CobaltBlue

Sustainable Solutions

for Recycling Mine Waste

2023

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Section 1
Introduction

Our world has a rich history in mining, particularly in the extraction of metals. Significant quantities of metals are still required to build the infrastructure and deliver the technology required to achieve a net zero energy transition.

However, mining activities generate substantial quantities of waste materials including tailings, waste rock, and slag, which can have adverse effects on ecosystems and human health. The traditional approach of disposing of mine waste in containment facilities has reached limitations in terms of space requirements, long-term stability, and potential for contaminant release.

This waste can lead to soil and water contamination, habitat destruction, and ecosystem disruption. The release of hazardous substances from these waste materials also poses risks to human health. Recycling mine waste offers the opportunity to recover the lost mineral inventory, whilst addressing these challenges for a more sustainable outcome.

A circular economy model generates the following benefits:

1. **Environmental:** Resource conservation, waste reduction, and lower emissions
2. **Economic:** Job creation, improved competitiveness, and cost savings
3. **Social:** Enhanced resource security and public health
4. **Critical Minerals Extraction:** Resource independence, technological innovation and sustainable supply chains

This paper introduces Cobalt Blue Holdings, an Australian based company with unique technology and experience targeting the processing of sulphide waste into sustainable environmental outcomes whilst recycling mine waste to obtain the contained metals. This processing generates metal compounds and elemental sulphur, thereby helping to meet metal demand for clean energy whilst simultaneously resulting in nature-positive outcomes. In addition, elemental sulphur is essential for fertiliser production and industrial metallurgical applications whilst extraction results in de-sulfidation of acid-generating mine waste.

Section 2
The Opportunity

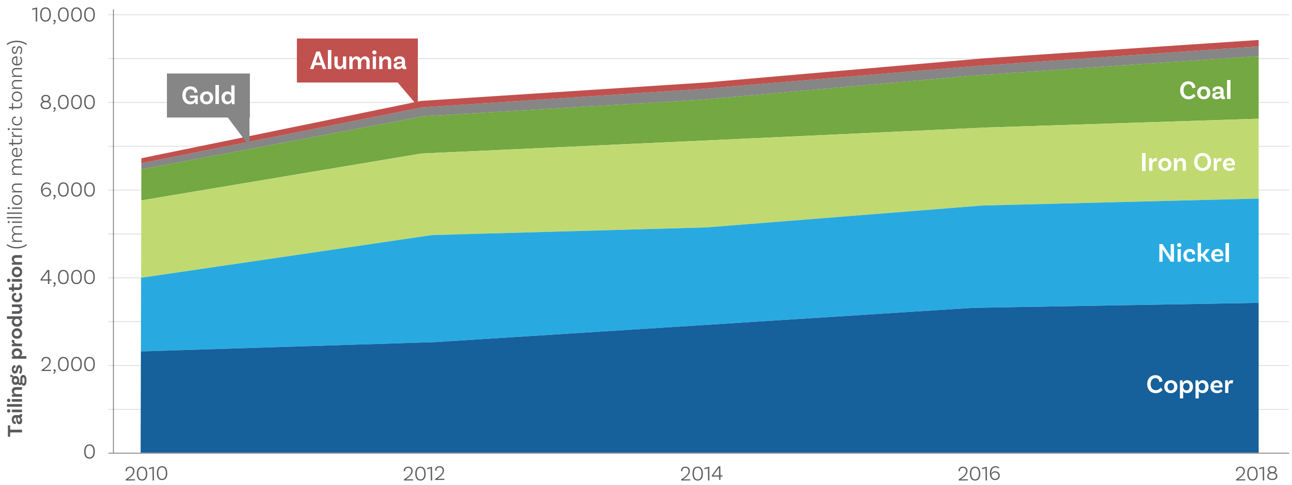
Allied nations are working to strengthen their critical minerals supply chains, as evidenced by introduction of the US Inflation Reduction Act (IRA) in 2022 and the European Critical Raw Materials Act (CRMA) in 2023, amongst others. The aim of these is to reduce dependencies on dominant source regions and reduce supply chain risk through diversification and/or domestication.

