Think & Act Differently
powered by OZ MINERALS

CHALLENGE
WHITE PAPER

OZ MINERALS

June 2022

# INGENIOUS EXTRACTION

Finding modern ways to extract metals

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# PURPOSE AND ACKNOWLEDGEMENTS

**OZ Minerals have set out to contribute to the acceleration of responsible metal production by the copper industry and summarise the outcomes of the Ingenious Extraction innovator challenge.**

## Purpose of this document

The purpose of this document is to explore potential extraction methods and technologies, specifically utilising concentrate leaching techniques that can perform economically at scale. This includes a summary of the outcomes of the Ingenious Extraction challenge within this context.

This document outlines the next steps that will be taken based on the momentum created through the challenge and how this supports OZ Minerals in the achievement of producing clean, value-adding products in a transparent manner.

## Acknowledgements


### Acknowledgement of Country

From the past, to today, and for forever into the future: these are the Lands of the Traditional Owners. Always have been, always will be.

### Dave Dreisinger, Ingenious Extraction mentor

The Think & Act Differently team would like to acknowledge the invaluable role that Dave Dreisinger played in sourcing, selecting and mentoring the innovators throughout the challenge. The role of the mentor in each of our challenges is to help innovators connect the dots by providing industry context, access to networks and subject matter expertise.


## The Think & Act Differently team

**Katie Hulmes**
*Challenge Sponsor*

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*Ingenious Extraction Mentor, Professor at UBC*

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*Ingenious Extraction Cohort Facilitator*

## Collaborators

The Think & Act Differently team would like to acknowledge the input received from the companies and teams in imagining, delivering and running the Ingenious Extraction crowd challenge, including the composition of this document.

Unearthed Deloitte.

**Mike Bellemore**
*Monitor Deloitte*

**Tristan Harris**
*Monitor Deloitte*

**Larissa Steele**
*Monitor Deloitte*

**Elizabeth Brookman**
*Unearthed*

> **To achieve decarbonisation of the minerals and mining sector we need to work together with all our Stakeholders taking a "why not" or a "how might we?" approach to unlocking technology and mutually creating value.**
>
> **- Katie Hulmes**

# EXECUTIVE SUMMARY

**Ingenious Extraction has accelerated the development of seven novel technologies for metal extraction that have the potential to unlock the benefits of economic on-site copper production (cont.)**

## Copper's role in global decarbonisation

The next decade will see an acceleration of disruptive change to the energy, transport and mining sectors as we strive to achieve our net zero goals and create a sustainable supply of raw materials. As a core material used in renewable energy infrastructure and many critical everyday items, copper is an essential ingredient in the transition to net zero. Therefore, the demand for the metal is set to grow steadily over the next decade.

## OZ Minerals' vision for metal production

OZ Minerals is guided by its purpose of "going beyond what's possible to make lives better" and aspires to produce clean, value-adding products in a transparent and low-impact manner. These aspirations inspired Think & Act Differently to launch the Ingenious Extraction challenge to search for new extractive technologies that could disrupt the traditional value chain, enable closer connections with end consumers, provide full traceability from resource to end use and minimise the production footprint.

## The search for innovative methods

Various concentrate leaching systems suitable for OZ Minerals' concentrate are currently available. However, the high capital costs and energy intensity of these solutions restrict their ability to be commercially viable, compared to third party smelting. In light of this, Think & Act Differently framed a targeted crowd challenge inviting innovators to propose novel leaching processes that could demonstrate material changes in key economic drivers such as energy usage, while maintaining metal recovery rates equivalent to the incumbent systems.

## Experts mobilised from around the globe

260 participants from 40 countries took part in this challenge through the incubator, creating long-lasting and valuable industry networks. From this group, Think & Act Differently selected seven teams as finalists. Each team proposed new and innovative extraction systems with potential for economic recovery of metals from copper concentrate. Various experiments were funded to validate the performance of these processes.

# EXECUTIVE SUMMARY

**Ingenious Extraction has accelerated the development of seven novel technologies for metal extraction that have the potential to unlock the benefits of economic on-site copper production**

## Key learnings from the experiments

The completed experiments demonstrated that there are various suitable processes for extracting metal from copper concentrates, but the economics are challenging (see Table 1). These findings have been derived, in collaboration with the following organisations (see right).

Minetometal
Metso:Outotec
Curtin University
MPS Mining & Process Solutions
DCS Technical
Clean & Recover
T.P. McNulty & Assoc
tfgMM Strategic Consulting
UBC The University of British Columbia

| # | Key learnings | Implications |
|---|---|---|
| 1 | The ferric chloride, glycine, ammonia-ammonium-chloride, roast-leach and bacterial oxidation systems are all able to achieve high copper extraction rates | All of these technologies from this challenge could conceivably form the basis of a suite of new commercial processes |
| 2 | The thiocyanate and glycat systems are both able to achieve high gold extraction rates | Cyanide can be eliminated for gold recovery, realising significant safety, environmental and cost benefits for any new process |
| 3 | A cobalt product can be produced from OZ Minerals copper concentrates; a metal that is currently not recovered by third party smelters | New revenue can be realised from responsibly produced cobalt, an important critical mineral used in Electric Vehicle (EV) batteries |
| 4 | The ferric chloride system minimises the use of oxygen and production of waste sulphuric acid | Operating costs can be materially lower by minimising oxygen use and acid neutralisation requirements |
| 5 | Roasting concentrates before leaching simplifies the leaching stage significantly, but at higher capital cost | Roasting is less likely to form the basis of a commercial process unless other cost savings can be realised |
| 6 | Electrodialysis is effective at removing metals from solutions containing low levels of copper and cobalt | Electrodialysis may be a useful process for treating process waste streams and acid mine drainage |
| 7 | An redesigned electrode could unlock direct electrowinning from chloride solutions. | Solvent extraction could be eliminated and power consumption by electrowinning could be cut in half |

Table 1: Key learnings from the Ingenious Extraction experiments

## The path forward for copper miners

The copper industry could benefit from a technology that enables the economic production of copper metal at every mine site. The key opportunities that need to be unlocked to enable this are the cost of reagent schemes, the use of energy-intensive electrowinning, labour intensity and the cost of project execution. These key areas should continue to be a focus for further development by researchers and industry at large. OZ Minerals will continue to play a key role by exploring options through additional experimentation.

## The path forward for OZ Minerals

OZ Minerals will continue development of a number of promising technologies. The BIOX technology, which uses bacteria to leach copper and cobalt minerals, is currently undergoing pilot testing and will soon be the subject of a feasibility study. The ferric chloride system is being tested further, with the intention of moving to pilot testing and prefeasibility later in 2022. The thiocyanate and GlyCat systems for gold recovery are also being tested further and will be incorporated into future pilot programs.

