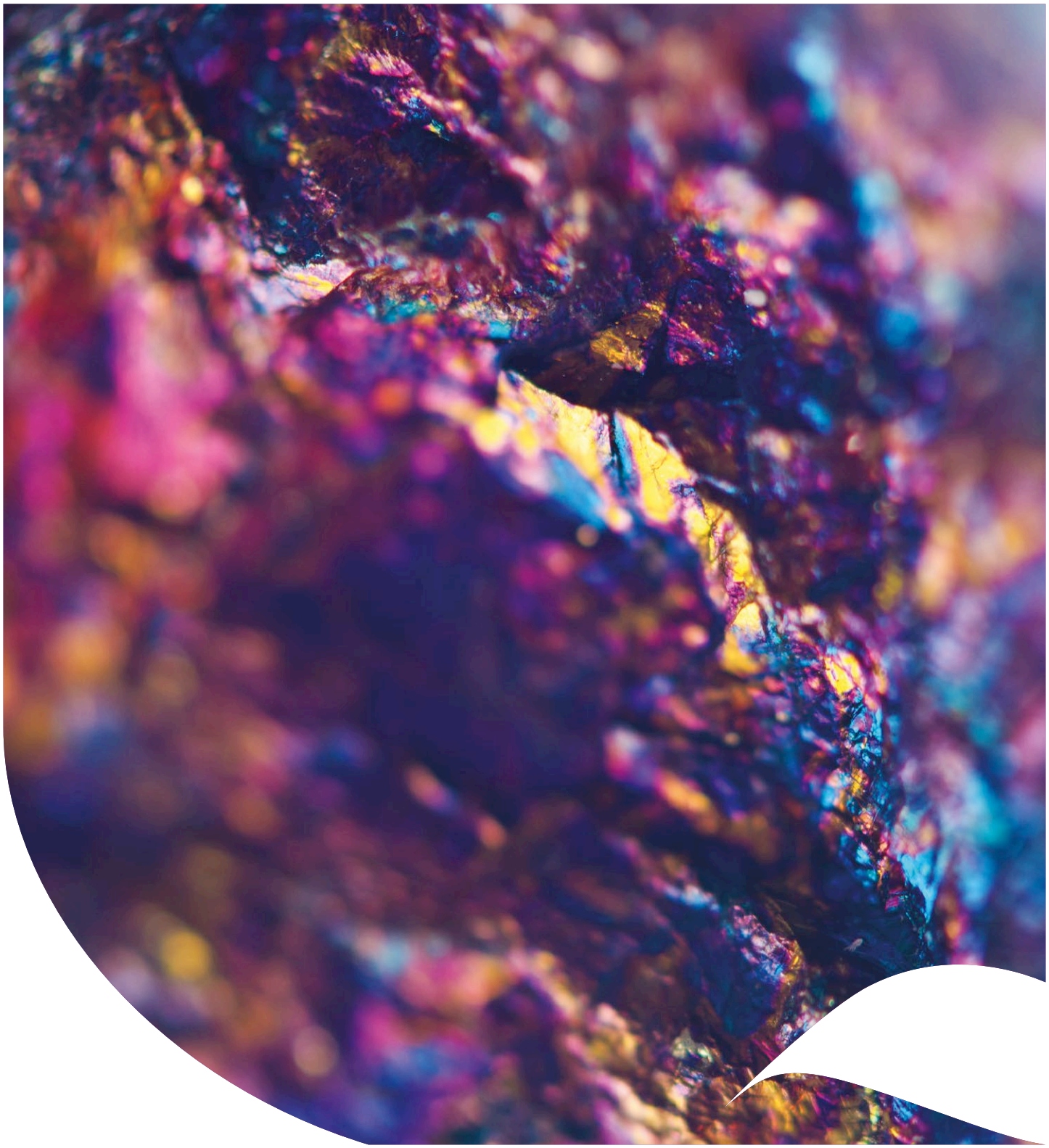
Sustainable Minerals Institute

The University Of Queensland
AUSTRALIA

CREATE CHANGE

Collaboration and impact: Complex Orebodies Program

2018–2022



Sustainable Minerals Institute structure

Centres

Julius Kruttschnitt Mineral Research Centre

Minerals Industry Safety and Health Centre

The International Centre of Excellence in Chile

W.H.Bryan Mining and Geology Research Centre

Centre for Mined Land Rehabilitation

Centre for Social Responsibility in Mining

Centre for Water in the Minerals Industry

Strategic Research Programs

Complex Orebodies

Development Minerals

Governance and Leadership

Transitions in Mining

Future Autonomous Systems and Technologies

Technology Transfer Company

JKTech

Contents

Sustainable Minerals Institute

Collaboration and impact: Complex Orebodies Program

2018–2022

The University of Queensland's Sustainable Minerals Institute (SMI) is a world-leading research institute committed to developing knowledge-based solutions to meet global sustainability challenges.

The work of SMI is multidisciplinary. It integrates expertise in exploration, mining, mineral processing, workplace health and safety, mine rehabilitation, water and energy, social responsibility and governance to reduce the minerals industry's impact on communities and the environment, and reshape its role in sustainable development.

SMI works collaboratively with industry, governments, civil society and a wide range of other stakeholders; and translates research into impact through commercialisation, contract research and consulting. SMI delivers professional development, higher degrees by research and formal teaching programs to train the next generation of industry and community leaders.

The Complex Orebodies Program is one of five 'cross-cutting' programs within SMI. Its focus is to ensure a sustainable supply of raw materials, including the supply of critical metals for the energy transition to a low-carbon future.

Message from

The University of Queensland's Vice-Chancellor and President

The Complex Orebodies Program at The University of Queensland's Sustainable Minerals Institute is a prime example of how academia, industry and government can work together to benefit the whole of society.

As the world's population continues to grow and society transitions to a low-carbon future that is dependent on critical metals, there will inevitably be increased demand for the raw materials that are produced through mining.

The Complex Orebodies Program is focused on ensuring a sustainable supply of raw materials for the future by developing the social understanding, environmental innovation, and mining and processing transformations required to access orebodies that have previously been inaccessible or complex.

Over the past four years, researchers have collaborated with industry, government and communities to increase understanding of future challenges to mineral supply, and to develop innovative solutions to address those challenges.

Researchers in the program have built global databases that track the supply risks for critical metals.

They have worked on making water supplies in mining regions more productive, efficient and sustainable. They have explored ways to reduce the footprint of mining operations. And they have investigated ways to make mine waste safer, or even a source of value for companies and local communities.

The Program has partnered with 26 organisations, and generated or supported more than 20 different projects.

In total, 89 researchers from 15 UQ Schools and Centres have contributed to the work of the Program, publishing over 40 journal papers. The Program has also provided funding to 11 higher degree by research students and 17 postdoctoral research fellows.

The research undertaken by the Program team truly exemplifies our vision of knowledge leadership for a better world. I look forward to seeing the team continue to build partnerships and collaborations that will contribute to a sustainable future for everyone.

Professor Deborah Terry AO,

Vice-Chancellor and President
The University of Queensland

Introduction from the Complex Orebodies Program Leader

The Complex Orebodies Program was established in 2018 with the aim of integrating the depth of expertise within the Sustainable Minerals Institute and the broader University of Queensland community, to find real-world solutions to the challenges facing the minerals industry – now and into the future.

As society transitions to a low-carbon future, the global demand for minerals – many of which are new and unfamiliar – is increasing. Against this backdrop, the industry is also reshaping itself to reduce its impact on communities and the environment.

As leader of the Complex Orebodies Program, I wanted to develop a collaborative consortium with industry and academia to facilitate and deliver impactful research outcomes across the mining value chain to support the future supply of raw materials.

The Program invests in strong, innovative ideas, and enables research teams to develop them to a point where they are directly accessible and attractive to industry. This is an important part of university research, and I am pleased to say we have built significant collaborations and partnerships over the past four years – a number of which you will read about in this report.

Developing solutions to complex problems takes time and teamwork; a great example of this is the bioengineering for *in situ* recovery of metals.

One of the 'holy grails' of mining research is the quest to extract metals without mining at all – by pumping fluid into rocks and having that fluid dissolve the metals and then get pumped back out of the rocks, with no blasting, no tailings, no acid-generating waste, no dust and so on.