Sustainability, and achieving climate change abatement goals is also a key driver of global legislative change with respect to the sourcing, mining and refining of critical minerals, and downstream manufacturing of clean energy solutions. An example is the European Circular Economy Action Plan (Plan), which is a comprehensive and ambitious initiative aimed at transitioning the region towards a sustainable and resource efficient economic model.

Adoption of a circular economy approach emphasizes the importance of reducing waste generation across various sectors, including mining. A circular economy promotes resource efficiency, waste prevention, and the reuse, recycling, and recovery of materials.

Mining is traditionally a linear economic activity, with mining and extraction of metals leading to manufacturing, use and disposal of metals. Mining and processing activities themselves generate some of the largest waste volumes of any global industry in the form of tailings, waste stockpiles, leach heaps, slag and more. The International Council in Mining and Metals (ICMM) published a Tailings Reduction Roadmap in 2022, breaking down the volume of tailings produced by key commodity streams including alumina, gold, coal, iron ore, nickel and copper (Figure 1).

Figure 1 – **Estimate of global annual tailings production by commodity, from the ICMM Tailings Reduction Roadmap (2022).**[1]



1 https://www.icmm.com/en-gb/guidance/innovation/2022/tailings-reduction-roadmap

Figure 1 shows that base metal mines, such as nickel and copper, generate the largest volumes of tailings of any commodity stream. Nickel and copper mining globally created nearly 6 million tonnes of tailings waste in 2018 alone. The volumes of this waste are also shown to be increasing, particularly as global demand for copper and nickel is driven by electrification and battery technologies necessary for the energy transition. However, in parallel with this increased demand, the metal grade of mines globally is decreasing for the biggest deposits. Decreasing grade results in the mining of more waste per tonne of metal.

Mine waste, and tailings dams in particular, are an environmental legacy that must be rehabilitated and managed for decades to centuries following mine closure. Structural failure of improperly designed and managed tailings facilities can cause devastating loss of life. Metalliferous mine waste is also often associated with acid mine drainage, formed from oxidation of sulphur bearing minerals when they are exposed at the earth's surface. Acid mine drainage can cause significant environmental harm to waterways, landscapes and ecosystems.

By adopting circular practises within the mining industry, the volumes of waste, including acid-forming waste can be reduced. In a circular economy, everything has value, including material traditionally discarded. Re-branding of mine waste as a valuable asset, and re-processing of that discarded material is a first step towards increased efficiency and circularity of the mining activities.

Mineral deposits are rarely created of a 'pure' singular metal for extraction, but rather a polymetallic blend of minerals, metals and other elements. Subject to market forces, mining companies ordinarily target a single 'economic' commodity for extraction at a particular mine site. Therefore, it is normal practise for significant volumes of valuable material to be sent to waste. A key example in this instance is cobalt; an important component of lithium-ion batteries that commonly occurs in nature associated with nickel or copper. A typical host for cobalt in these deposits is pyrite (cobaltiferrous pyrite), a difficult mineral to process and therefore a common constituent in metalliferous mine tailings. Pyrite is one of the main sulphide minerals contributing to acid mine drainage around the world. Re-processing of pyrite-rich (and cobalt bearing) waste using Cobalt Blue's proprietary technology offers a meaningful opportunity to extract important metals for the energy transition, whilst simultaneously improving environmental outcomes for historical and existing tailings sites.

This technology can also be applied to fresh pyrite-rich tailings material, prior to being pumped to the tailings dam, creating greater efficiency in active mining processes. In other words, re-thinking our approach to mine waste can be applied to:

1. Existing and historical mine waste, through re-processing material from mine waste facilities; and
2. Reducing the volume and impact of new and future waste streams, through processing and removal of valuable and reactive material prior to storage in waste facilities.

2.1 Environmental Benefits

Key environmental outcomes from the adoption of circular mining practises, including re-processing of existing and new waste streams include:

- Resource conservation
- Waste reduction
- Lower emissions
- Conservation of biodiversity and ecosystems

By minimising resource extraction, and maximising the use and value of existing resources, waste volumes are reduced and natural resources are conserved. Environmental impacts are also reduced, mitigated or improved with the potential to generate nature-positive outcomes for mining activities.