# THINK & ACT DIFFERENTLY

**Think & Act Differently (TAD) is a discovery-driven incubator powered by OZ Minerals; established in 2021, its purpose is to accelerate the achievement of the company's strategic aspirations**

Think & Act Differently provides a unique approach to innovation, attracting the best minds from both inside and outside the mining industry, connecting the dots in new and exciting ways.

Central to its success is the active participation of a network of thousands of people from across multiple industries, organisations, community groups, governments, research organisations and others who want to play a role in solving complex mining challenges.

The incubator provides these stakeholders with access to tools, skills and processes to help identify new, low impact ways to mine and process minerals and create valuable opportunities for society.

At the core of Think & Act Differently is a unique human-driven process where the ecosystem works together to Frame opportunities, Diverge in our thinking to generate ideas, Converge experiments that we can use to test the best ideas and then Accelerate these ideas by providing funding, technical expertise, access to sites and support.

Think & Act Differently powered by OZ Minerals

## Value Created by Ingenious Extraction

**Employees**

- Employees actively working with early technology learning pathways for commercial products
- 90 employees and contractors attended the Pitch Event
- 40 employees present at the Insights Panel, which shared progress of selected experiments

**Suppliers**

- 260 innovators from 40 countries registered as a part of the Crowd Challenge
- A record 55 submissions to the challenge received
- Cohort upskilled their understanding of mining and commercialising technology

**Government**

- Identification of pathways for greater local value add
- High participation of universities, with two of the experiments conducted by academic institutions

**Community**

- Identification of pathways for local business development
- Identification of lower environmental impact solutions

**Shareholders**

- Identification of pathways to diversify mining industry customer bases, spreading risk
- Identification of opportunities to benefit from sustainable metal production

# THINK & ACT DIFFERENTLY

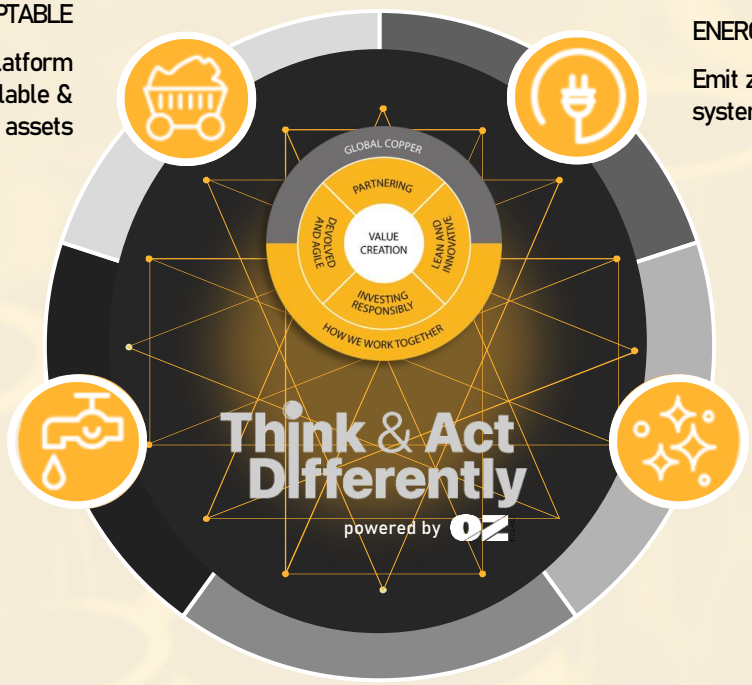
**Think & Act Differently (TAD) focuses on four transformation themes which are delivered using a humanistic systems-driven approach to innovation**

### SCALABLE & ADAPTABLE

Leverage modular/platform solutions for scalable & adaptable assets

### ENERGY & EMISSIONS

Emit zero Scope 1 emissions, and systematically reduce Scope 2 & 3




### WATER & WASTE

Minimise water usage and generate zero net waste

### CLEAN PRODUCTS

Produce clean value adding products in a transparent manner

## Humanistic systems driven innovation, Sustainable Development Goals and TAD

OZ Minerals' Strategic Aspirations are aligned with specific United Nations Sustainable Development Goals (SDGs), as well as TAD's humanistic, systems-driven approach to work which acknowledges the complexity of our challenges and prioritises the interests, needs and welfare of people. This is in synergy with the OZ Minerals purpose of 'going beyond what is possible to make lives better'.

SDGs are addressed through TAD themes of clean products, energy and emissions, water and waste, and scalable and adaptable. TAD is committed to demonstrating the impact of technologies developed through the incubator process towards the SDGs and their associated targets.

DRAFT FOR DISCUSSION

01

# Clean products and a sustainable value chain

**In collaboration with:**

**John Fennell**
*CEO, International Copper Association Australia*

As the world moves toward energy transition and decarbonisation, copper producers will play an increasingly important role in extracting the copper tonnage needed to meet the demands of the modern world.

The pace of change towards zero emission mining is rapidly gaining momentum as producers seek to address the challenge of processing increasing volumes of ore in a way that minimises the impact on the environment and on the atmosphere.

Navigating complexities to achieve operational resilience and best practice is accelerated through programs like the OZ Minerals Ingenious Extraction challenge. Working broadly across a diverse and multi-disciplined, open-innovation network, OZ Minerals is taking an important step in focusing our industry to the key technologies that could achieve a zero-emissions copper mine of the future.

The International Copper Association Australia congratulates OZ Minerals on their leadership with the Ingenious Extraction as we seek to find new ways to extract the metals for our future.

**- John Fennell**

# 1.1 Global context

**At the forefront of green innovation, copper is integral to the global decarbonisation journey and OZ Minerals is committed to being a force for positive change in the metals industry**

## The global decarbonisation journey

Our global climate is changing and climate science tells us that there is a need for large reductions in the emission of greenhouse gases in order to avoid catastrophic impacts. Many countries are now committed to achieving net zero by 2050, and company roadmaps are pushing for dates much sooner than this. Consumers are increasingly demanding responsibly produced products with low emission, water and land use impacts. In particular, the next decade will likely see an acceleration of disruptive change to the energy, transport and mining sectors as we strive to achieve our net zero goals and create a sustainable supply of raw materials for society.

## Responsible metal demand

There are now numerous examples in the market, of companies and industry bodies seeking to respond to the demand for responsibly produced metals. Well known consumer products companies such as Apple, Tesla and Mercedes are making public their efforts to improve the responsibility and traceability of source feed materials. In 2019, the London Metal Exchange (LME) released its responsible sourcing requirement to ensure the metals traded on the LME are responsibly produced. Finally, the Copper Mark organisation provides a credible certification that producers have demonstrated responsible production practices, with 24 sites certified to date.