A team of researchers from UQ's School of Chemistry and Molecular Bioscience, the School of Earth and Environmental Science, the Australian Centre for Water and Environmental Biotechnology, and the SMI has been working on this challenge for four years, and I'm pleased to report is making solid headway towards this goal.

As an academic institute, education and training is also a key part of our business – the Complex Orebodies Program has funded a number of PhD scholarships and post-doctoral research fellowships that ensures we are contributing to training the next generation of industry and academic leaders.

In its final two years of operation, the Program has delivered a direct 4:1 return on the initial investment of $5 million. We now want to secure funding for the next phase of the program – to build a portfolio of innovative, transdisciplinary, translatable research projects designed with and for industry.

This brochure showcases some of the Complex Orebodies Program's work from the past four years, across our diverse range of topics and stakeholders. Please contact me if you would like to know more.

Professor Rick Valenta

Program Leader, Complex Orebodies
Deputy Director (Production), SMI
r.valenta@uq.edu.au

Complex Orebodies Program snapshot

$5m
strategic funding over 5 years
Commenced Q1 2018

89
UQ researchers participating

$17m
over 5 years for the overall program

28
projects

15
UQ Schools and Centres

1
hosted international conference

3
presentation days

64
journal publications
More under review

15
conference presentations with abstracts

2
patent applications

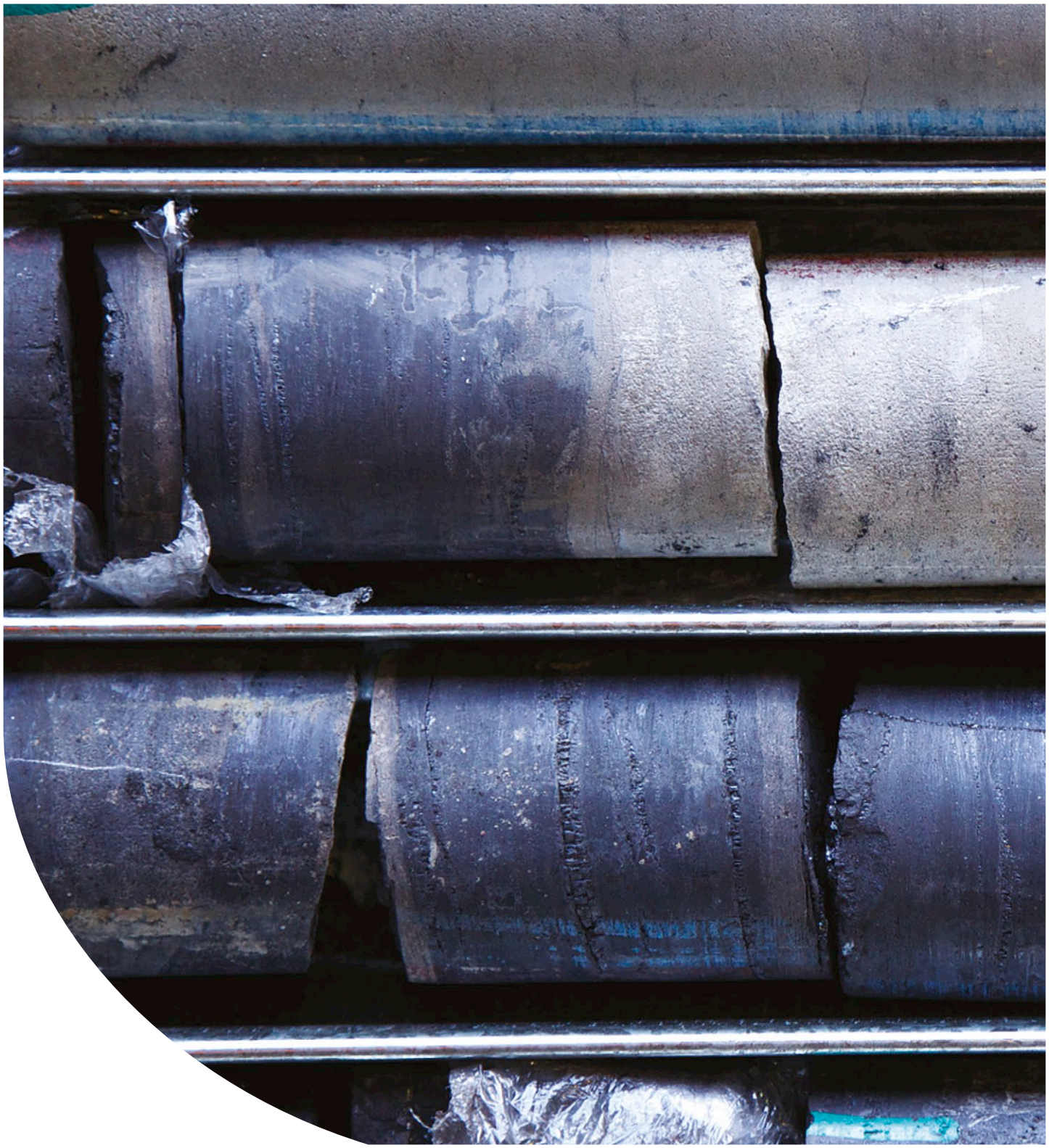
17
postdoctoral research fellows funded

11
Students funded for higher degree by research

Project collaboration:
91% cross-cutting within SMI
57% cross-cutting across UQ
85% with external collaboration

26
external funding partners from industry and government

Showcase projects



From waste to wonder

The Mine Waste Transformation through Characterisation (MiWaTCH) research group investigates the characteristics of mine waste to support the industry's work on their environmental and social legacies, and potentially find unrealised revenue streams. It also enables new mining projects to plan how they will manage environmental risk. The Complex Orebodies Program provided the initial funding to develop this research expertise within the SMI.

"Perfect planning prevents pathetic performance – I heard it on TV one day – and it's relevant," Associate Professor Anita Parbhakar-Fox said.

"Through the complex orebodies approach, we can help mining companies better plan what they're going to do with their waste, up-front."

The MiWaTCh research group, led by Associate Professor Anita Parbhakar-Fox, uses tools rooted in chemical, mineralogical, mineral chemistry, physical and metallurgical tests.

Associate Professor Parbhakar-Fox and her team investigate:

- the properties of mine waste using a combination of established industry tools and new technologies
- how waste can be used to recover critical metals important in new technologies
- how waste can be best managed to reduce environmental risks.

MiWaTCh research responds to accelerating environmental and industry needs

As global demand for minerals increases, mining companies are developing orebodies with lower grades that produce more mine waste, and the industry is under pressure to protect people and the environment by better understanding what happens to the waste.

Many mine waste dumps contain sulphides (e.g. pyrite and pyrrhotite) that, when exposed to oxygen and water, oxidise to produce sulphuric acid. This forms 'acid and metalliferous drainage', which is extremely damaging to groundwater, ecosystems and human health. There is now a growing interest in exploring the possibility for critical (or technology) metals that can be recovered from mine waste, often called a 'supplementary secondary resource'.

"Once you start looking, you start finding; for example, we've identified the potential for a historic tailings storage facility at the Savage River Mine [in Tasmania] to be a significant resource of cobalt, which is a globally sought after critical metal and key battery ingredient," Associate Professor Parbhakar-Fox said.

"These waste streams can be weird and wonderful sources of a whole gamut of critical metals."

"One site we went to – Phosphate Hill in Queensland – produces ammonium phosphate fertilisers. A by-product is phosphogypsum 'slime' that we characterised in the search for rare earth elements.

"We found a significant enrichment of two rare earth elements (erbium and yttrium) hosted in the mineral fluorapatite."

"We're working across the life of a mine, looking at operational waste storage facilities and abandoned mines, and showing the potential available to mining companies or new investors as well."

Associate Professor Parbhakar-Fox

One of MiWaTCh Group's first partnerships was an agreement with Japan Oil, Gas and Metals National Corporation (JOGMEC) and the Queensland Government. This paves the way for an international study to examine whether cobalt can be retrieved economically from old copper mine tailings. It is part of a larger study, funded under the Queensland Government's New Economy Minerals Initiative, which aims to undertake first-pass characterisation of mine wastes on at least six sites per year – with 15 sites already completed and three more recently sampled.

Industry enthusiastic to jump onboard, especially for reprocessing waste

"There's no shortage of work with all the different waste streams," Associate Professor Parbhakar-Fox said.

"There are so many ways in which you could try and recover metals, as we recently published. We do an integrated suite of geometallurgical characterisation to figure out which one suits the mineralogy best."