2.2 Economic Benefits

In a circular economy, new business models, technologies and infrastructure lead to the following outcomes:

- Job creation
- Improved competitiveness
- Cost savings
- Enhanced resource security
- Sustainable supply chains and markets

Circularity is fundamentally about supporting all parts of a system to exist at their highest value for as long as possible. This requires innovation, entrepreneurship and new skills, creating both jobs and sustained value. Organisations that have adopted circular practices show greater competitiveness through increased efficiency, reduced costs and optimised material usage. Furthermore, companies that proactively embrace circular practices are better positioned to adapt to evolving consumer preferences and comply with new and future regulatory requirements.

A circular economy will also enhance a region's resource security by reducing its dependence on imported raw materials. By promoting the use of secondary raw materials obtained through recycling and recovery processes, the reliance on primary resource extraction from international markets is decreased. With localised supply chains, the vulnerability of businesses to disruptions in the global supply chain is minimised. This resource security not only strengthens the stability of a nation's economy but also reduces its environmental footprint by mitigating the impacts associated with resource extraction and transportation.

2.3 Social Benefits

Building on the environmental and economic benefits described above, social outcomes directly flow from a stronger environment and economy. Through improved resources security and efficiency of associated industries, as well as better environmental outcomes and ecosystem stability, the following social benefits are realised:

- Improved public health
- Social equity and inclusion

A stable and healthy environment can have direct impacts on air, water and soil quality, which in turn lead to healthier communities. Risk of respiratory and waterborne diseases is decreased, whilst the emphasis on waste management and recycling reduces exposure to hazardous materials. By reducing greenhouse gas emissions and air pollutants, the circular economy contributes to climate change mitigation and promotes public health.

The creation of job opportunities and sustainable, locally-focused industries promotes social equity and inclusion. The transition to a circular economy requires a skilled workforce, encouraging investments in education, training, and skills development.

2.4 Critical Minerals Extraction

As described above, mine waste may contain trapped critical minerals that can be extracted from the host mineralisation using appropriate technologies. Extracting these critical minerals not only complies with the goals of a circular economy by improving resource efficiency practises and minimising waste, but also provides several advantages:

- Resource independence
- Technological innovation
- Sustainable supply chains

After a millennia of global mining history, and active mining continuing into the modern day, numerous opportunities exist for the re-evaluation of mine waste using modern approaches. Furthermore, many of the minerals that are today considered ‘critical’ were not a focus for traditional mining activities even as recently as a few decades ago. By re-examining, and re-processing, tailings material from both currently operating and historical sites, a new frontier of ethically and sustainably sourced critical minerals can be established within regions close to manufacturing centres.

The use of modern and innovative approaches within traditional, inefficient settings such as mining, fosters the development of new extraction technologies and sustainable mining practices. This will enhance competitiveness in the global market and drive the transition towards a more sustainable and circular economy. By integrating mining operations with downstream industries, such as manufacturing and recycling, the region can establish closed-loop systems that minimise waste and optimize resource utilisation. The proximity of critical mineral sources reduces transportation distances, lowering the carbon footprint and environmental impacts associated with their extraction and distribution.

Photo courtesy of Anita Parbhakar-Fox

CobaltBlue

Section 3
Introducing Cobalt Blue

3.1 Our Aim

Cobalt Blue Holdings (COB) is a mining and processing technology company with a core focus on the development of both primary and secondary extraction of metals, in particular cobalt. COB's aim is to become a leading global supplier of ethical and sustainable metals, supporting the transition to a clean energy future. We will achieve this through the following steps:

- Resource development
- Research and development
- Ethical and sustainable practises

COB is committed to responsible mining practices that prioritise environmental protection, social engagement, and community development. COB aims to set high ethical standards and contribute to the sustainable development of the regions in which it operates. COB's flagship project, the Broken Hill Cobalt Project in New South Wales, Australia, will produce large scale, high purity cobalt chemicals. Cobalt is an essential component of lithium-ion batteries used in electric vehicles and energy storage systems. COB aims to develop cobalt and other metal projects that can contribute to the global supply chain and support the growth of the clean energy sector.

COB is at the forefront of mineral processing innovation, with a patented flow sheet developed for the Broken Hill Cobalt Project orebody that can be applied in numerous other settings, including mine waste. COB is committed to continuous research and development efforts to enhance cobalt and other metal extraction, processing, and utilisation technologies.