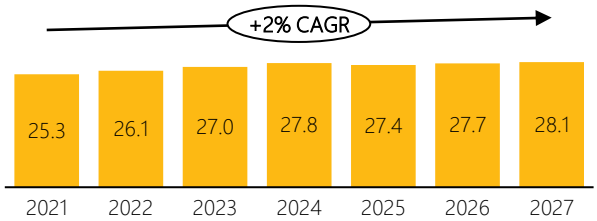
## Copper in a low-carbon future

Copper is an essential ingredient in the transition to a low carbon future. Electric vehicles will replace combustion vehicles, with the average EV containing 83 kilograms of copper[1]. Renewable energy solutions including solar and wind will replace coal and gas, with a standard wind turbine containing up to 4.7 tonnes of copper[2]. Copper is the best non-precious conductor of electricity and heat and will therefore play an essential role in the transition to green technologies.

## Consumption set to remain high

Not only is copper essential in our transition to green technologies, it is also a key ingredient in everyday items that we all take for granted such as mobile phones, computers, household electrical wiring and plumbing. As a highly conductive metal, copper is also essential in our electricity distribution networks. Demand for copper continues to grow, with global consumption forecast to grow steadily over the next five years[3].

Figure 1: Global Copper Consumption Forecast[3]
*Million metric tons, 2021 – 2027*




## Challenges facing production

It is widely accepted that the average ore grades in copper mines are steadily reducing. As the ore grades have dropped, mines have become larger in order to maintain profitability, creating greater pressure on energy, water and land use resources. The mining industry will need to respond to the challenge of creating a sustainable supply of responsibly produced raw materials against this backdrop of falling ore grades.

## OZ Minerals strategic aspirations

With this global context in mind, OZ Minerals has aspirations to produce clean, value adding products in partnership with our customers in a transparent manner, to emit zero scope 1 emissions and strive to systematically reduce scope 2 and 3 emissions. OZ Minerals is also striving to minimising water use and consume and produce in a way that generates net zero waste. These aspirations are the key drivers of the Ingenious Extraction challenge.

# 1.2 Copper production

**Leaching copper production presents an exciting opportunity for mining companies to bring metal extraction on-site but there are large cost and performance barriers still to be overcome**

## The two routes to copper production

Copper metal is produced in two ways: smelting, which is the most common method and accounts for approximately 80% of global copper production, or leaching.

Smelting uses high temperatures exceeding 1200°C to extract copper from concentrates. These high temperatures are used to break down concentrate minerals to form "blister" copper. This form of copper contain impurities, which then undergo refining to form LME Grade copper. At this grade, the copper can be used in modern applications including wiring, communications, piping and transportation via electric vehicles.

Leaching uses lower temperatures and water to extract copper from ores and concentrates. Currently, commercial application is largely limited to copper oxides and secondary sulphides. Oxide ores are typically heap leached, which involves the use of acid to dissolve copper minerals to create a dilute copper salt solution. This solution undergoes solvent extraction and electrowinning stages to recover LME Grade copper metal, which can be completed on-site. For secondary sulphides, biological heap leaching can be used, which relies on natural bacteria to catalyse the extraction of copper from ore.

## Smelting dominates production

Smelting is the dominant method for copper production as the process is technically simple, coupled with relatively low operating costs at commercial scale. However, smelting is capital intensive and only makes economic sense at scale, and even then, the profit margins of many commercial smelters are small. As a result, the smelting industry tends to be based in lower cost jurisdictions e.g. India, China and Eastern Europe. Lastly, not only is the smelting process extremely emissions intensive, transportation adds to the emissions intensity of processing concentrate using smelting methods.

## Unlocking value with leaching

Leaching presents significant opportunities to both mining companies and their stakeholders. Mining companies benefit through the decentralisation of metal production away from large overseas smelters, in addition to reducing their scope 3 emissions associated with smelting and transportation. Local production provides the opportunity to harness renewable energy, whilst providing greater transparency across the value chain for their customers and the market. Mining companies would also have the potential of creating branded products adding to their value creation narrative.

Economically, onshore leaching would allow (copper) mining companies to recover other payable metals (e.g. cobalt) which they are not currently being paid for by smelters, increasing the overall revenue they derive from their concentrate. Lastly, local communities and governments benefit through capturing the value through increased job demand and economic activity.

## Barriers to adoption

There are many barriers to the economic viability of on-site leaching, specifically across the major cost categories:

- Power costs (~30% of total costs), dominated by the requirements of electrowinning (~25% of capital cost) to produce copper cathode
- Labour costs (~20% of total cost), with complex multi-stage processes requiring more operators
- Reagent costs (~30% of total operating expense), dominated by the cost of oxidising sulphur, then neutralising any acid generated
- Project execution (~25% of capital cost)
- Waste products e.g. iron and sulfur must be managed effectively by either forming stable products to be safely disposed or commercially valuable products

# 1.3 Industry landscape

**Many technologies and processes to extract metal from copper ore and concentrate have been developed over the years and these are at various stages of commercial use**

## Ore and concentrate leaching methods

This section will summarise existing and emerging technologies in ore leaching and concentrate extraction, the two dominant methods for extracting copper metals.

Ore leaching is typically carried out by either acid heap leaching or biological heap leaching. Acid heap leaching is commonly applied to ores containing oxide minerals. Biological heap leaching is typically used on those with secondary sulfides. Concentrate extraction is carried out by a wide variety of leaching processes.

## Emerging innovations in ore leaching

The JX Group (Japan) have developed Iodine – catalysed heap leaching of chalcopyrite, while Jetti Resources is commercialising catalytic heap leaching of copper using technology developed at the University of British Columbia (Canada). Various organisations have pioneered "hot heap" leaching of chalcopyrite ores using special classes of natural bacteria (Archaea) that thrive at high temperatures in a low pH, copper solution environment. These technologies offer promising pathways extracting metal direct from primary copper ores.

## Concentrate leaching technologies

The leaching technology most widely used in commercial applications for processing copper concentrates is pressure oxidation (POX). This technology has found application on sites where there are mixed oxide and sulphide resources. POX can be used to recover copper from sulphide concentrates, while producing dilute acid that can be used in the heap leaching of copper oxide ores. Numerous variations on POX that have been developed to address specific issues with the technology.

Multiple other commercially available technologies have been developed to address specific issues such as arsenic content or treatment of mixed metal concentrates containing other base metals such as lead, zinc and nickel.