Based on the success of the New Economy Minerals Initiative project, the team has attracted more external state government partners and new projects, with plans to characterise sites in the Northern Territory and New South Wales under a new partnership led by Geoscience Australia.

"We could recover so much value by looking at secondary 'waste' products – but this can only be understood if the waste has been thoroughly characterised," Associate Professor Parbhakar-Fox said.

"The SMI MiWaTCh group is the only team dedicated to researching this in Australia – and there are so many opportunities. With reports suggesting there are 50,000 abandoned mines across the country, there is a lot of work to do."

> *"Through this process we can deliver new information to industry to help them reduce their future environmental liabilities and transform mine waste into something usable."*

Results already show industry that new solutions are possible

Associate Professor Parbhakar-Fox said it is encouraging to see industry looking closely at its waste.

"If they do, we can break the source–pathway–receptor chain by recovering additional value and environmental de-risking."

One major outcome for the team will be the collation of a secondary prospectivity atlas for Australia, giving industry and the public an idea where critical, base and precious metals are located in mine wastes.

Associate Professor Parbhakar-Fox explained that an interactive, online version would be very powerful for mining companies undertaking this type of exploration.

"Then companies can start to identify if there is potential for reprocessing, and start building business cases to do that. It's a win–win in many ways.

"We can demonstrate to industry that they should not rely on existing data on mine wastes from old reports of tailings and grades, but that they must 'go back, drill it and characterise it', because minerals evolve over time in mine waste environments. This means any further mineral processing needs to be modified to achieve profitable recoveries.

"We've shown the necessity of treating these sites like an ore deposit, because these secondary mine wastes are complex orebodies in themselves," she said.

"For new mining projects, applying robust sampling methods to fully understand the heterogeneity of waste and using integrated, analytical workflows is how 'perfect planning will prevent pathetic performance'.

The seed of MiWaTCh's research has sprouted into additional projects such as:

- an agreement with Cobalt Blue to test cobalt recovery from a bulk sample collected from a Queensland mine site
- funding from Geoscience Australia to undertake a large-scale secondary prospectivity of mine waste across Australia
- characterising the potential for co-recovery from historic iron-ore tailings at the Savage River mine, thought to be a significant resource of cobalt
- contributions to a Queensland taskforce to use the information from characterisation at the Wolfram Camp Mine site as a commercial opportunity
- establishing new methods to measure environmental indices from existing mine waste datasets (e.g. hyperspectral) and establish improved mine-planning tools
- improving critical metal field characterisation and understanding the geometallurgical properties of indium for its recovery from mine waste.

Addressing the challenge of water scarcity in Chile

The arid Atacama region of Chile faces significant water supply challenges which are greatly impacting communities, industry and agriculture.
The Complex Orebodies Program provided seed funding to advance initial research at SMI's Centre of Excellence in Chile (SMI-ICE-Chile), and the Centre for Water in the Minerals Industry (CWiMI) to develop an idea for a planning tool to optimise water availability and protect local ecosystems.
As a result, the idea advanced to a stage where it attracted industry support, and SMI-ICE-Chile are now partnered with M.C. Inversiones Limitada (MCI) on a three-year project.

Sea spray blurs the view of towering cliffs of Chile's central northern coastline, hiding the high, dry region of Atacama behind it.

Hidden under the reddish desert soil are significant deposits of copper and lithium, iron ore, silver and gold. Nearly half of the region's GDP comes from mining – and accounts for $9 out of every $10 of its exports.

But rainfall in Central Chile has dropped by a third in the past decade. Prolonged droughts are increasing along with climate change, and inadequate water management magnifies the problem for these water-intensive industries.

The mining sector has made a considerable shift to using desalinated seawater from the many plants producing it along Chile's coastline since around 2011.

However, desalinated seawater takes a lot of energy, emissions and construction to produce; it increases the cost of water supply; there is still unequal access to water for people and sectors; and the new pipelines and associated infrastructure are expensive and contested.

The opportunity: optimising Atacama's water supply system for sustainability

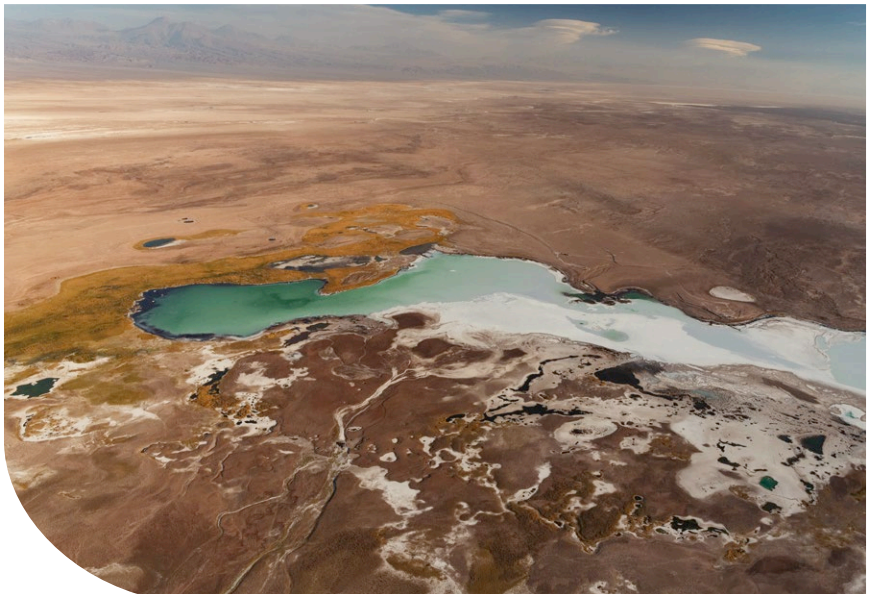
2022 marks the end of the first year of the multidisciplinary, consultative project undertaken by SMI-ICE-Chile in partnership with Mitsubishi Corporation subsidiary M.C. Inversiones Limitada (MCI), and local partners in Atacama.

Led by SMI-ICE-Chile's General Manager Dr Doug Aitken, the research team and MCI are working together to develop tools that support and help planning a sustainable water supply system.

Dr Aitken said regional communities need solutions that protect natural ecosystems while reliably and equitably getting water to people and sectors.

"Water supply systems in these arid zones currently face five challenges: they are overexploited, disconnected, inefficient, suboptimal and minimally sustainable," he said.

The project objective is to facilitate the development of sustainable and



As the largest global copper producer, Chile supplied nearly one-third of the copper produced in 2020 (28.5 per cent), with a value of more than US$33 billion. Copper and lithium are critical not only for traditional electrical appliances, but also enable industry to create renewable energy storage/batteries and electric cars.

Steadily increasing demand already outstrips the world's capacity to produce copper and lithium, signalling Chile's important role in future supply.

integrated water supply systems by creating tools to support how water supply alternatives and management options are identified and communicated. The team is:

- (for experts) developing a GIS (Geographic Information System) water supply planning tool for integrated and optimised systems based on physical, social and environmental data and applying optimisation algorithms
- (for non-experts) developing an online educational water supply planning tool for basic planning and optimisation tasks
- identifying and engaging with appropriate stakeholders to support the toolset development and project continuation.

"The tools could create beneficial outcomes, such as mines at the highest elevations accessing freshwater that would otherwise be used by downstream users, and those users can instead access the desalinated seawater.

"It's more cost-effective, generates lower environmental impacts overall, and can benefit the other users."

The project is proceeding with two streams of work simultaneously, Dr Aitken said.

"We are developing the toolset while engaging local communities – it's worked really well, and is a very fluid process."

Priorities for the next phase include:

- continued development of the expert GIS water supply planning tool and non-expert online educational water supply planning tool
- smart water supply scenarios
- a consolidated governance structure
- project impact evaluation
- continuity planning and dissemination of results
- a piloting plan

"One of the challenges of the project is looking at how barriers can be overcome – through public policy, new catchment–integrated water supplies, water boards, new regulations, and finance from government subsidies – to make a sustainable water supply system a reality"

Stream 1 – Developing tools for non-experts and for experts

Led by Dr Liliana Pagliero in Brisbane, this stream aimed to validate whether the project was feasible, and to look at its value.

Workshops with water users in Atacama – including Indigenous and rural communities, public agencies and institutions, agriculture and mining companies – helped to identify a wide range of opportunities, risks and constraints.