3.2 Our Technology

3.2.1 Description

COB has developed and patented a metallurgical process for treating sulphide mineralisation and producing metal sulphate and elemental sulphur. The technology targets metals that are encapsulated within the pyrite structure, making it difficult to liberate the metals and extract them using conventional processes.

Primary ore is crushed, and a sulphide concentrate is recovered using a combination of gravity and flotation unit operations. In the case of an existing tailings facility the material is already mined, crushed and typically located at surface, thus reducing significant costs compared to extraction from a primary ("in ground") resource.

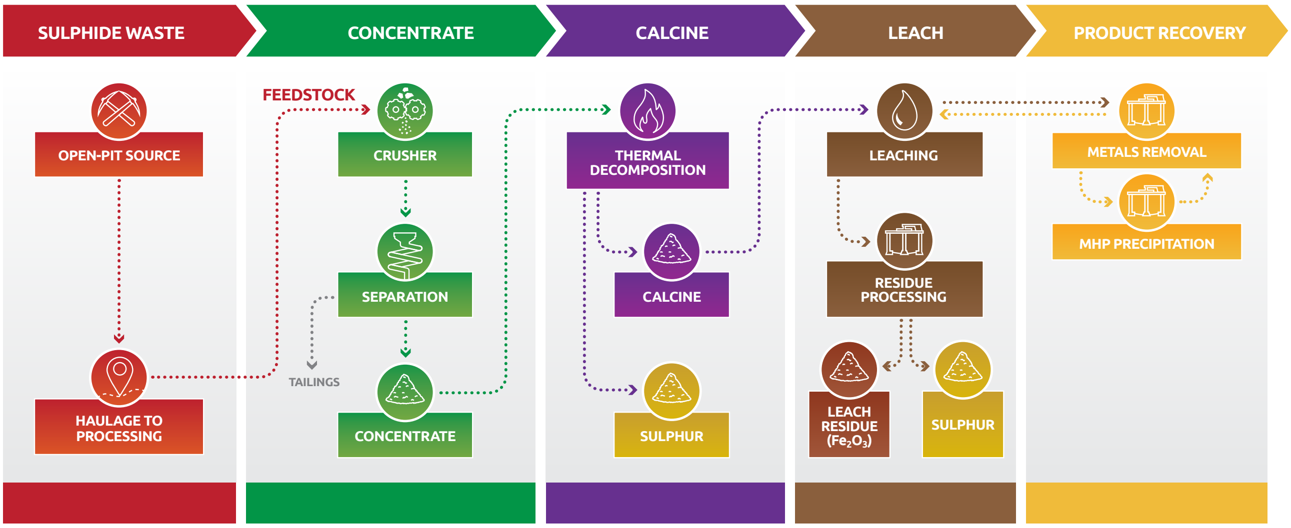
The pyrite concentrate is then thermally treated under an inert atmosphere to produce artificial pyrrhotite (calcine) and elemental sulphur. The sulphur is condensed from the kiln off-gas and turned into solid prills. Test work has achieved >99% grade sulphur samples.

The pyrrhotite is forwarded to a low-temperature and low-pressure autoclave for leaching. The extraction of cobalt and other metals is typically >95% into the solution. The leach residue is removed by filtration, and further processed for sulphur recovery by remelting.

The leach solutions are advanced through iron removal steps. The target metals are then precipitated as a commercially accepted Mixed Hydroxide Precipitate (MHP). The MHP is then refined, for production of high purity cobalt sulphate heptahydrate. We can consistently achieve a high quality (>20.5%) cobalt sulphate crystal.

The target recovery from ore to commercial product for cobalt is 85–90%, and for sulphur is 60–65%. The overall flowsheet (as applied to a sulphide-rich waste source) is summarised in Figure 2.

Figure 2 – **COB Waste Stream Processing, Indicative Only.**



3.2.2 Advantages

COB has developed and tested its proprietary processing technology since 2018. The test work has advanced from bench scale to a 24/7 Demonstration Plant facility capable of producing battery grade products. This facility operates on a quasi-commercial scale and employs 35 full time staff. The following advantages of the COB process set it apart from traditional pyrite-processing technologies:

- Reduced sulphur dioxide (SO_2) emissions
- Generation of elemental sulphur
- Lower project costs
- Metal recovery from pyrite

The application of a circular economy lens to traditional mining activities requires parallel increased efficiency and reduction in physical waste, energy usage and harmful emissions. COB's patented process achieves that goal, outlined in detail below, providing sustainably sourced metals for the energy transition.