A selection of concentrate leaching processes is shown in Table 2 below.

| Process | Description |
|---|---|
| Activox® | Ultrafine grinding and high pressure oxidative leaching |
| Albion Process™ | Ultrafine grinding and oxidative leaching at atmospheric pressure |
| AAC-UBC(1) | Ultrafine grinding and leaching with surfactants for sulfur dispersion |
| Bactech/ MINTEK | Bioleaching using bacteria to catalyse oxidation of concentrates |
| BioCOP™ | Bioleaching using bacteria to catalyse oxidation of concentrates |
| CESL Copper Process | Mixed chloride/sulfate leaching system at high pressure |
| FLSmidth® Rapid Oxidative Leach | Mechano-chemical leaching using stirred media reactor (SMRt) |
| Galvanox™ | Galvanically-assisted leaching under mild conditions in acidic solution |
| Glycine Leaching | Glycine-based leaching in alkaline environment |
| INTEC® Copper Process | Chloride-bromide halide leaching in a cyclic circuit with chloride electrowinning |
| MTPOX(2) Process | Ultrafine grinding and leaching with surfactants for sulfur dispersion |
| Nikko Chloride Process | Leaching at low temperature in chloride-bromide halide solution |
| Metso:Outotec Chloride Process | Chloride leach and copper precipitation |
| PLATSOL™ | High temperature chloride-assisted pressure leaching |
| Total Pressure Oxidation | High temperature and high pressure oxidation of sulfides |

**Table 2:** Selected copper concentrate leaching processes



Notes: (1) AAC-UBC is a joint venture between Anglo American Corporation (AAC) and University of British Colombia (UBC) (2) MTPOX is Medium Temperature Pressure Oxidation

# 02

# Ingenious extraction challenge

**In collaboration with Unearthed:**

**Elizabeth Brookman**
*Systems Partner*
*Unearthed*

> For our Industry to deliver on our goals and aspirations for net zero emissions targets, the innovation we need will come from both inside and outside our businesses. No one organisation has all the necessary skills and expertise it needs to drive sustainable positive change and by opening up our businesses to global communities of innovators, start-ups and entrepreneurs, we can fast track the innovation we need to advance our industry towards a greener future.
>
> With a record level of engagement from the crowd, Ingenious Extraction demonstrated that by engaging a diverse community across industries and the world, we can find passionate innovators, experts and ideators ready to collaborate to unlock new and novel ways to solve problems.
>
> – Elizabeth Brookman

# 2.1 Challenge framing

**Think & Act Differently was seeking novel concentrate leaching technologies that could drive down key operating and capital costs while maintain high rates of metal recovery**

## Our vision for metal extraction

OZ Minerals is guided by the purpose of "going beyond what's possible to make lives better." Within this, OZ Minerals aspires to provide clean, value adding products in partnership with our customers in a transparent manner, emitting zero scope 1 emissions, striving to systematically reduce scope 2 and 3 emissions, and striving to minimise water use and waste generation.

These strategic aspirations have inspired Think & Act Differently to launch Ingenious Extraction in the search for new extractive technologies that could disrupt the traditional value chain, enabling closer connections with end consumers, the ability to provide full traceability of products from resource to end use and to minimise the footprint of the products we produce.

## Why do we need new solutions

As described in Section 1.3, various concentrate extraction systems are technically feasible and commercially available. However the cost structure of these solutions typically renders them uneconomic compared to the incumbent process of using third party smelters.

## Key cost drivers for leaching

For a typical commercial concentrate leach and electrowinning process, the majority of costs come from reagents (~30% operating expense (OPEX)), power (~30% OPEX) and electrowinning cells (~25% capital expense (CAPEX)).

The costs for power for on-site leaching treatment is high, with electrowinning of copper using approximately 8 times the power of the competing electrorefining process (used in conjunction with smelting), in addition to labour costs and project execution. The costs for reagents can include oxygen supply for leaching and lime or limestone for neutralisation of acid and precipitation of iron. In addition, costs for cyanide for gold recovery can be significant and is exacerbated by the need for cyanide destruction prior to residue disposal.

Finally, conventional electrowinning of copper operates at low current density, thereby requiring a large number of electrowinning cells, resulting in high capital costs.

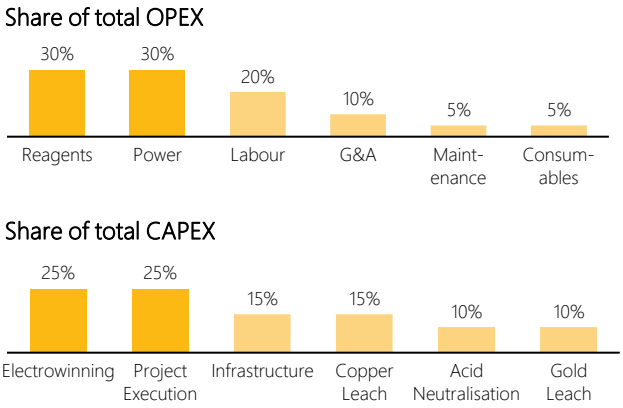



**Figure 2:** Cost estimates for typical commercial concentrate leach and electrowinning process

## Key focus areas of the challenge

The high costs of reagents, power and electrowinning cells are a key barrier to the commercial adoption of concentrate extraction systems for OZ Minerals. As such, the primary focus of the challenge was to identify new processes that could demonstrate a material reduction in these costs, while maintaining metal recovery rates equivalent to the incumbent systems.

Therefore, Think & Act Differently framed a targeted crowd challenge inviting innovators from around the world to propose unique and novel leaching processes for concentrate extraction, as well as experiments to demonstrate the performance and economics of the solution.

# 2.2 Innovator overview

**OZ Minerals identified seven new and innovative extraction systems that have the potential to support economic copper recovery, and a range of experiments were funded to validate performance**

| | Technology | Potential Impact | Experiment |
|---|---|---|---|
| Clean&Recover<br>Start-up | Replace electrowinning stage with electrodialysis | Lower the capital cost of the process to make a clean copper metal product and separate copper from cobalt | Demonstrate technology on an electrodialysis pilot plant |
| MPS & Curtin University<br>University research collaboration | Glycine leaching and sulphate electrowinning | Process uses low intensity alkaline leach to reduce operating costs and generate non-toxic by-products | Conduct pre-oxidation processing of concentrate followed by copper and gold recovery |
| DCS Technical<br>Consultants | Halide leaching and chloride electrowinning | Reduce the energy related costs for electrowinning – new electrowinning cell (EWC) can halve power consumed | Design and test a prototype EWC to improve existing Intec EWC design |
| tfgMM Strategic Consulting & T.P. McNulty & Associates<br>Boutique consulting company | Roast & water leaching and sulphate electrowinning | Roasting generates electricity and requires no reagents, reducing operating costs | Conduct proof of concept roast and leach tests supported by a thermodynamic study |
| Minetometal<br>Small consulting company | Ammonium and ammonium chloride leaching and metal precipitation | Reduced operating costs through the use of alkaline leach and precipitation | Conduct proof of concept testing of a flowsheet combining leaching, crystallisation and reduction |
| University of British Columbia<br>University | Ferric chloride & thiocyanate leaching and sulphate electrowinning | Process leaches metals together in a single step, reducing operating and capital costs and environmental impact | Conduct reactor leaching tests to study the effect of key process variables on copper and gold extraction efficiency |
| BIOX<br>Technology company | Bacteria leaching and sulphate electrowinning | Apply existing established extraction process to copper concentrate | Testwork for continuous leaching and solvent extraction, and replication of experiments in large pilot plant |

Table 3: Overview of experiments funded as part of the Ingenious Extraction challenge

# 2.3 Key learnings and next steps

**The completed experiments demonstrated that there are a range of technically suitable processes for extracting metal from copper concentrates but the economics continue to be challenging**

## Learnings from novel methods

All experiments were successfully completed, and results generated many valuable insights into the performance and viability of the novel processes (see table 4 below).