Two tools were identified to support better planning for water systems:

1. a simplified, visual tool publicly available for non-experts to explore interconnected water supply options and inform decision-making
2. a comprehensive, algorithm-based tool for water-planning experts in the public or private sectors to identify and analyse reliable, sustainable and cost-efficient solutions.

Stream 2 – Working with local communities to engage and foster sectoral collaboration

Stakeholder engagement is critical to the project. In Chile, conflicts over water use and mining can be very divisive, so the team began by identifying the key stakeholder and impacted groups – focusing on engaging three main sectors: mining, agriculture and public institutions.

In separate workshops, those key groups and the project team discussed the group's perspective and the potential benefits of taking part in the project.

"It was essential for the project to develop strong working relationships with the region's water users, suppliers and managers as potential partners – otherwise the tools would not meet users' needs," Dr Aitken said.

The two areas of need that these partners contribute to are:

- creating a database to build water supply and demand models
- helping validate the models for supply and demand of water, together with optimisation tools.

"We know that ongoing engagement with stakeholders is critical for developing the impact roadmap that can influence discussions of future water policy, and especially to transition the project into strategic national and regional programs of work."

Next steps for the project

Engagement with mining, agriculture and public agencies and institutions continues throughout the entire project via workshops, meetings and network development.

Towards the end of the third year, this will expand to training and building capacity with the expert and non-expert tools.

Increasing energy efficiencies in mineral processing operations

The Collaborative Consortium for Coarse Particle Processing Research (CPR) focuses on the multidisciplinary aspects of coarse particle processing – such as flotation, comminution, classification, equipment design and process chemistry – to reduce energy use and the environmental footprint of mining operations. The Complex Orebodies Program supported the early development of this industry–research partnership.

Crushing and grinding rock (comminution) in the processing stage is incredibly energy-intensive – accounting for nearly half (40 per cent) of the energy that mining operations use. One estimate puts comminution at 0.4 per cent of the world's total electricity use for producing base and precious metals.

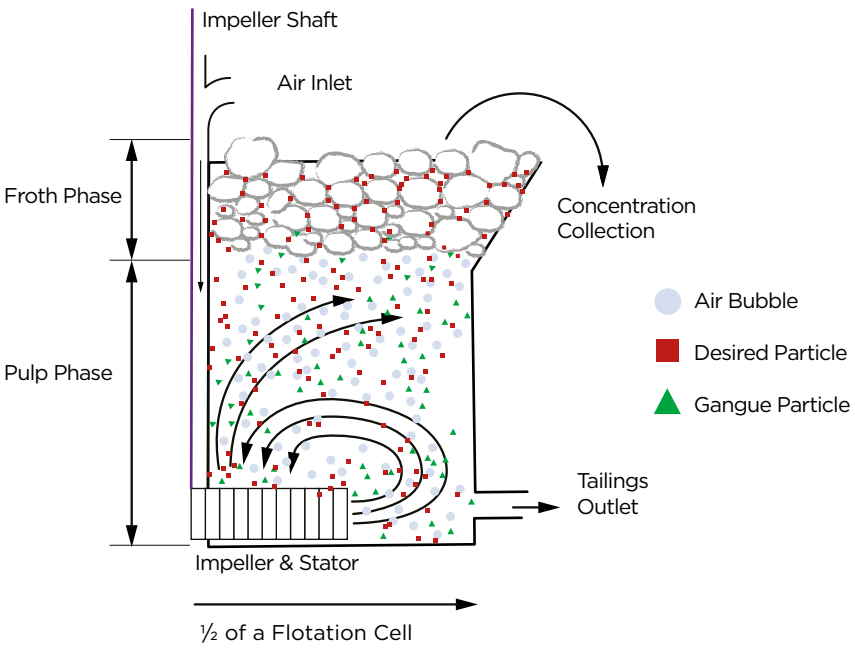
Reducing the energy cost of comminution is therefore a prime target for the mining industry and researchers. If flotation circuits could work with coarser particles (0.5–1 mm), much less crushing and grinding would be needed.

Flotation is the process where fine mineral particles are added to large bubbling tanks, and the valuable particles are recovered at the top in the form of a mineral froth.

The good news, Associate Professor Liza Forbes said, is that there is an existing technology.

Associate Professor Forbes is the co-technical director of CPR and leads the Flotation Chemistry Research Group at SMI's Julius Kruttschnitt Mineral Research Centre (JKMRC).

"We are trying to develop and integrate technology that is able to process particles and extract value from them without having to grind them very fine."



Increasingly difficult mining context drives coarser particle processing

Associate Professor Forbes explained that modern issues have accelerated the urgency of processing coarse particles:

- There is now less metal in the ore extracted by mining.
- More energy use leads to more greenhouse gas emissions, exacerbating climate change.
- Using more energy costs mining operations more money, and more comminution takes more time.
- Earthen tailings dams, which store fine mine waste, can be huge hazards if they fail.
- Processing only fine particles reduces the ability to reclaim tailings wastewater.
- There are stricter regulations for tailings disposal.

"Being able to process coarse particles is acknowledged as a key method for industry to improve the energy efficiency of its processing operations.

"This is all about achieving a very substantial drop in energy consumption and, in turn, reducing greenhouse gas emissions," Associate Professor Forbes said.

She also highlighted that improving coarse particle processing increases the ability to recycle the water that mining operations use by reclaiming it when tailings are disposed on mine waste sites – which could move the industry towards using dry stacking [tailings], instead of tailings dams that are prone to catastrophic failure.

"We want to fully unlock all of coarse particle processing's possibilities. We are finding out the best way to make use of it in the industry to give mining companies enough understanding and enough comfort to be able to implement it in their operations."

New flotation technology comes with its own challenges for industry

Associate Professor Forbes said "the traditionally conservative background of the mining industry means there is little appetite for risk", so uptake of new technology – such as the market-ready technology called Eriez HydroFloat® – is low.

Patented in 2002, HydroFloat® technology has proven successful for recovering larger particles with much less exposure of the valuable minerals on their surface. However, it cannot immediately replace traditional systems: it does not work well with very fine particles, so they need to be removed before the process.

Untangling this problem – and others such as performance, reliability and maintenance – requires careful work between mining companies with researchers. In 2018, Associate Professor Forbes and Associate Professor Kym Runge initiated that process after receiving support from the Complex Orebodies Program.

"We discovered that all our industry contacts had similar problems in common," Associate Professor Forbes said.

Genuine, open collaboration flowed from COB cultivating atmosphere of trust

The long consultation process began with CPR's first key partners, Eriez FD and Newcrest Mining, and rested upon an important foundation of trust.

"People were very reserved – these are highly competitive institutions – but Kym and I were very careful to make sure we did everything with complete transparency."

"We had representatives from Newcrest, Rio Tinto and Anglo American talk about some of the plan trials that had not been successful, and going into reasons why.

"This momentum has continued: the industry–researcher forum meets every quarter, and every six months for a full technical review."

Associate Professor Forbes said the forum has created a pool of diverse knowledge about mining operations, their understanding and concerns.

The consortium of CPR members includes researchers from SMI's JKMRC and representatives from Anglo American, Aeris Resources, the Eriez Flotation Division, Glencore, Hudbay Minerals, Newcrest Mining and Newmont.

CPR projects will deliver results plus a very valuable collaboration

The CPR has developed an ambitious scope of work to meet five main objectives: maximising recovery of coarse particles; predicting what will be recovered, how and how much; optimising the flotation circuits; evaluating the advantage of the HydroFloat® technology; and scaling up HydroFloat® technology.

"We will then assess how far we can go with implementing this technology with the information that we have," Associate Professor Forbes said.

"In research, your work never ends, because you always find something that you don't know. But the collaborative structure of the forum and the framework of what we're doing is almost as valuable as the technical work itself."

"It's exciting to get all of these minds together, to collaborate and work together for a free and collegial sharing of information and discussion."

Lessons from Izok Lake: an innovative and integrated approach

Izok Lake, in northern Canada on the border of Nunavut and the Northwest Territories, and High Lake are two exceptionally high-grade mineral deposits in a beautiful, remote, natural environment. The mining company MMG Limited is the latest custodian of those resources. They approached the Complex Orebodies Program leader to assemble a team and undertake a broad-based study of the area to seek innovative, sustainable and economically viable approaches to production.

The Izok Lake Corridor project is technically and logistically complex, so the team brought the collaboration and expertise to match.

