climate change to boardroom leaders. As global understanding of climate change continues to mature, so too does the duty to act on this foreseeable risk.

" … company directors who ignore or mismanage climate-related risks could be held personally liable for breaching their legal duties under the Corporations Act." (25)

- **Social licence to operate**: Australian mining companies rely heavily on a 'social licence' to operate. Activities leading to emissions are among those that pose considerable reputational risks. Mining companies failing to have a clear plan to decarbonise or to act on that plan, risk reputational consequences with lasting effects on long-term value.

The CSIRO report, "How social licence is driving innovation in the mining industry said: "Unlike fixed, tangible environmental and legislative licences issued by governments, the relationship between a company and community that constitutes a social licence is under constant renewal and renegotiation." (26)




ENERGY
STORAGE

02 Technology solutions for decarbonisation

Technology solutions for decarbonisation

Technology plays a significant role in the decarbonisation of mining, whether in terms of energy source and demand, or emissions impact. Understanding current and emerging technologies and the applications presents a challenge for the mining sector, given the pace of change and the individual circumstances of each mining operation.

The major sources of emissions from the mining industry are generally associated with energy generation, material movement, in-mine operations and mineral processing.

A comparative analysis of stationary energy and material movement technologies, scoring each based on a range of social, technical, market, regulatory and economic factors, is a useful tool for decision makers. The resulting **decarbonisation scores provide a reference point, in advance of site-specific planning and assessment, with scores towards a maximum of 10 representing higher decarbonisation potential and commercial readiness.** For mineral processing applications and in-mine operations, assessment of the ease of electrification and the potential to contribute to decarbonisation provide useful insights.

The highlights of the comparative analysis completed to inform this work are presented below. For the detailed analysis and methodology behind the decarbonisation scores, please visit the CEFC or MRIWA websites to download: Technology solutions for decarbonisation: Mining in a low-emissions economy.

Energy requirements

Mines are large energy consumers, particularly with respect to gas and diesel fuel. While some processes require a specific fuel input, technological developments mean others are increasingly compatible with alternative, lower emissions energy sources.

Decarbonising stationary energy requirements is an important first step for immediate emissions reduction potential and the ability to unlock future reductions. Stationary energy for power generation is a significant contributor to the cost and total energy requirements of mines, and can exceed 60 per cent of total energy requirements for some commodities (11). Priorities include:

- **Renewable energy generation**: Solar and wind power will play an increasingly important role in the decarbonisation of electricity generation, having achieved the lowest levelised costs of energy and are deployed at scale in Australia. Bioenergy technologies including biogas and biodiesel are also emerging opportunities for mine site generation. Paired with energy storage, renewable generation can provide dispatchable power to match the energy demand profile of a mine.

Figure 9
Decarbonisation scores for key energy generation technologies

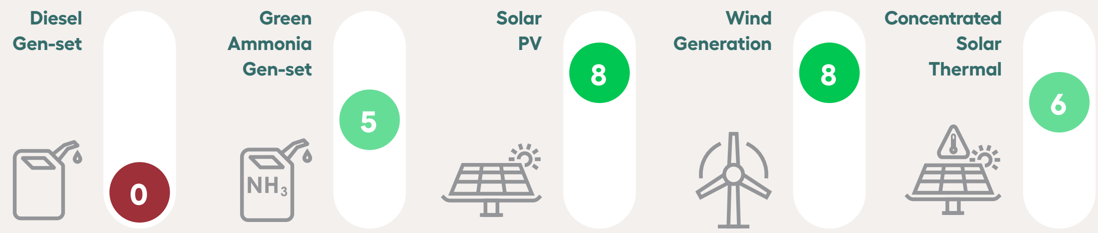
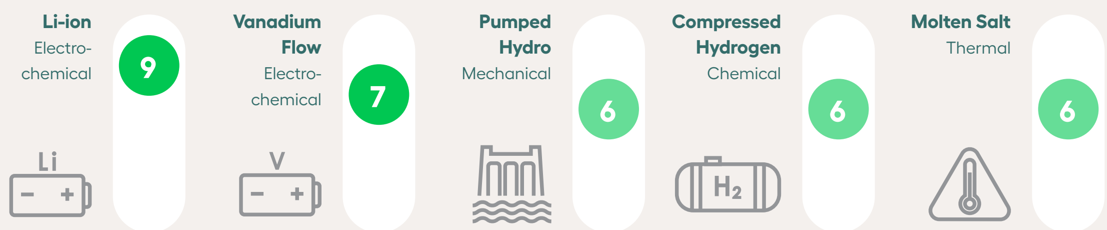


Figure 10
Decarbonisation scores for key energy storage technologies



- **Energy storage technologies**: Lithium-ion batteries (Li-ion) are the primary energy storage technology currently in use, particularly for short-term storage applications[5]. Vanadium flow batteries are attracting increasing interest due to their suitability for long-term storage and longer service life than Li-ion batteries. Disused mine pits may be transformed into pumped hydro storage in some situations.

Technology insights

- **Renewable energy leads decarbonisation impact**: Oversized solar installations and well located wind generation can deliver low cost, zero-emissions electricity and charge batteries for night-time energy consumption. Bioenergy also needs to be considered.
- **Energy storage offers broader solutions**: Modularity, energy density and declining costs make Li-ion batteries suitable for most applications, with vanadium flow batteries gaining traction for longer term storage applications.
- **Green hydrogen and green ammonia gain momentum**: Improving production processes are increasing access to these energy sources, which are suitable for critical mining and processing needs, including chemical reduction and process heat, as well as storage and transport applications.

Practical considerations

- **Focus on stationary energy first**: To address a large part of the immediate decarbonisation challenge and create opportunities for ongoing electrification of other activities.
- **Invest in energy storage as an enabler**: For power quality and flexibility, delivering on demand integration and dispatch of renewable energy.
- **Connect and/or build network connections**: With neighbouring grids and generation assets where possible, to share costs in creating geographic and technology diversification and reducing outage risks.

5. Refer to Storage technologies within 'Technology solutions for decarbonisation: Mining in a low-emissions economy'.

Decarbonisation in action
Hybrid generation – Gold Fields

Gold Fields' Agnew mine, approximately 870 km north-east of Perth, is leading the way in the transition to renewable power for off-grid mining operations (27). The Agnew Hybrid Renewable Project is Australia's largest hybrid renewable energy microgrid and the first mine in Australia to utilise large-scale wind generation at a mine site.

The Agnew microgrid consists of 18 MW gas and 3 MW diesel generation, a 10,000-panel 4 MW solar farm, five wind turbines delivering 18 MW, a 13 MW/4 MWh battery energy storage system (BESS) and an advanced micro-grid control system. EDL owns and operates the micro-grid as part of a Power Purchase Agreement (PPA) with Gold Fields.

Since the commissioning of the microgrid, 54 per cent of Agnew's electrical power is renewable source power, resulting in a 42 per cent net emissions reduction (28), and under the right conditions, more than 85 per cent of the site's electrical power can be generated by the solar farm and wind turbines (27).