## The path forward

The experiments completed to date by the Ingenious Extraction cohort have successfully demonstrated a range of technically suitable processes for extracting metals from copper concentrates. The economics continue to be challenging compared to the base case of third-party smelting, however there are promising signs that with further development, several technologies may prove to be economically competitive at scale. OZ Minerals will continue to explore these options through further experimentation.

More broadly, the copper industry and society as a whole could benefit from a technology that enables the economic production of copper metal at every mine site.

The key opportunities that need to be unlocked include the cost of reagent schemes, which are strongly leveraged to the extent of sulfur oxidation, the use of electrowinning, which significantly impacts capital cost and the operating cost associated with power, the cost of labour, for which robotics and automation is potentially able to unlock, and the cost of project execution. These key areas are, and should continue to be, the focus for further development by the researchers and the industry at large.

## The path forward for OZ Minerals

OZ Minerals will continue development of a number of promising technologies. The BIOX technology, which uses bacteria to leach copper and cobalt minerals, is currently undergoing pilot testing and will soon be the subject of a feasibility study. The ferric chloride system is being tested further, with the intention of moving to pilot testing and prefeasibility later in 2022. The thiocyanate and GlyCat systems for gold recovery are also being tested further and will be incorporated into future pilot programs.

| # | Key learnings | Implications |
|---|---|---|
| 1 | The ferric chloride, glycine, ammonia-ammonium-chloride, roast-leach and bacterial oxidation systems are all able to achieve high copper extraction rates | All of these technologies from this challenge could conceivably form the basis of a suite of new commercial processes |
| 2 | The thiocyanate and glycat systems are both able to achieve high gold extraction rates | Cyanide can be eliminated for gold recovery, realising significant safety, environmental and cost benefits for any new process |
| 3 | A cobalt product can be produced from OZ Minerals copper concentrates; a metal that is currently not recovered by third party smelters | New revenue can be realised from responsibly produced cobalt, an important critical mineral used in EV batteries |
| 4 | The ferric chloride system minimises the use of oxygen and production of waste sulphuric acid | Operating costs can be materially lower by minimising oxygen use and acid neutralisation requirements |
| 5 | Roasting concentrates before leaching simplifies the leaching stage significantly, but at higher capital cost | Roasting is less likely to form the basis of a commercial process unless other cost savings can be realised |
| 6 | Electrodialysis is effective at removing metals from solutions containing low levels of copper and cobalt | Electrodialysis may be a useful process for treating process waste streams and acid mine drainage |
| 7 | An redesigned electrode could unlock direct electrowinning from chloride solutions. | Solvent extraction could be eliminated and power consumption by electrowinning could be cut in half |

**Table 4:** Key learnings from the Ingenious Extraction experiments

# 2.4 Challenge process

**260 participants from 40 countries took part in this challenge through the incubator, creating long-lasting and valuable industry networks that will continue to flourish in the Alumni program**

## Framing – curating the crowd

Global research was conducted by Unearthed for the challenge, with the cohort primarily based in Australia, Singapore and North America. The challenge outreach focused on identifying research teams and professionals that have the interest, expertise and capabilities to investigate novel and innovative approaches to extracting metal from copper sulphide concentrates.

## Divergence – building innovator community

Over a seven week period, the challenge attracted 260 participants from 40 countries, with 55 teams putting forward a submission.

Organisations that expressed interest in the challenge were diverse, with start-ups, university researchers and consultants. Their focus was distributed across numerous extraction methods including roasting, leaching, solvent extraction and electrowinning. While some submissions focused on improvements to existing processes (e.g. reducing costs and energy requirements), other submissions focused on replacing components of the metal extraction process with more efficient and economic alternatives and reducing the number of stages required in the incumbent process.

During this phase, the Think & Act Differently team also hosted a mid-challenge webinar on the topic of metal extraction hosted by experts in the field; it was promoted widely on social media and attended by people from across the globe.

## Convergence – narrowing down on ideas

In selecting a cohort to support through the experimental Accelerate stage, Think & Act Differently focused on ensuring a spread of technologies within the metal extraction process, and selecting innovators that were highly collaborative, willing to share their learnings and had expressed interest in collaborating to build and improve upon the metal extraction process. By progressing to the Accelerate cohort, innovators have grown their networks and met others with complimentary solutions. Ultimately, six experiments were funded from a group of ten finalists. In addition, an OZ Minerals project focused on BIOX joined the cohort to share in the learnings, bringing the total number of experiments to seven.

## Accelerate – validation through testing

The six members of the Accelerate cohort (profiled on the following pages) spent between two to six months completing their experiments. They met every two weeks to share learnings and experiment progress in a Learnings Roundtable. Additionally, they have shared insights with OZ Minerals via Insights Panels. Notably, COVID circumstances including lockdowns did impact the experiments, specifically through delays in receiving supplies due to backlogs and transport holdups.

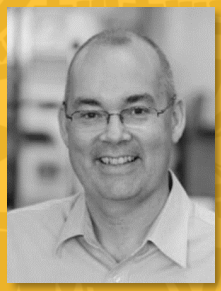
With experiments now complete, each innovator will have a personalised roadmap developed, providing a recommended future direction. In some cases, this will involve Think & Act Differently investing in further development of their concept. In other cases, their work will finish, but they will continue to stay connected to the ecosystem through our Alumni program.

The Think & Act Differently team would like to acknowledge the time and effort all participants and innovators that have contributed and will continue to contribute to the Ingenious Extraction challenge.

# 03

# Accelerate learnings

**In collaboration with:**



**Professor David Dreisinger**
*Facilitator & Mentor*
*Ingenious Extraction*

> Economically extracting copper and other metals on a commercial mine site is equal parts exciting and difficult, and will only be solved with a collaborative effort across industry, academia and business.
>
> The Ingenious Extraction Challenge provided a unique opportunity for the OZ Minerals team and innovators to meet regularly, discuss results and findings freely and look for new ways to cooperate and innovate, putting us one step closer to achieving this grand vision.
>
> - David Dreisinger

# 3.1 Clean&Recover

**Luke Berry**
*Clean&Recover*

**Di Liu**
*Clean&Recover*

## Company and innovator overview

Clean&Recover's mission is to capture value from mining waste streams and clean the treated output to a high standard. Their product offerings centre around cleaning solids from waste water and treatment of acid mine drainage.

**Luke Berry** is the Chief Executive Officer. He has worked in heavy utilities and consulting and founded Clean&Recover in 2017.

**Di Liu** is the Chief Scientist, holding a PhD in Chemical Engineering from the University of Queensland and a Masters in Polymer Materials and Engineering.

## The opportunity

This opportunity aims to investigate electrodialysis as a method for direct metal separation and recovery from acidic solutions by formation of metal hydroxide precipitates.