It gathered more than 30 SMI researchers, a team from mining partner MMG and collaborators from the University of British Columbia.

Project leader Associate Professor Steven Micklethwaite, a principal research fellow in geology at SMI, said the original scope of the project was large, but he was confident he had a very good team of people who could deliver.

"The SMI team and MMG wanted to understand the challenges standing before the Izok Lake Corridor Project, then investigate innovative options to address those challenges and move the project toward a more sustainable and economically viable future."

Complex orebodies bring potential benefits despite challenges

The challenges for the orebodies can include energy supply; remote location; climate change; inadequate infrastructure; difficulty accessing the deposit; a complicated mix of different ores; the potential impacts on the local community; and the need to protect the waterways, groundwater and wildlife.

"This is a classic 'complex' orebody that has been known about for a long time," Associate Professor Micklethwaite said.

"There are potential, significant benefits for the local communities, but there is also a lot of complexity with the environmental, social, governance and technical challenges.

"Mining projects around the world and in Australia struggle, not for one reason, but for a whole range of reasons. A lot of those reasons are non-technical," Associate Professor Micklethwaite said.

"To de-risk a project, you can't really just address one factor. As one researcher summed it up during the project: 'You have to be generally awesome, not just specifically awesome'."

Integrating themes made for a genuinely holistic project

Associate Professor Micklethwaite said he was excited by the holistic nature of the project.

"It touched on every area of the mining process, from beginning to end – the people, the environment, obviously the technical dimensions, and how to integrate them.

"It was also exciting that MMG came to us. This was a client-driven project, and they were motivated to be holistic in how they tackled the processing, environmental and community challenges faced by mining projects.

"We knew that we could deliver solutions that deliberately integrated those themes."

> *"Our bigger vision was that, if we can get this right, then it could set a standard for the whole of the industry."*
>
> **Associate Professor Micklethwaite**

MMG's Head of Projects Mario Car explained that MMG approached the Complex Orebodies Program because an alternative approach was considered necessary to reassess the project.

"SMI's Complex Orebodies Program approach, and the access to the depth of industry experts, was seen as an ideal group to provide an innovative future-thinking and integrated sustainability approach for the Izok Lake Corridor," Mr Car said.

"The study outcomes exceeded expectations, and provided potential viable development configurations and valuable information to support us progressing the project.

"It was a pleasure working with the SMI team given their can-do approach in responding to challenges."

Lessons from the complex orebodies approach

There is a lot to be learned from this kind of integration.

"The complex orebodies approach is really the next step – helping projects become more sustainable from the moment of discovery until well after the mine has closed," Associate Professor Micklethwaite said.

"Many companies recognise a range of problems with projects, and they want to get them right.

"If we do get it right, we will have good, sustainable, well-regulated mining that is able to find the resources required to make the solar panels, wind turbines and electric car batteries we so desperately need to decarbonise."

"The complex orebodies approach is one way to do it right. I see projects like this and think, if we make the right decisions as a society and are able to implement them, the future is actually very bright."

Mapping the risks: the global database that highlights supply risk for critical metals

In 2018, the Complex Orebodies Program undertook a project to create a matrix of risks that the mining industry must overcome to unlock copper reserves. This work, led by Dr Eleonore Lebre, has evolved and developed into an even more layered global mining dataset that quantifies risks for companies across a range of indicators. The findings have a key role to play in equitably planning how and where to mine, and ensuring a just transition to a low-carbon future.

The focus of the dataset is to highlight the barriers to developing a site, which will inform companies about how to 'unlock' orebodies to meet future mineral demand.

These barriers may be a result of low-grade ore, technical challenges, political unrest, social outrage or environmental challenges.

Layering risks to create a global atlas

Starting with the eight main indicators of environmental, social, and governance (ESG) risk (water, tailings, biodiversity, social vulnerability, land uses, Indigenous peoples, political fragility, approvals and permits), a huge global dataset of mining projects were overlaid.

This includes current or soon-to-begin projects, and the mining source risk database holds about 36,000 mine sites. Spatial data is then layered on top, and more indicators are placed on that.

Dr Lebre said over the last three years she has been using around 50 different global datasets.

"These are the different layers you add on the map. And it's far from static – it's always changing, and the method is evolving over time," she said.

Researchers can then use global data about mining projects and ESG information to work out and quantify the risks that would come with operating mines and making new discoveries.

"There are a few datasets published out there with different purposes, but they don't focus on mining. In this project, the data I have access to is reported by mining companies.

Environmental, social and governance risks pose justice and financial threats

Undoubtedly, mining activities significantly change their host environments and exacerbate vulnerabilities that already exist – particularly in places with inadequate governance to prevent impacts to the environment and communities.

Already, many mining projects experience delays or abandonment because ESG risks become reality.

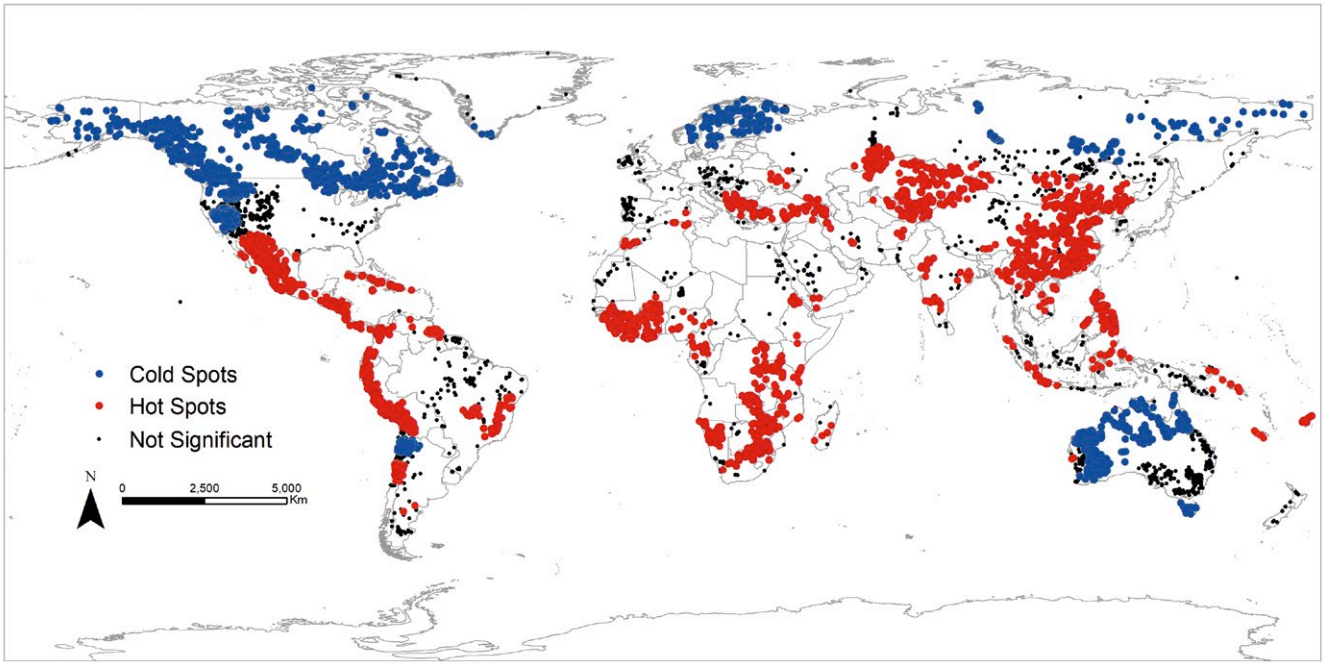
Dr Lebre said the trend will continue if projects are not designed and developed more innovatively.

"Additionally, the growing demand for energy transition metals (ETMs) necessary for the transition to a low-carbon future could create high-risk mining 'hotspots' that will put further pressure on communities and environments.

"Our research quantitatively confirms people's concerns that without strategic planning to address the risks from mining, transitioning to a low-carbon economy will lead to higher ESG–risk mining.

These high-risk mining hotspots place pressure on environments and their communities:

- high-risk iron orebody areas often experience social vulnerability, political fragility, and approvals and permits challenges.
- bauxite orebodies (the main source of aluminium) are nearly all located in high-risk contexts.
- copper orebodies are often plagued by water and waste risks – 65 per cent are in areas with medium to extremely high water risk.