The total project cost was \$111.6M, with \$13.5M funded by the Australian Renewable Energy Agency (ARENA) (29). The Agnew hybrid microgrid is forecast to reduce the mine's carbon emissions by 40,000 tCO_2-e/year (29), contributing to Gold Fields' recent commitment to reduce its Scope 1 and 2 carbon emissions by 30 per cent on a net basis and 50 per cent on an absolute basis by 2030 (30).

The Agnew project demonstrates that technology and commercial risk can be mitigated, providing a blueprint for other companies to deploy similar off-grid energy solutions and demonstrating a pathway for commercialisation (29). The outcome of this project also provides key learnings for Gold Fields to consider as it develops similar and even more ambitious strategies at other mine sites.

Figure 11
Wind turbines at the Agnew Renewable Energy Microgrid (image courtesy of EDL).

Material movement

Material movement is dominated by diesel-fueled internal combustion engines, commonly accounting for 30-50 per cent of onsite energy demand across commodity groups (11). If integrated at the start of a mine's life, capital-intensive technologies, such as trolley-assist for electrified haulage and in-pit crushing and conveying, offer effective and long-term decarbonisation solutions. Fuel switching or indirect electrification (through green hydrogen or green ammonia produced with renewable electricity) is likely to be more suitable for operations with shorter mine lives, and brownfield sites.

Technology insights

- **Trolley assist**: Historically proven, advanced solutions exist to support haulage electrification at appropriate mine ramps, particularly in new build scenarios.
- **Battery electric vehicles**: Proven benefits in small to mid-sized vehicles, personnel carriers and underground applications, with range and battery technologies evolving for larger vehicles.
- **Green hydrogen/fuel cell electric vehicles**: Gaining increasing focus and investment to achieve commercial readiness, especially for larger and long-haul vehicles.

Practical considerations

- **Decarbonise electricity and electrify first**: Electrification using renewable energy will cut emissions and operating costs, and unlock co-benefits in complementary technologies such as transport and automation.
- **Invest in material movement**: As the scale of material movement emissions is significant, decarbonisation provides a significant opportunity to become best-in-class, broadening investor appeal.
- **Coordinate infrastructure investment**: Combine new electrification infrastructure investments with other relevant decarbonisation initiatives to maximise value, whether in designing new operations or retrofitting existing approaches.
- **Underground operations offer earlier opportunities**: Development of electrified underground technologies is more mature and offers more timely decarbonisation benefits while open pit solutions gain momentum.
- **Plan to save emissions and cost**: Mine planning is an important risk mitigation measure to ensure mine design is compatible with low-emissions technologies, avoiding sunk costs and maximising life-of-mine returns.

Figure 12
Summary of decarbonisation scores for key haulage technologies

Figure 13
Summary of decarbonisation scores for key rail technologies

Decarbonisation in action

Electric mining trucks – Caterpillar + BHP

BHP and Caterpillar have entered an agreement to develop and deploy zero-emissions battery powered large mining trucks at BHP sites to reduce its operational GHG emissions (31).

These new trucks will be designed and built by Caterpillar and facilitate the path of zero-emissions mining worldwide. This milestone is the result of 12 months of close collaboration between BHP and Caterpillar in analysing the energy demands and the options to apply this new technology on BHP sites (32). BHP will provide input to the development and testing processes of these trucks.

Hydrogen powered trucks – FMG

Fortescue Future Industries (FFI) has completed the design and construction of the world's first hydrogen powered demonstrator haul truck, with systems testing now underway in Perth, WA (33). This is a fuel-cell electric vehicle (FCEV) utilising both hydrogen fuel cells and batteries.

FFI's Green Team are trialling technology on hydrogen, ammonia and battery power for locomotives, ship engines, haul trucks and drill rigs for technology demonstration purposes. Prototype machines will be developed and deployed to Fortescue Metals Group (Fortescue/FMG) sites.

Haul trucks at Fortescue mine sites account for 26 per cent of their Scope 1 operational emissions in 2021 (34), therefore decarbonising haul trucks either by hydrogen or electric fleets will have a substantial impact on Fortescue's carbon footprint across their operations. The hydrogen FCEV in these prototypes will produce no harmful fumes, and the only exhaust produced will be water.

Figure 14
FMG hydrogen haul truck trial (image courtesy of FFI).

In-mine operations

Outside of material movement, operational activities within a mine vary widely depending on the mine's maturity, stage of development, commodity and deposit characteristics. These activities generally represent a smaller proportion of total energy requirements compared to material movement. They may also have a lower emissions profile. With in-mine operations largely in fixed locations, electrification can be easier to achieve as a key decarbonisation measure.

Technology insights

- **Drilling**: Electric drill options are readily available. A range of technologies exist and drills can either be electric, diesel-electric, or diesel-powered.
- **Blasting**: While decarbonising ammonium nitrate emulsion is challenging, embedded emissions can be decarbonised by suppliers using green hydrogen in ammonia production.
- **Excavation**: Electrification options are available for major equipment, such as backhoe excavators. Design for electrified equipment at the mine planning phase.
- **Loading**: Fully electric front-end loaders are available for underground mining. Decarbonised open pit solutions are in development with progress being made on mobility challenges.
- **Dewatering**: Electrification options exist for direct substitution of diesel-powered pumping in dewatering technologies, with demand expected to increase due to diminishing ore grade and deeper mines.
- **Ventilation**: Use electric solutions for heavy-duty ventilation fans and further reduce underground ventilation requirements by electrifying mobile equipment.

Practical considerations

- **Decarbonise electricity needs**: Significant decarbonisation can be achieved in in-mine operations, particularly underground, as significant amounts of equipment are already electric.
- **Invest in stationary energy**: Stationary equipment may be easier to decarbonise using renewable energy and energy storage compared with the diverse requirements of mobile equipment.
- **Manage ventilation requirements**: Electrification can reduce ventilation needs due to lower levels of heat generation and particulate emissions.
- **Address Scope 3 emissions**: For example, in explosives and reagents, especially where reductions in Scope 1 and 2 emissions are more difficult to achieve across the mining operation.

Figure 15
Summary of electrification and decarbonisation potential of in-mine operations

Activity / Original energy	Drilling / Physical	Blasting / Chemical	Excavation / Chemical	Loading / Chemical	Dewatering / Electrical	Ventilation / Electrical
Electrification potential	Moderate	Low	High	Moderate	High	High
Decarbonisation potential	High	Scope 3 Source	High	Moderate	High	High

Decarbonisation in action

Battery technology for heavy vehicles – 3ME Technology

3ME Technology (3ME Tech) has developed a scalable and powerful energy-dense Li-ion battery system, replacing diesel-powered engines in mining and defence vehicles with battery electric systems, cutting emissions and creating safer and more efficient mining operations (35).