3.2.2.1 Reduced SO_2 emissions

Under the COB process, harmful SO_2 emissions are reduced. As described above, thermal decomposition of pyrite uses a rotary kiln where the feed material is heated under an inert gas (nitrogen) which breaks down the pyrite into pyrrhotite and produces elemental sulphur. The use of nitrogen in pyrite heating significantly reduces the release of harmful emissions into the atmosphere. Historically, pyrite oxidation can result in the atmospheric release of SO_2, a major contributor to air pollution and acid rain. By minimizing oxidation through inert gas heating, the emission of SO_2 and other pollutants are significantly reduced.

3.2.2.2 Generation of Elemental Sulphur

The COB process produces elemental sulphur rather than sulphuric acid. Elemental sulphur is inert and can be readily transported long distances to end consumers, who then convert the material into sulphuric acid. By comparison, sulphuric acid is a highly corrosive and hazardous substance, posing significant risks to human health, infrastructure, and the environment. It is also a strong oxidizing agent and can react violently with certain materials. Consequently, transportation/handling of elemental sulphur is far safer than sulphuric acid at ~1/3rd of the equivalent weight. Elemental sulphur can be stockpiled safely prior to conversion to acid, to safeguard against shortages and supply disruptions.

Sulphuric acid is a crucial part of our modern industrial society. It is required for the production of phosphorus fertiliser and for industrial/mining applications. Globally, over 246 million tonnes of sulphuric acid are consumed annually (Mtpa). Rapid growth in the green economy and intensive agriculture could see demand increase to over 400 Mtpa by 2040.

Today over 80% of the global sulphur supply comes from desulphurisation of fossil fuels to reduce emissions of SO_2 gas. Decarbonisation of the global economy to deal with climate change will greatly reduce the production of fossil fuels. This will create a shortfall in the annual supply of sulphuric acid of between 100 and 320 Mtpa by 2040, depending on the rate of decarbonisation.

Sourcing elemental sulphur from acid-forming mine waste is a far more sustainable solution to current and future acid demand. The COB process allows for de-sulfidation of otherwise harmful material, simultaneously and safely producing a critical component of future food supply solutions.

3.2.2.3 Lower project costs

As mine waste storage facilities are generally above surface, and the material has already been mined, crushed and ground, capital costs for a waste-reprocessing operation can be calculated largely exclusive of those traditional components. Furthermore, with the production of elemental sulphur as a by-product, and associated reduction in the volume of potentially acid-forming material remaining in the environment, environmental bonds may be lower.

Elemental sulphur represents only 1/3rd of the mass equivalent of sulphuric acid so materials handling requirements are significantly smaller. In our experience the relative capital cost of elemental sulphur producing plant on site is around 30% of a comparable sulphuric acid producing plant on site.

3.2.2.4 Recovering metals from pyrite

Metal recovery from pyrite is technically challenging and economically viable only when the concentrations of the target metals are sufficiently high. Overall, metal recoveries from pyrite require specialised knowledge, expertise, and carefully designed processes to maximise extraction and minimise environmental impacts.

COB's comprehensive test work has demonstrated the ability to recover ~85–90% of the base metals contained within the pyrite matrix. Test work has been undertaken over a four-year period and included over 4,000 tonnes of mined material from multiple jurisdictions. These outcomes are in line with the best practice recoveries available from commercial extraction processes globally.

3.2.2.5 Applicability in a waste streams scenario

Testwork conducted on variable pyrite chemistries representing mine waste has demonstrated the applicability of COB's processing technology in global waste streams scenarios.

As pyrite is a difficult mineral to process, it is commonly concentrated in metalliferous mine tailings as a by-product of processing for other minerals. Furthermore, many critical minerals including, but not limited to cobalt, have not been the focus of traditional mining operations, and are therefore present in tailings facilities and waste stockpiles. COB's patented process is able to extract these valuable metal units in mine waste, whilst concurrently removing sulphur, one of the key minerals responsible for acid mine drainage. The technology is therefore ideal for waste streams projects.