"People interested in mapping these risks include the mining industry, investors, governments, and downstream users of metals, who are all dependent on accessing the fruits of these complex orebodies. It will be up to these people to ensure ESG risks in mining locations are managed appropriately."

"Companies that seek to create new projects will face social challenges if they do not demonstrate their credentials and plans for evaluating, managing and reducing ESG risks – ultimately putting limits on the supply of ETMs.

"We believe the synergies and trade-offs at the source of ETM supply chains [at mine sites] should be interrogated with greater focus and depth than has occurred to date," Dr Lebre said.

"Our mining atlas generates global knowledge, and pulls together the global picture and all its patterns. It's not dependent on internal knowledge at each mining company, where it can disappear if one person leaves."

"It's the first time that someone has created a map like this. There are no other methodologies like it, and none have examined the supply source [mine sites] before."

Dr Lebre

Industry demand and an Early Career Researcher award

Dr Lebre and her team have been working with industry research consortia, as well as projects with industry partners including Rio Tinto, Newcrest, MMG and OceanaGold.

She has applied her methodology to benchmarking projects at various companies, benchmarking against peers to evaluate risk levels for projects, and portfolio analysis for companies (for risks and complexity) – by varying the scale and the data used.

Dr Lebre coordinated the database projects across SMI centres, and the versatility and timeliness of the project has led to seven industry-commissioned projects.

"It has taken many forms over the last few years, and it's quite multidisciplinary, and very broad. There is a lot of demand from industry," she said.

Dr Lebre's work on complex orebodies was recently recognised and rewarded with an Australian Research Council's (ARC) Discovery Early Career Researcher Award (DECRA) to further enhance her research.

"I'll look for data reported about the projects themselves: qualitative data. I can access companies' reports of what happens at the mine site, and will process and categorise it to create a global repository of data about local-level sites."

"Proactively managing ESG risks that accompany ETM mining can increase a company's long-term value but, more importantly, is at the core of the 'just transition' concept."

Dr Lebre said it would be "an eye-opener" for whoever wanted to see the material and financial consequences of not managing ESG risks that come with energy transition.

"The social and environmental implications of the anticipated rise in ETMs' extraction are rarely acknowledged in energy transition scenarios, but the complexity of complex orebodies is not just something that is below the ground."

Research projects funded by the Complex Orebodies Program

Phytomining: can plants accumulate metals from tailings?

Australia is home to a number of plants that could supply a sustainable source of the metals needed for the future: 'hyperaccumulators'. In this project, researchers assessed these plants' unique ability to accumulate metals from the soil into their biomass, specifically from lead–copper–zinc mine tailings, and the potential to extract those metals via phytomining.

The Frieda River interface between large-scale and artisanal and small-scale mining

Papua New Guinea is home to a wide array of mining operations, rom large-scale mining (LSM) to artisanal and small-scale mining (ASM). This project examined the interface between these groups through fieldwork on Misima Island, an in-country ASM-LSM workshop, and desktop research. It resulted in the first ever paper characterising the LSM-ASM interface in Papua New Guinea.

What 'just transitions' to low-carbon economies means for mining

Applying the concept of a 'just' transition to low-carbon economies will have ramifications across many industries. This project explored what the concept will mean for the mining industry, and how the concept intersects with resource extraction.

Understanding tungsten in mine tailings at Wolfram Camp

Project researchers sought to understand the mode of occurrence and mobility of tungsten in mine tailings at the abandoned Wolfram Camp mine in North Queensland. The outcomes have reformed rehabilitation of the site, and identified potential pathways for the recovery of critical elements from the mine waste.

Predicting comminution using primary breakage characteristics in rock

In this project, researchers developed a new geometallurgical approach to comminution which uses high-resolution characterisation information and a rock's primary breakage properties to support the prediction of ores' comminution behaviour. It found the primary breakage properties of rocks are related to quantifiable characteristics and can be used to predict the distribution of primary breakage characteristics.

Increased efficiency processes for rare earth elements

Queensland is positioning itself as a future supplier of the rare earth elements (REE) that will be critical to the energy transition. This project investigated alternative extraction routes for materials known to be rich in REE. The aim was to identify more energy efficient, less wasteful hybrid process routes, and potentially the processing of REE-rich materials not currently considered as REE ores.

New, selective reagents for arsenic minerals flotation

This project involved a literature review of arsenic minerals flotation with a focus on novel, selective reagents, as well as establishing relationships with other research groups. The knowledge collected from the literature review will be further built upon to write a broader literature review of arsenic processing technologies for MMG.

Predictive tools for geometallurgical characterisation of copper deposits

Many mineralogical techniques are known to industry, but not applied in the field. This project, jointly funded by NuevaUnión (Teck–Barrick joint venture), aims to reduce mineral processing risk by developing predictive tools for geometallurgical characterisation in porphyry copper deposits using rarely applied mineralogical, geochemical and hyperspectral techniques.

Assessing environmental, social and governance risks for complex orebodies

The world is set to need more metal than ever, but will need to mine in increasingly risky locations to extract it. This project proposed innovative methods to investigate the productivity of these complex orebodies and, by considering uncertainties in the estimation process, investigated the potential environmental and socioeconomic issues raised by mining them.

Creating tools to quantify the impacts of production on environmental, social and governance risks

This multidisciplinary research project explored the linkages between technical, environmental and social challenges facing mining projects. The project has delivered an integrated process prediction tool for quantifying the impacts of alternate processing configurations on environmental and production measures, and developed a prototype sociotechnical system dynamics model to understand how production decisions affect ESG risk.

High voltage pulse comminution: more effective and efficient?

Effective and efficient techniques for comminution will be key for the mining industry, and the world, to reduce emissions. High voltage pulse technology, which breaks rocks according to their mineralogy by sending surges of electricity through them, is one of the alternatives with serious possibility. This project is now moving to pilot stage with Newcrest, having attracted $6 million industry and federal funding through the Australian Government's Trailblazer Universities initiative.

Using a Geographic Information System to demonstrate optimised water-sharing in Atacama, Chile

The Complex Orebodies Program supported SMI researchers to demonstrate the concept of optimising networks of shared water supplies in arid mining regions through ArcGIS. It enabled SMI researchers in Australia to collaborate with colleagues at SMI-ICE-Chile and present the proposal to Mitsubishi. The outcome was a US$1 million, three-year project funded by Mitsubishi (2020–23).

Critical data analysis to support SMI's Complex Orebodies Program projects

This project provided critical data analysis, visualisation and mathematical modelling support to other COB projects, plus several that were co-funded by external sponsors: Lessons from tailings facility data disclosures (Global Tailings Review), Alternative sand from mineral ores (Vale), Battery metal supply and source risk (The Metals Company via DeepGreen Inc), Mining transitions and climate change (CRC for Transitions in Mining Economies), Pyrite Estimates: Centre Pit expansion, Savage River Mine (Grange Resources).

Mapping the world's mining areas and biodiversity conservation

This project mapped the world's mining areas and assessed their spatial coincidence with biodiversity conservation sites and priorities. It found most mining areas (82 per cent) target energy transition minerals (ETMs) and that the overlap with Protected Areas and Remaining Wilderness contain more mines per square kilometre than coal mining areas overlapping these sites. Mining threats to biodiversity will increase with the expected surge in ETM mining without strategic planning.

Source risks to future mineral supply

Over the past three years, Dr Eleonore Lebre coordinated the source risk project across SMI centres. The project has been very productive in terms of both academic and industry research outputs. The developed methodology can be used to address a wide range of research problems. The versatility and timeliness of the project led to seven industry-commissioned works.

Integrating coarse particle flotation into processing – a research consortium

This project is developing techniques to successfully integrate coarse particle flotation technologies into existing minerals processing flowsheets through significant industry–academia collaboration. The consortium behind the project includes Aeris Resources, Anglo American, Baker Hughes, the Eriez Flotation division, Glencore, Hudbay, Newcrest Mining, Newmont and Rio Tinto.

The Izok Corridor Project

This project grew out of complex orebodies 'locked up' in the Arctic. A feasibility study from 2013 concluded access was not feasible. Significant challenges included geometallurgical processing, groundwater issues, wildlife conservation, community engagement and remoteness of access. The output of this project was a review of the 2013 feasibility study and recommendations on improvements relative to best practice. These are being used in the next stage of planning for project optimisation.