According to 3ME Tech, its Bladevolt® battery system allows for remote performance monitoring of the battery packs, as well as a modular design that is powerful enough to transform a 20-tonne loader into a fully electric vehicle (36).

The technology can also be scaled to fit a variety of applications including light vehicles, personnel carriers, load-haul-dump vehicles, and integrated tool carriers. 3ME Tech's battery system incorporates novel safety features to prevent thermal runaway, which is extremely beneficial for underground mining (36).

The Bladevolt® battery system has been successfully retrofitted on underground mining equipment (36). 3ME Tech has been backed by the CEFC and Australian Business Growth Fund (ABGF) with $5m and $15m investments, respectively.

Figure 16
3ME Tech mine vehicle (image courtesy of 3ME Tech).

Mineral processing

While the range of commodities and the required processing solutions are diverse, there are opportunities to decarbonise mineral processing with the growing use of electrification of stationary energy in many mineral processing purposes and some heating applications.

While the electrification and, therefore, decarbonisation potential of physical processing and electrometallurgy is considered high, decarbonisation solutions for pyro-metallurgy and hydro-metallurgy are more complex. These solutions need to consider resource availability and embedded emissions associated with process inputs such as chemical reagents.

Technology insights

Physical processing

- **High degree of existing electrification**: Physical processing activities and equipment are already largely electrified and can be paired with renewable energy to support accelerated decarbonisation.
- **Load-management potential**: In energy systems with high renewable energy penetration, such as physical processing, demand-response techniques typically require more flexible milling and crushing production capability with intermediate buffers or stockpiles to match availability of renewable energy.
- **New comminution technologies**: Solutions such as vertical roller mills may provide greater flexibility to support higher renewable energy penetration.

Electrometallurgy

- **Complete electrification achieved**: Electrowinning uses electrical energy and therefore can be completely decarbonised when paired with renewable energy generation and battery storage.
- **Load-management potential:** There is potential to capitalise on flexible production and load management with enhanced demand-response techniques, by matching the electrowinning load with the profile of renewable energy generation.

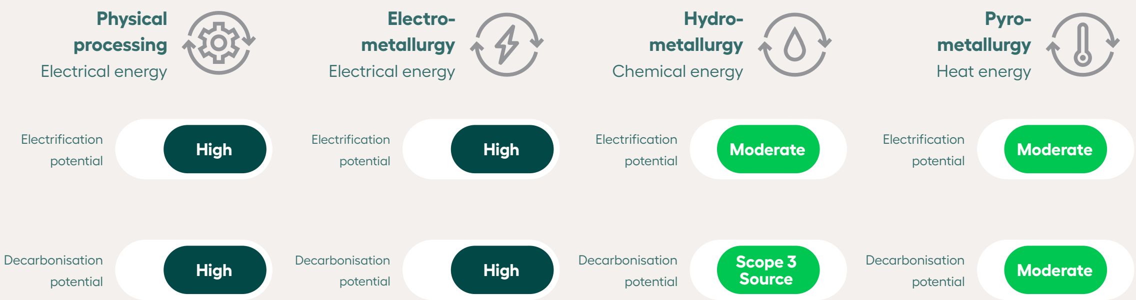
Hydrometallurgy

- **Little or no direct emissions**: Hydrometallurgy consists of many liquid and aqueous solution processing techniques, and as a result is rarely a source of significant direct process emissions. Pumps and agitators providing motive force are typically electrified.
- **Potential significant source of embedded emissions**: The upstream production and transportation of chemical reagents may produce significant Scope 3 emissions.
- **Work with suppliers**: It will be necessary to work with suppliers to signal and encourage zero-carbon production of required process inputs, particularly where organisational targets require Scope 3 emissions inventories and decarbonisation.

Pyrometallurgy

- **High-temperature processes can be electrified**: High-temperature pyrometallurgical applications are increasingly able to be heated directly with electricity, or indirectly through green hydrogen.
- **Consider hydrogen for chemical reduction**: Depending on the process, replacing carbothermic reduction techniques with hydrogen reduction techniques is becoming increasingly feasible.

Figure 17
Summary of electrification and decarbonisation potential for four high-level categories of mineral processing activity.



Practical considerations

- **Decarbonise electricity and electrify first**: Decarbonisation of mineral processing can be enabled by shifting energy consumption to electrical energy, which can be supported by renewables, load management and energy storage.
- **Green hydrogen can provide flexible electricity**: Green hydrogen can provide an indirect way to use renewable electricity supply, particularly where energy would be spilled due to excess production. While it may be less efficient than direct electrification, the flexibility of this stored energy can help unlock further electrification solutions.
- **Investigate alternative processing solutions**: For hard-to-abate processes, alternative inputs such as hydrogen to replace coke for reduction, or recovering and reusing waste heat, may achieve the desired product.
- **Consider future energy requirements**: As demand for minerals and metals increases, the depletion of currently defined ore bodies will accelerate. Over time, the quality of ore-bodies is likely to diminish, and the associated energy required to process ore and deliver the same amount of product will increase.

Decarbonisation in action
Mechanical vapour recompression – Alcoa

Alcoa of Australia Limited (Alcoa) is currently conducting technical and commercial studies to adapt Mechanical Vapour Recompression (MVR) technology to their refining process (37). Alumina refining accounts for approximately 24 per cent of Australia's direct, non-electricity (Scope 1) manufacturing GHG emissions, or 14 million tonnes annually (38). MVR technology is well understood, however it has never been implemented within the alumina industry or used on a large scale in Australia.

This project will trial MVR, using renewable energy to recycle waste steam that would otherwise be vented (39). If the feasibility studies are successful, Alcoa plans to install and commission a 3MW MVR module with renewable energy at its Wagerup Refinery in WA by the end of 2023 to test the technology at scale (37).

The total project cost is $28.2M, with $11.3M funded by ARENA (39). The MVR technology powered by renewable energy could reduce an alumina refinery's carbon footprint by 70 per cent (39). Using lower carbon alumina in smelting will help decrease the carbon footprint of aluminium and reduce emissions down the value chain. If this trial is successful, it will provide an electrification alternative to fossil fuels for thermal demand requirements within the alumina refining process.

Figure 18
Alcoa's Wagerup Refinery (image courtesy of Alcoa).

Credit:
Tristan Freemantle –
Gold Fields Australia

03
Creating a roadmap to decarbonisation

Creating a roadmap to decarbonisation

The use of decarbonisation pathways to form a roadmap provides a structured approach for decision makers to group and evaluate relevant technologies, while accounting for decarbonisation goals, budgets, risks, and other site-related constraints.

Developing a robust decarbonisation roadmap requires a clear understanding of the baseline energy and emissions profile of the mining asset and an assessment of applicable decarbonisation technologies.

With multiple competing technology solutions, and uncertainty around how these will mature, scenario analysis helps decision makers navigate complexity and reach conclusive assessments.

Decarbonisation pathways also establish options to cope with technology uncertainties and a changing commercial and regulatory landscape, while also helping decision makers distinguish between immediate low-risk investments and long-term strategic considerations.