Electrodialysis is the process by which metal ions present in a feed solution are precipitated from solution using electricity, rather than chemicals. This process has a number of mining and non-mining commercial applications. Initially, the process was developed for desalination of brackish water in the 1950s, with subsequent applications in demineralisation of food products, waste water treatment and table salt production.

The process has never been applied in the mining industry to-date. In the production of copper metal, it offers potential improvements to conventional electrowinning as it can separate metals from each other based on pH control.

Clean&Recover have identified the opportunity to demonstrate the application of electrodialysis in the selective separation and precipitation of metals. They have recently developed an electrochemical cell, ElectroClear (ECR), which uses electrodialysis to treat acid mine drainage (AMD) by separating dissolved metals in the AMD from clean water and recovering the metal-rich precipitates from the process.

Clean&Recover seek to investigate a secondary use for the ECR in precipitation and separation of copper and cobalt metals from each other in acidic sulphate solutions.

## Experiment summary

Clean&Recover designed an experiment to determine if copper and cobalt could be selectively separated and recovered from an acidic solution based on the different pH's at which they typically precipitate from solution. The experimentation consisted of precipitating two synthetic leach solutions: a copper solution and a mixed copper/cobalt solution.

To test the precipitation of copper, an artificial copper sulphate solution was run through the ECR. The copper was fully recovered from the acid solution by increasing the pH to 6.6. Separation of copper and cobalt precipitates was tested using a mixed copper/cobalt solution. Based on experiment results, 99% of copper and 9% of cobalt coprecipitated at pH 5.9, while the remaining 91% of cobalt in the solution precipitated by increasing the pH to 9.5.

The main barrier to Clean&Recover's ECR technology was developing the ECR further to reduce the energy required to raise sufficiently the pH of the solution. Overall, the ECR technology demonstrated success in the full recovery and separation of copper and cobalt hydroxides from leach solutions.

## Next steps for this technology

Testing was conducted at Clean&Recover's pilot plant. Further testing and process improvements are proposed to improve the energy efficiency of the process. Improvements are available in areas including optimising the cathode, anode, membrane, flow turbulence, power supply, configuration of cells in series, cell residence time, flowrate and process kinetics.

> **We got to learn about the mining industry from the inside, and how our offering fit within it.**
> **– Luke Berry, CEO, Clean&Recover**

# 3.2 Curtin University and MPS

**Ivor Bryan**
*MPS*

**Prof. Jacques Eksteen**
*Curtin University*

**Dr. Elsayed Oraby**
*Curtin University*

## Company and innovator overview

The Curtin University and Mining and Process Solutions (MPS) teams have been commercial partners since 2014. Curtin University has extensive research facilities at their Bentley and Kalgoorlie campus, while MPS is an independent company that operates a development laboratory in Perth with a principal focus of commercialising glycine based leaching systems.

From MPS, **Ivor Bryan** is the Managing Director. Ivor has over 35 years experience in the mining industry across a variety of operational, project management and senior management roles.

From Curtin University, **Professor Jacques Eksteen** is the co-inventor of the glycine leaching technology. He is a Professor in extractive metallurgy, with over 29 years' experience in industry and academia. He is an inventor on 9 patent families and has published over 200 peer reviewed articles. Also from Curtin University, **Dr. Elsayed Oraby** is an Associate Professor in the Gold Technology Group. He is a co-inventor of the glycine leaching technology and has extensive research experience in leaching. He has published over 50 papers in peer reviewed journals and articles.

## The opportunity

This opportunity aims to investigate alternatives to the smelting of concentrates to produce metal.

Current smelting methods have low cobalt payability, although they can achieve high gold and copper payability in smelters. Additionally, transporting concentrates to overseas smelters is both costly and emission intensive. Shifting metal extraction onsite could generate additional value for the broader community within which OZ Minerals (and other mining companies) operate.

However, onsite metal extraction utilising leaching techniques needs to address a few challenges. Specifically, these techniques require high selectivity and recovery of all payable metals, a low intensity process to be economically viable and both environmentally and socially sound (e.g. the management of onsite residue and by-products).

The Curtin University and MPS team have developed leaching processes using glycine, an amino acid. When used in an alkaline environment, it is selective for base and precious metals including copper, cobalt and gold. This process notably does not take iron and magnesium into solution, which simplifies downstream metal extraction process. This process operates within a low intensity alkaline system in low to modest temperatures, with no exotic materials required and where by-products are non-toxic. The glycine mixture is further not chemically consumed during the process, allowing it to be recycled, contributing to material circularity.

The Curtin University team seeks to investigate whether alkaline leach and sulphate electrowinning can achieve a high extraction of copper and select precious metals.

## Experiment summary

MPS and Curtin University performed a detailed mineralogical analysis of the Carrapateena concentrate followed by a large number of extraction tests. Extraction of the value metals was performed on the as-received concentrate and a pre-oxidised concentrate. Copper, gold, iron and sulfur in products were determined using liquid and solid sample analysis. In this experiment, four specific processes were tested: Oxidation (sulfur removal), GlyAmm™ (copper removal), GlyCat™ (gold and silver removal) and GlyLeach™ (cobalt removal).

## Next steps for this technology

Further testing is suggested for the four processes mentioned above to optimise the extractive abilities of each process and to demonstrate the process at a larger, continuous scale. Process integration of the sub-processes is required and metal recovery from solution and purification needs to be integrated.

> **Evaluating a new metallurgical process is traditionally very linear and rigid. The Ingenious Extraction approach facilitated the collaboration and flexibility required to consider options as they presented themselves.**
>
> **– Ivor Bryan, Prof Jacques Eksteen, Dr. Elsayed Oraby**

# 3.3 DCS Technical

**Dave Sammut**
*DCS Technical*

## Company and innovator overview

DCS Technical is a boutique consultancy that works with Australian minerals, waste recycling and general scientific industries. Hydrometallurgy consulting is one of their core services with specific application to the minerals and waste sectors.

Founder **Dave Sammut** completed Honours in Industrial Chemistry and a Masters of Business & Technology at the University of New South Wales. Across his career, Dave has worked extensively within R&D corporate management and commercialisation with both government and investor audiences and has a passion for creating value through innovation.

## The opportunity

DCS Technical's concentrate treatment system is based on halide leaching, a promising alternative to conventional sulphate-based practices.

Halide leaching offers significant economic benefits in CAPEX and OPEX cost savings due to reductions in the plant size required for atmospheric leaching and energy usage for electrowinning, along with the use of inexpensive reagents. This technology is able to minimise the environmental impact of copper concentrate processing. Specifically, it operates within a closed loop system where zero liquid wastes and gases are emitted and avoids the use of toxic reagents and produces environmentally stable solid residues.

This is not a new technology. It has been in development for over 30 years and is close to commercialisation. $50m have been invested in chloride-based hydrometallurgical extraction technology by Australian companies Dextec Ltd and Intec Ltd. In 1998 to 2000 and 2003, pilot and demonstration scale plants (~1t per day) were operated.