Developing a tool to map the carbon footprint of mining operations

This project aimed to develop a tool to map greenhouse gas emissions across the mining value chain, and to help evaluate opportunities for mitigating emissions in mining operations. We achieved our aim with a new, system dynamics–based tool. It integrates expert knowledge, emissions data from mining operations, and simulations. Mining companies' decision-making is supported, and they can evaluate opportunities to reduce operational emissions. We also promoted the tool to industry with publications, meetings and workshops.

Streamlining the Centre for Social Responsibility in Mining's focus on just transitions

We developed a streamlined focus on just transitions at SMI's Centre for Social Responsibility in Mining (CSRM). Our key activities included: mapping CSRM's strategy on just transitions, recruiting multidisciplinary PhD students to work on just transition challenges, and successfully creating and conducting an industry-facing 'pilot' workshop series on the social aspects of mine closure (with 21 industry participants, 2021). The series was received very well and will be adapted for other industry and government partners (2022 series).

Creating interactive online tools for communicating with the public about water

This project developed online tools to effectively communicate research results to stakeholders and the public, and contributes to the SMI-ICE-Chile smart water supply system project. The online interface allows people to explore alternatives for desalination water supply in Atacama, Chile. The prototype was already successfully used in Chilean workshops and seminars to make research results accessible and understandable. Our methods and increased internal capacity will benefit other projects that could use online communication tools.

Exploring for the Future – mapping and characterising mine waste

The recently funded second phase of the Geoscience Australia 'Exploring for the Future' initiative includes a component aimed at mapping and characterising Australia's mine waste. SMI has been engaged to play a key role in this initiative, working in collaboration with Geoscience Australia, other collaborating universities and state geological surveys.

Rehabilitation options for the Grange Resources Savage River tailings dam

If there is cobalt in the pyrite in the mine tailings dam at Savage River Mine (Tasmania), the Tasmanian government could consider economic rehabilitation in its long-term management plan. Bioleaching presents a possible method to recover the cobalt, but previously only the uppermost tailings were investigated. We successfully sunk five sonic drill holes (> 30 metres) in the dam, collected nearly 300 samples, analysed them with portable X-ray fluorescence (XRF), and selected 50 for detailed geochemical assay analysis. Soon, mineralogical characterisation begins.

Innovative bioleaching approaches to extract metals *in situ*

The aim of this project is to investigate innovative bioleaching approaches to *in situ* extraction of metals. The project has been a collaboration between UQ's School of Chemistry and Molecular Bioscience, the School of Earth and Environmental Science, the Australian Centre for Water and Environmental Biotechnology, and the SMI. This collaboration has built a powerful team across the university that is addressing a broader range of mining industry challenges by applying biotechnology.

A global review of communities and social performance of mining

This project focused on important questions about the mining industry's approach to social performance. We firstly published a frame of reference, *Establishing the Foundations for Effective Social Performance in the Global Mining Industry*. Then we captured insights from global mining industry's most senior social-performance leads (n=13), and published a snapshot, *Organising for Social Performance in the Global Mining Industry.* Finally, we compiled findings from publicly available documents about the social performance of 14 extractive companies.

Developing a diagnostic tool to evaluate companies' social-performance functions

This project created a methodological approach (tool) to evaluate companies' social-performance functions. The Centre for Social Responsibility in Mining (CSRM) then proposed testing the tool with two international mining companies, leading to commissioned research (> AU$300,000). This subsequent research enabled CSRM to speak directly with executive-level industry leaders about strategic decisions around community and social performance. We also shared the tool with the Centre for Water in the Minerals Industry and SMI's Governance and Leadership Strategic Program colleagues, who proposed adapting the tool for environment/sustainability use.

Visiting Professorial Fellow: Dr R. Anthony Hodge

Dr Hodge assisted with outreach, strategy, research and teaching.

In a 2018 masterclass on Mining and Society in the 21st Century, our discussion explored how to accelerate the industry's trajectory towards greater sustainability. The multidisciplinary class included doctoral students and academic researchers from diverse cultural backgrounds. Then, in 2019 at an MMG–UQ steering committee meeting, a proposal was presented regarding Preparing for closure: implementation of the Town Transition Tool process for MMG's Rosebery mine. This was after discussions between Dr Hodge and MMG; however, MMG decided not to proceed.

Where small and large-scale mining meet: characterising the interface

This project examined the interface dynamics between artisanal and small-scale mining (ASM) and large-scale mining (LSM) activities, recently termed 'ASM-LSM interfaces'. We characterised these interfaces across the project life cycle at operational, non-operational and future mines. Despite industry commitment to contemporary standards for social responsibility, our study showed that LSM actively co-constructs ASM-LSM interfaces and contributes to their intensification, which often results in violence, dispossession and entrenched inequalities.

Predicting ores' behaviours better by understanding their variability

This project assesses the variability in ore mineralogy and texture, hardness, and gold and copper recoveries between ore types identified by OceanaGold Didipio Mine. The data acquired from the physical tests will allow us to create a model that indicates how geological and mineralogical attributes influence the hardness and recovery for each ore type. Knowing the ore variability gives operators a better understanding of the ore behaviour, provides an opportunity to optimise mines and mills, and can reduce risk and uncertainty.

Appendix. Our outputs

(The associated Complex Orebodies Program [COB] research project is shown in brackets.)

Engagement

Resulting follow-on projects

- Eleonore Lebre applied the COB ESG risk procedure to Anglo American's portfolio as part of a project proposal led by Deanna Kemp, John Owen and Vigya Sharma. *(Source risks to future mineral supply)*
- Eleonore Lebre applied the COB ESG risk procedure to Rio Tinto copper assets. The analysis was integrated to an issues paper commissioned by Rio Tinto copper on 'ESG and the future of copper'. Paper editors: Deanna Kemp, John Owen, Rick Valenta, Eleonore Lebre. *(Source risks to future mineral supply)*
- Eleonore Lebre applied the COB ESG risk procedure to Newmont's portfolio as part of an assignment to evaluate the alignment of Newmont to the Global Industry Standard on Tailings Management (people involved: Deanna Kemp, John Owen and Vigya Sharma). *(Source risks to future mineral supply)*
- The COB project was seed funding that led to CSRM securing subsequent funding for complex research projects. *(Developing a diagnostic tool to evaluate companies' social performance functions)*

Meetings and workshops

- QEC Technical Forum 19 February 2020: Geometallurgical characterisation of Complex Orebodies: Comminution proxies using hyperspectral imaging and multi-element geochemistry *(Predictive tools for geometallurgical characterisation of copper deposits, presentation)*
- Contribution Analysis application – Faro Retrospective, Australian test: After discussions with MMG, the approach was changed to start with a visit to Hobart (Hodge and Verrier) to conduct additional foundational research. Contact was made with Chief Geologist and library staff at Mineral Resources Tasmania as well as the AusIMM local chapter. Briefing note was adjusted in light of the above to be a 'Preliminary Project Overview.' *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, industry meeting)*
- OceanaGold: Meeting with Sharon Flynn occurred. Contact made also with Kit Wilson at the mine site and arrangement made to visit during New Zealand trip. *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, industry meeting)*
- Government of Queensland: Link made with Andrew Gradaski. Made a presentation on 'Driving technical decisions of closure with societal values – an innovative approach' *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, presentation)*
- Evolution of societal values change and implications for natural resource management in general, mining more specifically: Discussion of the significance of evolving societal values in Masterclass and with colleagues, particularly John Owen, Deanna Kemp, Robin Evans. *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, workshop)*
- Masterclass: 10 seminars completed. *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, workshop)*
- Informal discussions and sharing with staff, students, colleagues and UQ Faculty in and around SMI; participation in meetings within and for SMI as requested: Many discussions with students in a mentoring mode; Ongoing discussions with colleagues; participated in the Oct 5 Advancement event on the role of social sciences; Env. Centres Advisory Board, 25 Oct.; 1 Nov meeting with Newmont, 1 Nov meeting with Anglo American; 2 Nov meetings with ICMM, 9 Nov. JKMRC seminar; 19 Nov. Complex Ore Bodies Conference, 21 Nov meeting with Oceana Gold, 22 Nov Student HDR Conference JKMRC; 27 Nov meeting with Rio Tinto. 6 Dec SMI Seminar series; 11 Dec JKMRC seminar on multi-interest closure options analysis using multi-attribute utility analysis to drive technical decision-making with societal values *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, meetings and workshop)*
- Eleonore Lebre ran a two-hour mini workshop on the ESG risk benchmarking of the MMG's Izok Corridor project, which was held during the Izok workshop on May 25th. *(Source risks to future mineral supply, workshop)*
- An industry workshop to promote the applicability of the approach to the industry *(Developing a tool for mapping the carbon footprint of mining operations, workshop)*