Where to begin: The emissions mitigation/reduction hierarchy

The global Institute of Environmental Management and Assessment (IEMA) has developed an emissions mitigation/reduction hierarchy that prioritises the elimination of emissions ahead of reduction, substitution and compensation. The hierarchy can be used to guide companies in implementing decarbonisation strategies that meet business, investor sustainability and stakeholder expectations (Figure 19).

Roadmap essentials

Roadmap development typically consists of ideas generation and screening, opportunity definition, opportunity analysis, and the development of a logical sequence of actions.

An effective roadmap will ideally:

- **Be context driven**: Factor in mine-specific characteristics such as location, mine type, commodity type and the extent of on-site mineral processing.
- **Prioritise technologies**: Clearly outline low-risk technology investments that can be made in the short term.
- **Prioritise emissions**: Preference emissions avoidance ahead of emissions reduction or mitigation.
- **Be flexible**: Anticipate the rapidly evolving technology landscape, with medium and long-term flexibility between investment phases to capitalise on emerging solutions.
- **Be analysis driven**: Use scenario analysis supported by engineering-grade, techno-economic assessments.

Figure 19
IEMA GHG mitigation hierarchy

1. Eliminate

- Influence business decisions/use to prevent GHG emissions across the lifecycle
- Potential exists when organisations change, expand, rationalise or move business
- Transition to new business model, alternative operation or new product/service

2. Reduce

- Real and relative (per unit) reductions in carbon and energy
- Efficiency in operations, processes, fleet and energy management
- Optimise approaches (e.g. technology and digital as enablers)

3. Substitute

- Adopt renewables/low carbon technologies (on site, transport, etc.)
- Reduce carbon (GHG) intensity of energy use and of energy purchased
- Purchase inputs and services with lower embodied/embedded emissions

4. Compensate

- Compensate 'unavoidable' residual emissions (removals, offsets etc.)
- Investigate land management, value chain, asset sharing, carbon credits
- Support climate action and developing carbon markets (beyond carbon neutral)

Roadmap insights

The following strategies provide a good starting point for analysis and will support robust roadmap development:

- **Scenario-based analysis**: Significant decarbonisation can be achieved if the right solutions are applied in the right context. Scenario-based techno-economic assessments provide a valuable tool for comparing a range of decarbonisation pathways, building an asset-level decarbonisation roadmap, and informing decision making.
- **Decarbonise electricity and electrify first**: The first step towards a zero-carbon mining operation is commonly to decarbonise the electricity supply with renewable energy. In general, Australian mine sites have some of the best wind and solar resources available. Shifting mining and mineral processing activities to electric-powered solutions, where possible, is a leading strategy for decarbonisation and should be the focus in the short to medium term to support further decarbonisation.
- **Capitalise on emerging technologies**: The global energy transition is fuelling technology advancements at a rapid pace. Mining is a challenging industry to decarbonise, with significant investment being channelled to research and development of new technologies. Nevertheless, there are many promising emerging technologies competing with one another. Regularly monitoring developments in new technology will help inform investment decisions and those planning to lead on decarbonisation should also consider piloting emerging technologies and supporting research and development.
- **Collaborate to accelerate decarbonisation**: Commercial and strategic opportunities exist through collaboration. Working with stakeholders and peers reduces overall risk, shares learning and costs, and drives scale. Financial institutions, geographic clusters, original equipment manufacturers (OEMs), and research bodies all provide opportunities to share learnings, reduce risks and create economies of scale.

The power of collaboration

Collaborating with other entities, along the mining value chain and with peers, can accelerate the journey to zero-emission mining. Certain mining and processing activities are more difficult to decarbonise, due to being higher risk, energy-intensive, requiring capital intensive solutions or needing an entirely new set of workforce skills. Pooling knowledge and resources on these broader challenges creates opportunity for greater learning and access to the benefits of economies of scale.

Collaboration approaches that may accelerate decarbonisation in mining include:

- Trialling new technologies: Work directly with OEMs to communicate functional technology needs, including through development and implementation phases to mitigate risk once operational. Deepen understanding between OEMs and miners around the pipeline of emerging technologies, investment priorities and delivery timelines.
- Sharing challenges: Collaborate with peers to address decarbonisation challenges, such as pooling resources around project management, research and development, and knowledge sharing. Consider models such as the Future Battery Industries Cooperative Research Centre, the Electric Mine Consortium, Charge On Innovation Challenge, and the International Council on Mining and Metals' Innovation for Cleaner, Safer Vehicles initiative.[6]
- Pursuing regional decarbonisation at scale: Take advantage of geographic co-location along the mining value chain and with other industrial entities to achieve localised economies of scale. Capture infrastructure benefits in renewable energy generation and storage, electricity transmission, transport hubs and e-fuels, with pooled investment approaches to lower costs per unit.
- Developing offtake agreements: Work with customers to lock in offtake agreements for low-emissions energy, production and sustainability output underpinning the business case for capital outlays to deliver decarbonisation.
- Broadening the finance approach: Work with specialist financiers and research and development organisations, such as the CEFC and MRIWA, to access grant funding and tailored sustainability-linked capital solutions to accelerate the transition from development to large-scale deployment.

6. For further information see: https://fbicrc.com.au; https://www.electricmine.com; https://chargeoninnovation.com; and https://www.icmm.com/en-gb/innovation/cleaner-safer-vehicles/icsv-about

Credit: Courtesy EDL

04 Project Zero – Greening a copper mine

Project Zero – Greening a copper mine

Project Zero illustrates the road mapping process and simulates the impact of four decarbonisation pathways on a hypothetical 'typical' existing copper mine and processing operation. The highlights are presented below. For the detailed report, please visit the CEFC or MRIWA websites to download: Roadmap to decarbonisation: Mining in a low-emissions economy.

About Project Zero

- Development of an asset-level decarbonisation roadmap.
- Simulated exercise on a hypothetical established copper mine.
- Scenario-based technology and economic assessment.