3.3 Re-processing Targets

COB's patented process specifically targets the mineral pyrite, and those metals and elements contained therein. Pyrite is the most abundant sulphide mineral in the Earth's crust, and its basic chemical formula is FeS_2, in which Fe is iron, and S is sulphur. Common substitutions for the Fe atom in the pyrite matrix include cobalt, nickel, arsenic and manganese. It may also contain trace amounts of other metals such as copper, zinc, gold and silver.

Re-processing of mine waste therefore targets the **sulphur,** associated valuable metals (**cobalt, nickel, copper and others**) and any deleterious elements that may also be captured within the pyrite lattice. The presence of deleterious elements within pyrite can be challenging due to their potential impact on downstream processes and the environment. COB can tailor a processing flowsheet to remove these elements from saleable products whilst ensuring they are converted into environmentally benign forms for long term storage.

3.4 Critical Minerals – Further Processing

COB technology targets the production of intermediate forms of nickel and cobalt, typically hydroxide or sulphide compounds. It should be noted that 70% of global cobalt is traded as a cobalt hydroxide with a large volume of nickel traded in a similar form.

COB has developed significant partnerships within the global battery supply chain with LG (Korea), Sojitz (Japan) and more recently, a leading Japanese trading house (name confidential at time of drafting) has partnered COB in the development of a 3,000 tonne per annum cobalt sulphate refinery located in Australia.

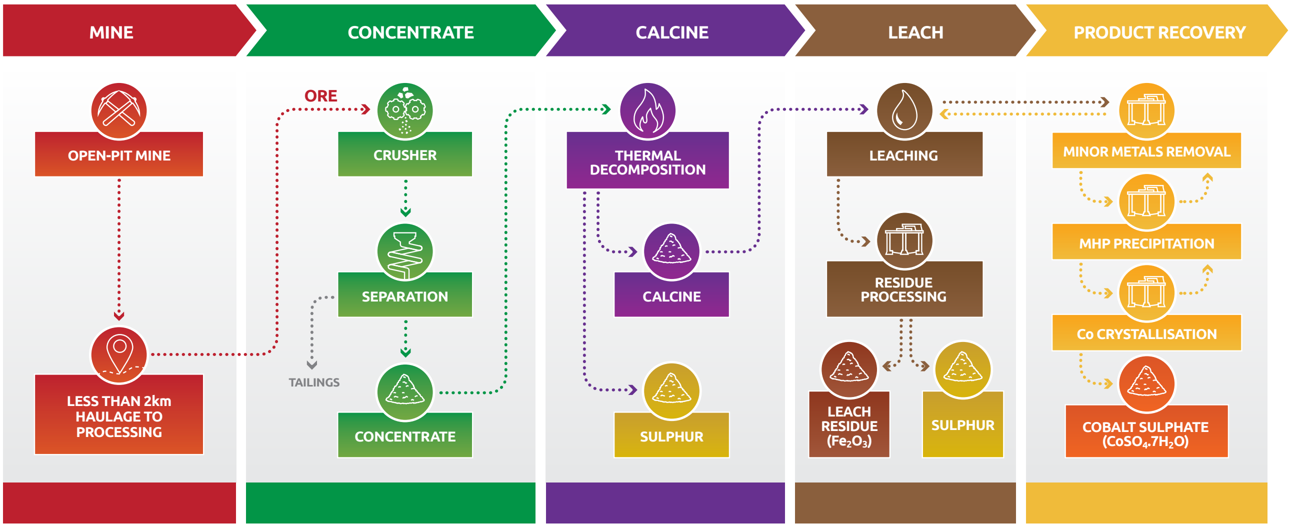
3.5 Demonstration Plant Facility

COB's Demonstration Plant allows our technical staff to monitor and de-risk operations and scaling of the COB process, targeting raw material production in large commercial volumes.

The Demonstration Plant operations are designed to treat up to 5,000 tonnes of ore with continuous operations beginning from mid-2022 and commissioning of full operations from Q1 2023. The plant is operated from a central control room with logged data from ~300 datapoints and actuation devices. This data has supported detailed independent engineering analysis to refine and optimise the plant design.

The plant continues to operate, employing some 35 staff and 10 technical/support staff targeting process optimisation. The Demonstration Plant will be tasked to perform large scale test work on alternate feedstocks to support the global rollout of the COB technology.