However, issues arising from the removal of crystalline copper dendrites during the electrowinning stage have prevented the technology from progressing further.

The Intec Process electrowinning (EW) cell required substantive modifications, maintenance and repairs. This was attributable to the complicated cell design, which included vertically arranged sawtooth cathodes and a bulky wiper mechanism. DCS Technical's halide electrowinning technology aims to reconfigure the halide leaching EW cell and prove commercial feasibility.

## Experiment summary

DCS Technical designed and tested a prototype EW cell to determine if it could improve the previous Intec Process design and continuously recover copper metal directly from cuprous halide electrolyte.

The prototype EW cell took a novel approach to the production and handling of the crystalline dendritic 'tree' structure that is characteristic of halide copper electrowinning.

This new prototype performed strongly under testing, and demonstrated its potential to reduce operational costs, maintenance and handling. Overall, the results suggest that the combination of halide extractive metallurgy and the DCS Technical EW cell system offer the possibility of direct copper recovery on site at recovery levels at or above those of commercial smelting processes

## Next steps for this technology

To validate long term performance of DCS Technical's EW cell and conversion rates, a pilot scale operation should be conducted for 6-12 months of continuous operation.

> **This breakthrough wouldn't have happened without OZ Minerals support. We are thrilled to be part of the Think & Act Differently Incubator Program.**
> **– Dave Sammut, Founder, DCS Technical**

# 3.4 Roast Leach Electrowin Reimagined

**Krishna Parameswaran**
*tfgMM Strategic Consulting*

**Terry McNulty**
*McNulty & Assoc*

**David Robertson**
*Missouri S&T*

## Company and innovator overview

This team comprises three experienced metallurgists with a dream of resurrecting and modernising an old commercial process for leaching roaster "calcine" for the recovery of copper, cobalt, gold and silver.

**Krishna Parameswaran** has a doctorate in metallurgy from the Pennsylvania State University and has over 30 years' experience at ASARCO LLC, an integrated copper producer based in Tucson, Arizona. He is now President of tfgMM Strategic Consulting, which specialises in the sustainable development of extractive industries with emphasis on primary metals production, metals recycling, energy and water use in metal production, mining industry decarbonisation, life cycle assessment and product stewardship.

**Terry McNulty** has a Doctorate in Metallurgical Engineering from Colorado School of Mines. Terry has over 25 years in various research, operating and management positions at The Anaconda Company, Kerr-McGee Chemical, and Hazen Research. Over 30 years ago, he founded T.P. McNulty and Associates Inc., a global consulting firm.

**David Robertson** has a doctorate in Metallurgical Engineering from the University of New South Wales. David taught at Imperial College, London (1969-1985), and later at the University of Missouri at Rolla where he was also Director for Center of Pyrometallurgy (1986-2008). He presently is an independent consultant and has been visiting professor at universities and industrial laboratories in Australia, Asia and South Africa.

## The opportunity

This opportunity aims to investigate a hybrid roast, leach, and sulphate electrowinning process as an alternative to smelting and electrorefining in the production of copper, gold, silver and cobalt from copper concentrates.

Slow leaching rates currently result in higher CAPEX and OPEX costs for leaching alternatives. Roasting generates electricity and requires no reagents during this stage, thereby reducing OPEX. Leaching with water also avoids producing highly acidic leach residue, simplifying downstream precious metals recovery by leaching.

The proposed process entails the selective roasting of copper concentrates to convert copper and cobalt to their water soluble forms (sulphates and oxy-sulfates), which then undergo solvent extraction and conventional sulphate electrowinning to recover copper. Cobalt is precipitated as a commercial product. Gold and silver may be recovered from the concentrates prior to roasting, or from the copper leach residue. Iron in the precious metals leach residue will be separately stored for potential recovery and sale.

## Experiment summary

A thermodynamic study was designed to establish optimum roasting parameters and determine whether the proposed selective roasting process can maximise the recovery of copper and cobalt.

A fluidised bed roasting test was completed to produce a calcine containing copper sulfate, copper oxide, copper oxy-sulfate and hematite. The leach extractions using pH 1 solution conditions were 97% for copper and 82% for cobalt. The experiment demonstrated adequate copper and cobalt extraction.

## Next steps for this technology

Further testing and process refining is suggested to confirm gold and silver extraction using either alkaline cyanide, glycine or a magnesium chloride/hydrogen chloride extraction process. Copper solvent extraction and electrowinning and cobalt recovery should be studied. Further cost efficiencies should be identified, such that this process can compete with smelting and refining, whilst reducing environmental footprint.

> **This challenge offered us a better understanding of a new model for innovative metallurgical process development, making it possible to evaluate more process alternatives in screening stage than possible in the conventional model, i.e., idea conception, laboratory testing, pilot plant and demonstration plant operations.**
>
> **– Krishna Parameswaran, North American team philosopher**

# 3.5 Minetometal

**Dr. Ray Shaw**
*Minetometal*

## Company and innovator overview

Minetometal is a boutique consulting company within the industrial minerals and metals industry. Their primary offerings are targeted towards mineral processing, copper and zinc hydrometallurgy, and smelting processes.

**Ray Shaw** is the director of Minetometal and has consulted clients on R&D Systems and Applications related to a range of industrial mineral and metal applications. Across his career, he has held the position of GM at Rio Tinto Technology and Chief Scientist across various mining companies.

## The opportunity

This opportunity relates to the use of alkaline chloride based leaching chemistry for copper concentrates. Numerous acid sulphate processes have been developed but are not commonly used for concentrates at a commercial scale. Alternative chemical reactions can be applied at each of the three key stages to achieve the same outcome at lower economic and environmental cost.

Firstly, ammonia-ammonium chloride leaching is used instead of sulphate leaching, which offers the benefit of being able to process concentrates from difficult ores. Secondly, crystallisation and thirdly direct hydrogen reduction are replacements for solvent extraction and electrowinning that eliminate the need for an additional neutralisation process whilst minimising carbon dioxide emissions.

These chemical reactions have been studied extensively over the past 50 years. However, a single process combining these and applying them to the treatment of copper concentrate has not yet been explored. This has created an opportunity to develop an integrated end-to-end flowsheet.

Minetometal has developed a conceptual ammonia-ammonium chloride leaching, crystallisation and direct reduction process and are working to prove its feasibility for niche applications.

## Experiment summary

Minetometal conducted experiments to determine the basic plant design and a preliminary economic study on the potential CAPEX and OPEX reductions. Supporting test work included the investigation of copper solubility, lime roasting, leaching, oxidation and crystallisation. Based on these results, Minetometal firmed up on sections of the flowsheet (MTM Process) that consisted of three stages: leaching, crystallisation and direct reduction.

During the leaching stage, Minetometal proposed two options to oxidise copper sulphide: roasting or direct leaching. Roasting exposed the concentrate to temperatures of 680°C prior to leaching with water and ammonia and ammonia-ammonium chloride. Alternatively, direct leaching was completed at 90°C, in which oxygen was injected in the ammonia-ammonium chloride leach.