About Mine Zero – initial status

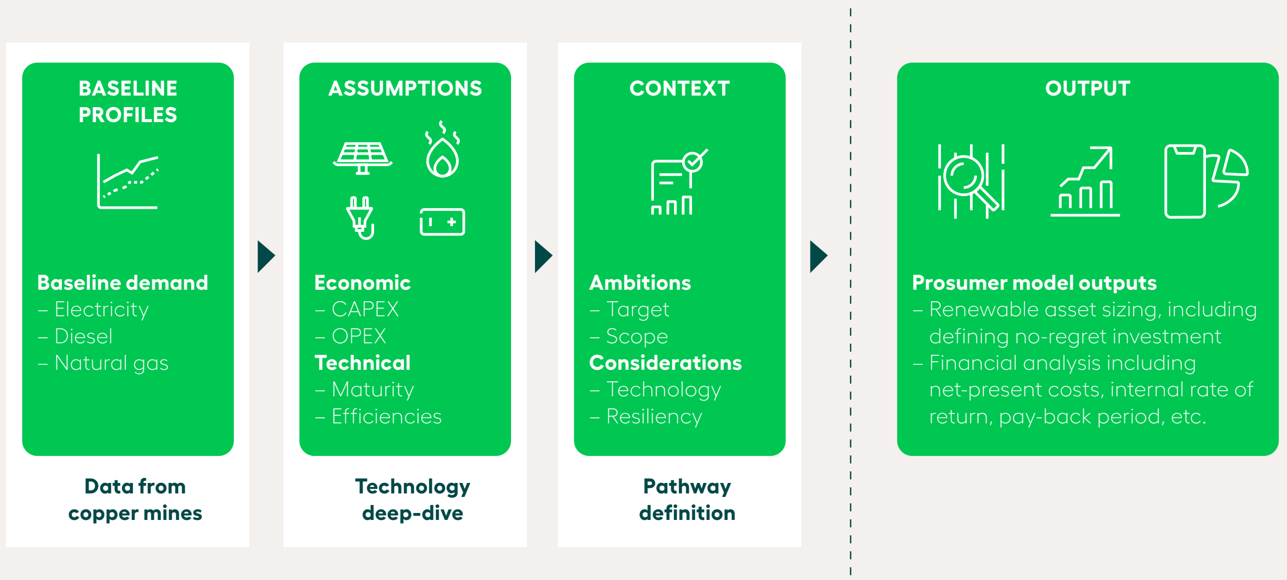
- Brownfield copper operation with on-site, mine-to-metal extraction and processing.
- Remaining mine life of 25 years, from 2025.
- Off-grid location.
- Total baseline annual energy demand: 1,486GWh, from electricity (43 per cent), diesel (40 per cent) and thermal (17 per cent).
- Use of on-site gas supply for power generation and smelting and refining thermal processing.
- Use of diesel for on-site equipment and mobility.
- Energy and emissions consistent with a mid-tier copper extraction and ore processing operation.
- Total annual emissions of 441ktCO_2-e.
- Net present energy costs over 25 years are $2.77 billion, assuming 7 per cent weighted average cost of capital and excluding costs of carbon (base case).

Modelling and analysis

The project used Prosumer, an optimisation and energy modelling software tool developed by ENGIE Impact to conduct extensive modelling and analysis for the simulation to determine:

- **Optimum combination of energy assets**: Including capacity and ability to exploit multiple energy carriers (e.g. electricity, heat, hydrogen, diesel).
- **Range of suitable technological options**: As well as the associated emissions footprint (e.g. solar PV, batteries, demand response, heat networks).
- **Budget considerations**: Regarding both investment levels and the ability to capture benefits over the life of the mine, based on a discounted cash flow model to aid quantitative evaluations per pathway.
- **2040 net zero target**: In line with public announcements by various mining companies.

Figure 20
Prosumer modelling: key input and outputs



Modelled decarbonisation pathways

There are many possible pathways to achieve a zero-carbon mining operation. However, selection of the most cost-effective pathway requires defining and modelling distinct and diverging decarbonisation options, and consideration of specific technologies. The four pathways considered for Mine Zero are:

1. **Established Technology**: A low technology risk pathway relying on technology that has reached technical and commercial maturity with carbon offsets for residual emissions.
2. **Electrification**: An electricity-centric pathway that aims to achieve zero-carbon by utilising direct and indirect electrification strategies where possible.
3. **Hydrogen Importer**: A hydrogen-centric pathway that relies on indirect electrification (e-fuel imports) for thermal processes and mobility.
4. **Hydrogen Producer**: A closed energy system pathway focused on energy resilience with on-site production, including hydrogen, meeting the mine's energy demand.

Implementation phases

1. **Phase 1**: Uses commercially mature technologies to implement a 'no-regrets' solution across each pathway, with renewable energy found to fit these goals.
2. **Phase 2**: Builds on Phase 1 with technology investments into emerging technologies to, for example, decarbonise thermal demand and in-mine equipment through electrification and green hydrogen.
3. **Phase 3**: Builds on previous phases to address the most challenging sources of emissions, such as material movement, and achieve zero or net zero emissions operations.

Project Zero: Technology and energy considerations

Technological solutions modelled for Mine Zero consider the diverging decarbonisation options and cost-effective application of specific technologies. The key technology and energy considerations applicable to the four pathways modelled for Mine Zero are shown in Table 1.

Table 1: Four decarbonisation pathways modelled for Mine Zero

	Business-As-Usual	Established Technology	Electrification	Hydrogen Importer	Hydrogen Producer
Emissions targets	Not established	Net zero emissions by 2040	Zero emissions by 2040		
Technology risk profile	Low	Low	Medium	High	High
Electricity generation options	Gas	Solar Wind	Solar Wind Concentrated solar + thermal storage Pumped hydro e-fuel: imported green hydrogen or green ammonia	Solar Wind Concentrated solar + thermal storage Pumped hydro e-fuel: imported green ammonia	Solar Wind Concentrated solar + thermal storage Pumped hydro e-fuel: green hydrogen produced on site
Energy storage options	Not used	Li-Ion	Li-Ion Vanadium Flow Sodium sulphur	Li-Ion Vanadium Flow Sodium sulphur Imported green ammonia	Li-Ion Vanadium Flow Sodium sulphur Green hydrogen
Thermal demand	Gas	Evaluate electrification	Electrification	Green ammonia	Evaluate electrification or green hydrogen
Mobility options	Diesel for in-mine and haulage	Electrified in-mine operations	Electrified in-mine operations Electrified haulage	Green ammonia powered in-mine equipment and haulage fleet	Electrified in-mine operations Green hydrogen long-haul fleet
Market-based solutions	None	Emissions reduced via offsets	Only in the short term, by 2040 emissions are brought to zero		

Project Zero: Financial and emissions metrics

All pathways assessed for Mine Zero require material capital investments in decarbonisation technologies, compared to BaU. For most pathways, these investments result in overall operating cost savings from avoided fossil fuel costs offset against the additional capital investment, thereby moving Mine Zero down the cost curve. They also reduce the volatility associated with oil and gas prices.

Key financial metrics based on the modelling outputs are presented in Table 2. (Please note that these are purely hypothetical and based on the specific mine assumptions and should not be used to extrapolate to other mine sites or generalised implications of uses of specific technologies).