Figure 3 – **COB Process, as applied to Broken Hill Cobalt Project.**



The Demonstration Plant is designed around the flowsheet shown in Figure 3 and further described below.

- **Concentration of Pyrite from Ore** (Figure 3 – Concentrate)

  Mined ore is crushed, milled and passed over gravity spirals to produce a pyrite concentrate (Figures 4 and 5). Gravity tails are then forwarded to a scavenger flotation circuit to enhance recovery of pyrite. Combined recovery from the gravity circuit and scavenger float tests on the gravity tails was typically 93–95% cobalt into pyrite concentrate from the ore.

- **Thermal Decomposition (Pyrolysis) Of Pyrite Concentrate** (Figure 3 – Calcine)

  The pyrite concentrate is processed via a kiln (Figure 6) to convert pyrite into pyrrhotite (calcine) and elemental sulphur by heating to 650–700 ˚C under a nitrogen atmosphere to prevent oxidation. Testwork to date has demonstrated a >98% conversion of pyrite to pyrrhotite is achievable with sulphur recovery grading >99% purity.

- **Leaching and Production of Mixed Hydroxide Precipitate / Cobalt Sulphate** (Figure 3 – Leach / Product Recovery)

  The artificial pyrrhotite is then subject to leaching via a low temperature (130 ˚C) and pressure (8–9 bar) autoclave (Figure 8). The resulting leach solutions are treated to remove iron before precipitating a MHP with approximately 30% Co and 6 % Ni (Figure 9). MHP is a stable and easily transportable product.

  Thereafter, the MHP is refined into high purity cobalt sulphate crystals (Figure 10) by first leaching the MHP, then removing minor trace metals by a series of ion-exchange steps. The cobalt is separated, and concentrated, by a solvent extraction circuit, with the solvent extraction strip liquor advancing to an evaporative crystalliser.

Figure 4 – **Demonstration plant, comminution circuit.**

Figure 5 – **Pyrite concentrate.**

Figure 6 – **Demonstration plant kiln.**

Figure 7 – **Elemental sulphur produced from the calcine and leach steps.**

Figure 8 – **Demonstration plant, pressure oxidation circuit.**

Figure 9 – **Mixed hydroxide precipitate containing both cobalt and nickel, produced from cobaltiferrous pyrite.**

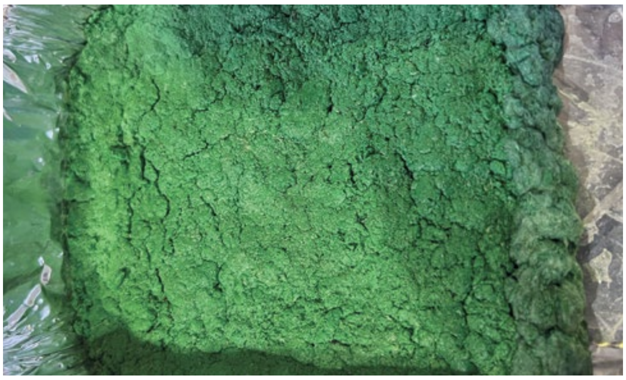


Figure 10 – **Battery grade cobalt sulphate produced from cobalt bearing pyrite.**

Figure 11 – **Demonstration Plant control system.**

Section 4
The Cobalt Blue Approach

COB undertakes waste stream assessment and development process targeting two opportunity categories:

1. Production – Tailings waste streams currently or potentially being produced, and
2. Storage – Waste in existing tailings or other mine waste storage facilities.

Re-processing of waste from active production streams involves re-directing tailings material from the existing plant through the COB process, prior to final deposition at the tailings facility (with additional metals and sulphur removed)..