Results confirmed that copper can be selectively extracted under both these conditions. The crystallisation stage involved precipitating copper crystals from the pregnant liquor with hydrolysis to remove any residual chloride. The hydrogen reduction stage is a well-known process, and the program did not extend to carrying out that step.

Results confirmed that the Minetometal process is technically viable, as demonstrated by the production of copper oxide crystals ready for reduction and an alkaline residue suitable for gold recovery by cyanidation. The sulphur is dumped in the residue as gypsum, rather than produce sulphuric acid and/or elemental sulphur. These would incur extra CAPEX and face potential issues with purity and marketing. The iron reports as inert hematite.

## Next steps for this technology

The next steps are to investigate metal purity, cobalt recovery, and leach residue cyanidation for gold extraction.

> **The TAD program enabled us to focus on a concrete opportunity and interact with a range of other R&D groups and the OZ Minerals technical team. Working in such a well-run program has been very stimulating and enjoyable.**
> **– Dr. Ray Shaw, Director, Minetometal**

# 3.6 University of British Columbia

**Wenying Liu**
*UBC*

## Company and innovator overview

**Wenying Liu** is an Associate Professor in the Department of Materials Engineering at The University of British Columbia. Since joining the Hydrometallurgy Chair within the Department of Materials Engineering in 2015, Wenying has been undertaking research in developing sustainable hydrometallurgical technologies for extraction of metals from ores and investigating fundamental processes involved in contaminant release from mine wastes.

## The opportunity

This opportunity relates to the leaching of copper-gold concentrate, specifically the use of acidic ferric chloride media and thiocyanate as opposed to sulphate in the leaching process.

In many of the conventional sulphate leaching processes, sulphides undergo oxidation to form sulphate. This produces large amounts of acid and residue. As a result, in the neutralisation stage, lime is required to treat the acid generated by this process. In the residue disposal stage, the gypsum waste by-product needs to be disposed of. Furthermore, gold must then be recovered in the cyanidation stage, which involves the use of cyanide in the leach solution. These stages in the current sulphate leaching process impose significant economic and environmental costs for the treatment of copper-gold concentrates.

The University of British Columbia team have proposed a process that eliminates the need for these additional stages, thereby avoiding the associated economic and environmental impact. Specifically, their solution is to replace the traditional acidic sulphate media with acidic ferric chloride and use thiocyanate to extract gold. This is intended to enable the leaching of copper-gold concentrates under acidic conditions. The use of acidic chloride reduces freshwater consumption as saline water can be used, and minimises mine water discharge.

The use of chloride based leaching for copper and thiocyanate for gold recovery has three benefits: eliminating the residue disposal stage as gypsum is no longer created as a waste by-product, eliminating the neutralisation stage by avoiding the use of lime and the associated carbon dioxide emitted in its production. Lastly, eliminating the cyanidation stage as cyanide is no longer required to extract gold. While there are numerous benefits, the use of acidic ferric chloride and thiocyanate to leach copper-gold concentrate is still in development and requires extensive testing.

## Experiment summary

The UBC team conducted an experiment to confirm proof of concept, with the aim to show high copper and gold extraction with negligible sulphur oxidation.

To test this, the team conducted numerous reactor leaching tests to study the effect of key process variables on copper and gold extraction efficiency. The outcomes of these tests show very high copper extraction (over 98%). Gold extraction exceeded 90% in the presence of thiocyanate. The elemental sulphur yield exceeded 93% confirming low sulphate generation rates.

## Next steps for this technology

Further testing is required with the next phase of work being scoped. This includes further investigations to test the oxidation of ferrous to ferric by air to oxygen-enriched air, gold extraction on activated carbon and solvent extraction of copper.

> **It was extremely valuable to receive continuous feedback from other teams participating in the OZ Minerals' Ingenious Extraction Challenge.**
> **– Wenying Liu, Associate Professor, UBC**

# 3.7 BIOX

**Joe Seppelt**
*OZ Minerals (BIOX team lead)*

## Company and innovator overview

BIOX refers to a concentrate leaching process that utilises bacteria, followed by solvent extraction and electrowinning to produce copper cathode from copper concentrate, in addition to gold/silver doré and cobalt.

This technology is owned by Metso Outotec and has been in commercial operation for over 30 years, with 13 successful plants commissioned globally. BIOX has been utilised in multiple plants and has proven to produce copper cathode, cobalt and nickel, depending on the concentrate and treatment conditions.

**Joe Seppelt** is the BIOX team lead and is an Operations Manager within OZ Minerals.

## The opportunity

This opportunity relates to the leaching of copper concentrate to produce copper cathode utilising bacteria, then solvent extraction and electrowinning.

The BIOX technology uses a 2-stage atmospheric tank leach utilising medium temperature mesophile and high-temperature thermophile cultures that extract copper and other metals into solution. Nutrients, acid liquor and air are added to assist the reaction. The leached solids are washed, thickened and neutralised. The solids go into a cyanide leach circuit for gold and silver recovery. Next, acidic liquor is clarified and goes into a 2-stage copper solvent extraction process to produce a strong electrolyte for copper recovery in the electrowinning stage. Overall, this process produces copper cathode, gold/silver doré and cobalt precipitate.

The BIOX technology has been used in commercial applications (particularly for gold) for over 30 years and has been utilised in 13 plants, including the world's first commercial bioleaching plant to treat nickel sulphide concentrate in Finland (2015).

However, critical areas need to be investigated to determine its suitability in commercial application at an existing site. These factors include economic viability (both CAPEX, OPEX and potential trade-offs), operational resilience (including risk management) and any potential impacts of site-specific conditions.

In addition, bacteria require careful temperature control and may be impacted by power outages. Both are risks that will require careful engineering and operational controls to ensure successful implementation.

## Experiment summary

OZ Minerals has been investigating BIOX concentrate leaching since 2019. Test work for continuous leaching is almost complete, as is the solvent extraction and electrowinning testing with 3 cathodes produced and currently being sampled. Development of additional scope is ongoing (e.g. gold and silver leaching).

Small scale experimentation has confirmed that very high copper, cobalt, gold and silver extractions are possible. Current work is focused on replicating these small scale experiments in a larger pilot plant in order to generate engineering data to support a feasibility study (see figure 1).

## Next steps for this technology

On completion of the pilot plant campaign it is expected that a feasibility study will be undertaken to confirm the capital and operating cost for a commercial scale plant.

Figure 1: BIOX small scale experiments

> **It was interesting to be involved in a group of innovators from such varied backgrounds, not only to see what they are working on but also how they think about the challenges and opportunities.**
>
> **– Joe Seppelt, BIOX Team Lead, OZ Minerals**

# Appendix

A.1 | References

A.2 | Disclaimer

# A.1 | References

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# A.2 | Disclaimer

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