Table 2: Key financial metrics for the four pathways modelled for Mine Zero

	Established Technology	Electrification	Hydrogen Importer	Hydrogen Producer
Net present costs	$2.19b	$1.84b	$2.22b	$2.91b
Total discounted savings vs BaU	$588m	$940m	$554m	Exceeds BAU by $137m
Phase 1: Years to BaU cost-parity	4	4	4	4
Phase 2: Years to BaU cost-parity	8	9	10	8
Phase 3: Years to BaU cost-parity	10	11	12	Does not reach cost parity with BaU within 20 years
IRR for Phase 1	26%	26%	26%	26%
IRR for Phases 1 and 2	19%	20%	15%	20%
Total IRR (Phases 1, 2 and 3)	18%	20%	17%	5%
Est avoided emissions vs BaU	7,620 ktCO_2-e	10,388 ktCO_2-e	10,633 ktCO_2-e	10,388 ktCO_2-e

Of the four pathways assessed, the Electrification pathway provides the most cost-effective route to reach zero-carbon for Mine Zero and the highest return on investment at 20 per cent due to:

- Significant cost reductions projected for on-site renewables (i.e. solar PV and wind).
- A projected increase in fossil fuel costs (i.e. diesel and natural gas).
- Increased efficiency of electrified mobility reducing the energy demand significantly and therefore costs.

Although an attractive pathway from a cost perspective, mining companies need to closely monitor the commercial availability of electrified mining fleet especially for surface mining operations, which are currently in the pilot stage of technical development.

Green hydrogen-based technologies should also be monitored closely for mining operations, as there is potential for green hydrogen and ammonia costs to fall faster than expected. While having the lowest IRR of the modelled pathways for Mine Zero, the Hydrogen Producer pathway demonstrates a 100 per cent closed energy system through on-site production of green hydrogen, negating any supply chain risks and commodity price fluctuations.

"The Electrification pathway provides the most cost-effective route to reach zero-carbon for Mine Zero and the highest return on investment at 20 per cent."

Figure 21
Mine Zero net present costs comparison for four decarbonisation pathways modelled, with phased implementation plan. Costs are shown as negative, with lower costs closer to zero.

Implementing Project Zero

As the most cost-effective pathway from the scenario analysis with the highest return on investment, an indicative roadmap for the Electrification pathway is shown below, showing the initiatives at each phase. The emissions profile relative to the BaU case is illustrated in Figure 22, illustrating the level of emissions to be abated over the life of the project to 2050.

PHASE 1

1. **Installation of on-site renewables**
   - Solar PV capacity of **71 MW**
   - Wind energy capacity of **92 MW**
2. **No short-term storage**
3. **Fuel imports**
   - Diesel for mobility
   - Natural gas for thermal demand and on-site electricity generation

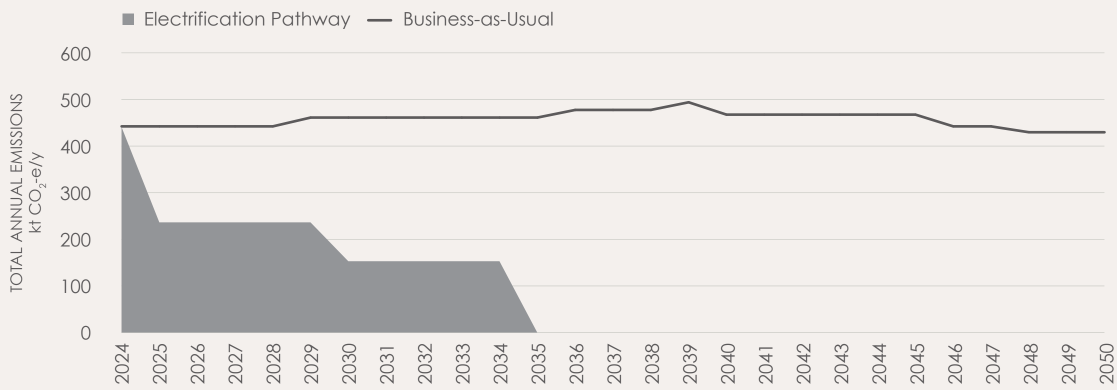
PHASE 2

1. **Additional on-site renewables capacity**
   - Solar PV capacity of **84 MW**
   - Wind energy capacity of **76 MW**
2. **Installation of short-term storage assets**
   - Battery of **109 MW/436 MWh**
3. **Fuel imports**
   - Diesel for haulage and road trucks
   - Natural gas for electricity generation

PHASE 3

1. **Additional on-site renewables capacity**
   - Solar PV capacity of **124 MW**
   - Wind energy capacity of **23 MW**
2. **Installation of additional storage assets**
   - Battery (power) of **120 MW/480 MWh**
3. **Fuel imports**
   - E-fuels for electricity generation

Figure 22
Emissions avoided compared to BaU for the Electrification pathway.



Project Zero next steps

Considering the risks and opportunities within the context of Mine Zero, practical next steps for the owners of the mine would be to:

1. **Finalise investment case and funding for Phase 1** as a no-regrets step to increase renewable share at the mine's location and significantly reduce the carbon footprint.
2. **Commit to the Electrification pathway** and electrify thermal demand where possible.
3. Continuously **monitor the commercial maturity for electric haul-trucks and in-mine equipment** (in this case, open pit), as well as monitoring advancements in e-fuel technology and its applications.
4. **Stage the deployment of the electrified fleet and related renewable energy generation beginning with pilots**, to capture learning and best practices.
5. **Weigh up the business' appetite to participate in the carbon offset market** in the short term to address hard-to-abate emissions that will be mitigated in Phase 3 implementation.
6. **Reassess Mine Zero's decarbonisation roadmap** prior to Phase 2 implementation.

Moving from intent to action

The case for addressing decarbonisation is clear. We have outlined how demand is building for low-emissions mineral production, the technologies available for immediate action and forward planning, and how a decarbonisation roadmap can generate strong returns.

Moving from intent to action is complex. The challenge of decarbonisation is not just setting targets but developing and executing transformational strategy and managing risks. To meet decarbonisation goals, mining companies should develop asset-level decarbonisation roadmaps and implementation plans.

Five practical steps to move from intent to action are:

01 **Identify** – Develop a baseline energy and emissions profile and BaU trajectory for the life of the mine. Identify a list of potential decarbonisation projects, understanding how they impact energy consumption and emissions.

02 **Target** – Determine the decarbonisation ambition for the mine in the context of group decarbonisation targets. Work with stakeholders to develop achievable, high-integrity targets for both cumulative and annual emissions.

03 **Plan** – Construct a range of decarbonisation pathways for the mine and undertake a thorough techno-economic assessment of the pathways. Build the decarbonisation roadmap by back-casting to identify required technology for the end-state, and include phasing and sequencing for implementation of key initiatives.

04 **Implement** – Explore partnerships and financing options to implement decarbonisation projects, and establish governance and accountability for implementation.