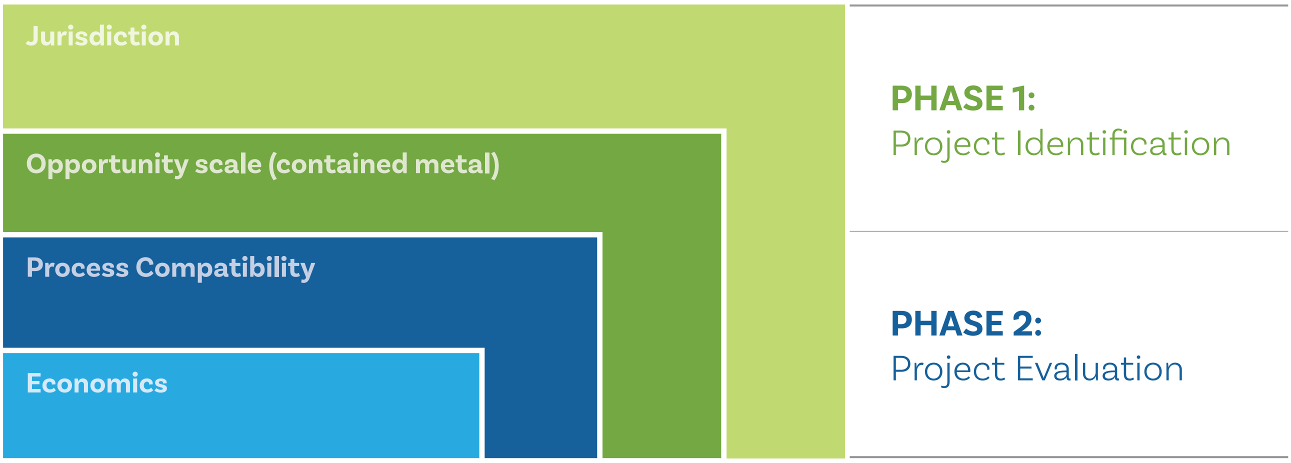
Re-processing of stored waste involves re-mining of the tailings dam (through hydromining or other means) prior to remobilisation to a processing facility to undertake the COB process. A new waste facility must be established to capture the new waste that is generated.

The opportunity presented by application of COB's processing technology to pyrite-rich mine waste has been recognised by the Queensland government's interest in the process, and integration of COB's process for selected sites in the Geological Survey of Queensland Secondary Prospectivity project. In collaboration with researchers from the Sustainable Minerals Institute at the University of Queensland, this project aims to define the potential for critical mineral endowment in Queensland's mine waste. For sites with high critical metal endowment, bespoke processing methodologies are being investigated. COB was asked to participate in the project specifically to apply our technology to key cobaltiferrous pyrite rich sites under an MOU signed between the Queensland Department of Resources and COB in December 2021. The Osborne tailings storage facility was the first site to be tested by COB under this arrangement and showed cobalt and copper recoveries of around 90% for the samples provided.

COB is independently conducting a desktop study on waste stream opportunities globally. The study is separated into two phases (Figure 12). Phase 1 is project identification, in which a priority list of projects (and project regions) is developed. Phase 2 is Project Evaluation, in which site-specific project evaluation is conducted, working with the incumbent site holder. During Phase 2, analysis and test work of samples are undertaken while barriers to commercialisation are identified and assessed for resolution.

Potential waste streams projects are required to meet the Company's ESG (environmental, social and governance) standards. Site-specific metrics are then applied on a case-by-case basis, including grade, tonnes, mineralogy and other operational factors affecting the project.

Figure 12 – **Waste streams project identification and evaluation process**



A major source of project risk is the lack of reliable mineralogical and chemical data available for tailings dams and other mine waste stockpiles. Therefore, COB also welcomes direct engagement from mining companies and site owners to discuss opportunities to deploy COB's patented process for battery metal and elemental sulphur production.

Our approach is collaborative, and we seek to work with potential partners to achieve the best outcome for both companies, the site, as well as local communities and the environment. In developing partnerships, we understand that each company, mine and waste facility is different, and our engagement is therefore tailored to accommodate these differences. We do not have a one-size-fits-all approach.

COB can:

1. Conduct Feasibility Studies for evaluating waste stream potential to:
   a. Reduce environmental liability and footprint
   b. Extract quantities of commercial grade elemental sulphur and key base/precious metals
   c. Provide marketing services for produced products, including relationship with sulphur trading houses and key battery industry participants
2. Provide or source direct equity investment in approved projects
3. Provide offtake for MHP regardless of the flowsheet used

Our goal is ethically sourced battery metals for a sustainable world. Our approach is to find value in waste hand in hand with nature positive mine site outcomes.

CobaltBlue

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Photo courtesy of Dominic Brown

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