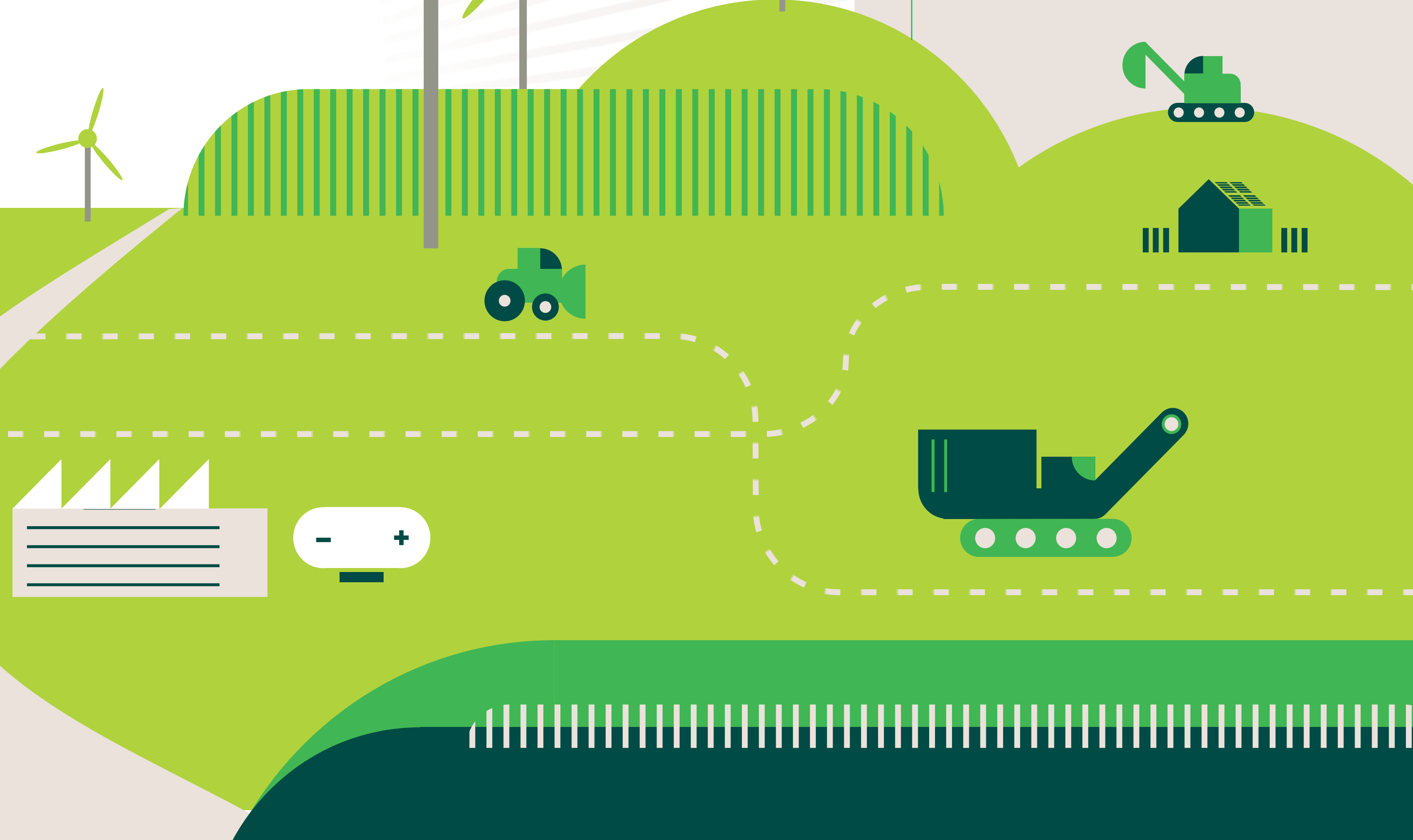
05 **Monitor** – Measure and report on progress on an ongoing basis to keep stakeholders engaged, and comply with relevant disclosure frameworks.

For junior and mid-tier mining companies seeking to capture the economic and sustainability benefits of a low-emissions future, the next steps are to consider decarbonisation technology options and create a decarbonisation roadmap.

CEFC, MRIWA and ENGIE Impact have collaborated on two further complementary reports in the *Mining in a low-emissions economy series*, which expand on the information provided in this report.

Technology solutions for decarbonisation
This provides a comparative analysis of proven and emerging technology options.

Roadmap to decarbonisation
This supports understanding on what to prioritise, drawing on a simulated mining operation.



References

(1) United Nations Framework Convention on Climate Change, “The Paris Agreement,” 2016. [Online]. Available: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement.

(2) Department of Industry, Science, Energy and Resources, “Resources and Energy Quarterly: March 2022,” Commonwealth of Australia, 2022. [Online]. Available: https://publications.industry.gov.au/publications/resourcesandenergyquarterlymarch2022/index.html.

(3) M. Roarty, “The minerals sector,” Commonwealth of Australia, 2010. [Online]. Available: https://www.aph.gov.au/About_Parliament/Parliamentary_Departments/Parliamentary_Library/pubs/BriefingBook43p/mineralssector. [Accessed May 2022].

(4) CEFC, “Case Study: Ark Energy hydrogen trucks support green zinc,” CEFC, 2021. [Online]. Available: https://www.cefc.com.au/where-we-invest/case-studies/ark-energy-hydrogen-trucks-support-green-zinc/. [Accessed May 2022].

(5) IEA, “The Role of Critical Minerals in Clean Energy Transitions,” IEA, 2021.

(6) Department of Industry, Science, Energy and Resources, “Outlook for Selected Critical Minerals,” Commonwealth of Australia, 2021.

(7) GeoScience Australia, “Australia’s Identified Mineral Resources,” Commonwealth of Australia, 2020. [Online]. Available: https://www.ga.gov.au/digital-publication/aimr2020/australias-identified-mineral-resources. [Accessed May 2022].

(8) CEFC, “Case Study: WA mine sees greener future with lithium ore,” CEFC, [Online]. Available: https://www.cefc.com.au/where-we-invest/case-studies/wa-mine-sees-greener-future-with-lithium-ore/. [Accessed May 2022].

(9) Department of Industry, Science, Energy and Resources, “Australian Energy Update 2021,” Commonwealth of Australia, September 2021. [Online]. Available: https://www.energy.gov.au/publications/australian-energy-update-2021. [Accessed January 2022].

(10) Department of Industry, Science, Energy and Resources, “National Inventory Report 2019,” Commonwealth of Australia, 2021.

(11) Engeco, “Mining Energy Consumption,” Singapore, 2021.

(12) K. Rolfe, “Sustainability-linked loans a new frontier for responsible mining,” CIM Magazine, 1 June 2021. [Online]. Available: https://magazine.cim.org/en/news/2021/sustainability-linked-loans-a-new-frontier-for-responsible-mining-en/. [Accessed December 2021].

(13) E. Kerencheva, “Leading Japan Financials Launch Initiative to Advance Impact Financing and Investment Efforts,” ESG Today, 30 November 2021. [Online]. Available: https://www.esgtoday.com/leading-japan-financials-launch-initiative-to-advance-impact-financing-and-investment-efforts/. [Accessed December 2021].

(14) M. Segal, “Investor Group Calls for Blended Finance Solution to Address Shortfall in EM Climate Finance,” ESG Today, 29 November 2021. [Online]. Available: https://www.esgtoday.com/investor-group-calls-for-blended-finance-solution-to-address-shortfall-in-em-climate-finance/. [Accessed December 2021].

(15) Climate Active, “Climate Active Carbon Neutral Standard for Organisations,” Commonwealth of Australia, 2020.

(16) Climate Change Authority, “Review of international offsets,” Commonwealth of Australia, 2022. [Online]. Available: https://www.climatechangeauthority.gov.au/consultations/previous-consultations/review-international-offsets.

(17) Minister for Climate Change and Energy, “Independent Review of ACCUs,” Commonwealth of Australia, 1 July 2022. [Online]. Available: https://minister.dcceew.gov.au/bowen/media-releases/independent-review-accus.

(18) F. Muller, H. Saddler and H. Melville-Rea, “Carbon Border Adjustment: what are they and how will they impact Australia?,” The Australia Institute, June 2021. [Online]. Available: https://australiainstitute.org.au/wp-content/uploads/2021/06/P1031-Carbon-Border-AdjustmentsWEB.pdf. [Accessed January 2022].

(19) W. Healy, “Low-carbon aluminum premium achieved at record Eur50/mt in Europe: producer,” S&P Global, 13 April 2021. [Online]. Available: https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/metals/041321-low-carbon-aluminum-premium-achieved-at-record-eur50mt-in-europe-producer. [Accessed June 2022].

(20) P. Ker, “BlackRock says green premium is coming in mining,” Australian Financial Review, 30 May 2022. [Online]. Available: https://www.afr.com/companies/mining/blackrock-backs-decarbonisation-value-over-mining-volumes-20220529-p5apbu. [Accessed June 2022].

(21) Investor Group on Climate Change, “Corporate Climate Transition Plans: A guide to investor expectations,” March 2022. [Online]. Available: https://igcc.org.au/wp-content/uploads/2022/03/IGCC-corporate-transition-plan-investor-expectations.pdf.

(22) S. Hughes, “Corporate governance update: climate change risk and disclosure. Speech by ASIC Commissioner Sean Hughes at the Governance Institute of Australia Fellows Roundtable,” ASIC, 14 October 2021. [Online]. Available: https://asic.gov.au/about-asic/news-centre/speeches/corporate-governance-update-climate-change-risk-and-disclosure/.

(23) Australian Prudential Regulation Authority, “Prudential Practice Guide: CPG 229 Climate Change Financial Risks,” November 2021. [Online]. Available: https://www.apra.gov.au/sites/default/files/2021-11/Final%20Prudential%20Practice%20Guide%20CPG%20229%20Climate%20Change%20Financial%20Risks.pdf.

(24) G. Debelle, “Speech: Climate Risks and the Australian Financial System, CFA Australia Investment Conference,” Reserve Bank of Australia, 14 October 2021. [Online]. Available: https://www.rba.gov.au/speeches/2021/sp-dg-2021-10-14.html. [Accessed May 2022].

(25) Centre for Policy Development, “Director’s duties and climate risks,” Centre for Policy Development, 2016. [Online]. Available: https://cpd.org.au/sustainable-economy-media-links-and-resources/directors-duties-climate-risks/.

(26) J. Lacey, “How social licence is driving innovation in the mining industry,” CSIRO, 8 July 2021. [Online]. Available: https://www.csiro.au/en/work-with-us/industries/mining-resources/resourceful-magazine/issue-22/how-social-licence-is-driving-innovation-in-the-mining-industry#:~:text=Unlike%20fixed%2C%20tangible%20environmental%20and,renegotiation%2C%20says%20Dr%20Justin.

(27) Gold Fields, “Agnew gold mine,” Gold Fields, 2021. [Online]. Available: https://careers.goldfields.com/Australia/content/Agnew/?locale=en_GB.

(28) Gold Fields, “The Challenge of Achieving Zero-Emissions Mining,” in Energy & Mines Australia Summit, Perth, 2021.

(29) ARENA, “Agnew Renewable Energy Microgrid,” Gold Fields, October 2021. [Online]. Available: https://arena.gov.au/projects/agnew-renewable-energy-microgrid/. [Accessed November 2021].

(30) Gold Fields, “Gold Fields announces 2030 ESG targets,” Gold Fields, December 2021. [Online]. Available: https://www.goldfields.com/news-article.php?articleID=11692. [Accessed December 2021].

(31) Caterpillar, “Battery Powered Mining Trucks to Support Customer Goals,” Caterpillar, 31 August 2021. [Online]. Available: https://www.caterpillar.com/en/news/caterpillarNews/2021/bhp-mining-trucks.html. [Accessed December 2021].

(32) BHP, “BHP and Caterpillar to accelerate development of zero-emissions mining trucks,” BHP, 31 August 2021. [Online]. Available: https://www.bhp.com/news/media-centre/releases/2021/08/bhp-and-caterpillar-to-accelerate-development-of-zero-emissions-mining-trucks. [Accessed December 2021].

(33) P. Moore, “Fortescue Future Industries begins testing of hydrogen powered mining truck and blasthole drill rig,” International Mining, 30 August 2021. [Online]. Available: https://im-mining.com/2021/08/30/fortescue-future-industries-begins-testing-hydrogen-powered-mining-truck-blasthole-drill-rig/. [Accessed December 2021].

(34) T. Parker, “Fortescue closes in on hydrogen-powered haul truck roll out,” Australian Mining, 1 September 2021. [Online]. Available: https://www.australianmining.com.au/news/fortescue-closes-in-on-hydrogen-powered-haul-truck-roll-out/. [Accessed December 2021].

(35) J. Hill, “CEFC backs Australian “Bladevolt” technology to electrify mine vehicles,” The Driven, October 2021. [Online]. Available: https://thedriven.io/2021/10/12/cefc-backs-australian-bladevolt-technology-to-electrify-mine-vehicles/. [Accessed December 2021].

(36) 3ME Technology, “3ME Technology charged for growth with $20 million investment,” 3ME Technology, October 2021. [Online]. Available: https://3me.technology/2021/10/07/3me-charged-for-growth-with-20-million-investment/. [Accessed December 2021].

(37) Alcoa, “Alcoa Exploring Technology to Further Reduce Carbon Emissions in Alumina Refining,” Alcoa, May 2021. [Online]. Available: https://news.alcoa.com/press-releases/press-release-details/2021/Alcoa-Exploring-Technology-to-Further-Reduce-Carbon-Emissions-in-Alumina-Refining/default.aspx. [Accessed November 2021].

(38) A. Taylor, “Supporting a low emissions future in alumina refining,” Minister for Energy and Emissions Reduction, June 2021. [Online]. Available: https://www.minister.industry.gov.au/ministers/taylor/media-releases/supporting-low-emissions-future-alumina-refining. [Accessed November 2021].

(39) ARENAWIRE, “Alcoa aluminium producer to trial renewable energy,” ARENAWIRE, May 2021. [Online]. Available: https://arena.gov.au/blog/alcoa-aluminium-producer-to-trial-renewables/. [Accessed November 2021].

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