Resources and technical work

- The cyanide socio-technical learning lab *(Creating tools to quantify the impacts of production on ESG risk, resource)*
- HyLogger Summary and Pyrite Estimates: Centre Pit expansion, Savage River mine, Tasmania *(Critical data analysis to support SMI COB projects, technical work)*
- Framework document for potential company guidelines in PNG relating to mining, women, and children in support of the work of Ume Wainetti and Ando Diya-sand. *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, technical work)*
- Establishing the Foundations for Effective Social Performance in the Global Mining Industry. This document provides a frame of reference for the project. *(A global review of communities and social performance of mining, technical work)*
- A Snapshot Study: Organising for Social Performance in the Global Mining Industry. We captured insights from a series of confidential interviews with 13 of the global mining industry's most senior social performance leads, across 10 mining companies. *(A global review of communities and social performance of mining, technical work)*
- A Rapid Desktop Scan of Social Performance of 14 extractive companies. This PowerPoint compiles our findings from a scan of public domain documents. *(A global review of communities and social performance of mining, technical work)*
- Integrated Process Prediction tool *(Excel model) (Creating tools to quantify the impacts of production on ESG risk, technical work)*

- The 'Greenhouse Gas Management Tool' *(Developing a tool for mapping the carbon footprint of mining operations, technical work)*
- Mining, women and children in PNG: Preparation of the 'framework document' completed. *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, technical work)*
- The Interviews. 'Innovative' multi-media mechanism for sharing ideas within and outside the industry based on 'expert' input from across the world addressing critical issues at the mining – society interface: Following the completion of the pilots, the shorts were created and an assessment undertaken of (1) what worked; (2) what could be improved and how; and (3) next steps. *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, technical work)*

Publications

Ahmad, S., Shankar, S., Steen, J., Verreynne, M.-L., & Burki, A. A. (2021). Using measures of efficiency for regionally-targeted smallholder policy intervention: The case of Pakistan's horticulture sector. *Land Use Policy, 101*. doi:10.1016/j.landusepol.2020.105179

Ali, S. H., Svobodova, K., Everingham, J. A., & Altingoz, M. (2020). Climate Policy Paralysis in Australia: Energy Security, Energy Poverty and Jobs. *Energies*, *13*(18).

Andre, F. P., Christian, A., & Shi, F. (2020). *Developing a continuous HVP system for mining operations*. Paper presented at the Next Generation Resources Student Conference 2020.

Andre, F. P., Christian, A., & Shi, F. (2020). *Development and Evaluation of an Integrated Small Scale Continuous HVP System. Technical Report.*

Arratia-Solar, A., Svobodova, K., Lèbre, É., Owen, J.R. Conceptual framework to assist in the decision-making process when planning for post-mined land-uses. Under review with Renewable and Sustainable Energy Reviews.

Azadi, M., Northey, S. A., Ali, S. H., & Edraki, M. (2020). Transparency on greenhouse gas emissions from mining to enable climate change mitigation. *Nature Geoscience, 13*(2), 100-104. doi:10.1038/s41561-020-0531-3

Bainton, N., Kemp, D., Lèbre, E., Owen, J. R., & Marston, G. (2021). The energy-extractives nexus and the just transition. *Sustainable Development, 29*(4), 624-634. doi:10.1002/sd.2163

Bainton, N., Owen, J. R., Kenema, S., & Burton, J. (2020). Land, labour and capital: Small and large-scale miners in Papua New Guinea. *Resources Policy, 68*, 12.

Corzo Remigio, A., Chaney, R. L., Baker, A. J. M., Edraki, M., Erskine, P. D., Echevarria, G., & van der Ent, A. (2020). Phytoextraction of high value elements and contaminants from mining and mineral wastes: opportunities and limitations. *Plant and Soil, 449*(1-2), 11-37. doi:10.1007/s11104-020-04487-3

Everingham, J. A., Svobodova, K., Lebre, E., Worden, S., & Owen, J. (2020). *Mining regions in transition-a global scan.* www.mineclosure.net/elibrary/mining-regions-in-transition-a-global-scan

Everingham, J., Svobodova, K. Mackenzie, S. Witt, K. (2020). *Participatory processes, mine closure and social transitions.* Centre for Social Responsibility in Mining. The University of Queensland: Brisbane: www.mineclosure.net/elibrary/participatory-processes-mine-closure-and-social-transitions

Everingham, J-A., Svobodova, K., Lèbre, É., Owen, J.R., Worden, S. Comparative capacity of global mining regions to transition to a post-mining future. Under review with *Environmental Innovation and Societal Transitions.*

Forbes, L., Runge, K., Yahyaei, M., Demir, K., & Miceli, H. (2021). *Collaborative Consortium of Coarse Particle Processing Research.*

Franks, D. M., Stringer, M., Torres-Cruz, L. A., Baker, E., Valenta, R., Thygesen, K., Matthews, A., Howchin, J., and Barrie, S. (2021). Tailings facility disclosures reveal stability risks. *Sci Rep, 11*(1), 5353. doi:10.1038/s41598-021-84897-0

Franks, D., Stringer, M., Baker, E., Valenta, R., Torres-Gruz, L., Thygesen, K., Matthews, A., Howchin, J., Barrie, S. (2020). Lessons from Tailings Facility Data Disclosures. In Bruno Oberle, D. Brereton, & A. Mihaylova (Eds.), *Towards Zero Harm: A Compendium of Papers Prepared for the Global Tailings Review.* (pp. 26). London, UK: Global Tailings Review.

Han, Z., Edraki, M., Nguyen, A. D., & Mostert, M. (2021). Efficiency of acid digestion procedures for geochemical analysis of tungsten mining wastes. *Geochemistry: Exploration, Environment, Analysis, 21*(3). doi:10.1144/geochem2021-034

Han, Z., Golev, A., & Edraki, M. (2021). A Review of Tungsten Resources and Potential Extraction from *Mine Waste. Minerals, 11*(7). doi:10.3390/min11070701

Hao, L., Ahmad, S., Chang, H.-L., & Umar, M. (2021). Knowledge spill-over and institutional quality role in controlling Dutch disease: A case of BRICS countries. *Resources Policy, 72.* doi:10.1016/j.resourpol.2021.102114

Hendrychova, M., Svobodova, K., & Kabrna, M. (2020). Mine reclamation planning and management: Integrating natural habitats int post-mining land use. *Resources Policy, 69.*

Huang, W., & Shi, F. (2019). Selective breakage of mineralised synthetic particles by high voltage pulses. Part 1: Metalliferous grain-induced breakage in a two-particle paired system. *Minerals Engineering, 134*, 261–268. doi:10.1016/j.mineng.2019.02.024

Huang, W., & Shi, F. (2020). Selective weakening of mineralised synthetic particles by high voltage pulses. *Minerals Engineering, 146.* doi:10.1016/j.mineng.2019.106110

Huang, W., Shi, F., Christian, A., & Runge, K. (2020). Influence of grade heterogeneity and gangue mineralogy on the efficacy of high voltage pulse enabled ore pre-concentration. *Minerals Engineering, 159,* 106654.

Kemp, D. (2019). *Mining and Social Performance: A Review - A Rapid Desktop Scan.* www.smi.uq.edu.au/mining-and-social-performance-review

Kemp, D., & Owen, J. (2019). *Establishing the Foundation for Effective Social Performance in the Global Mining Industry.* www.csrm.uq.edu.au/publications/establishing-the-foundations-for-effective-social-performance-in-the-global-mining-industry

Appendix. Our outputs

Kemp, D., Owen, J., & Lebre, E. (2020). Tailings facility failures in the global mining industry: Will a 'transparency turn' drive change? *Business Strategy and the Environment, 30*(1), 122-134.

Kung, A., Svobodova, K., Lèbre, E., Valenta, K., Kemp D., Owen, JR., 2021. Governing deep sea mining in the face of uncertainty. *Journal of Environmental Management*, 279, 111593.

Lay, Daniel, 2021, Thesis – "Factors Affecting High Voltage Pulse Breakage and Pre-concentration", The University of Queensland. www.espace.library.uq.edu.au/view/UQ:90d18ba

Lebre, E. (2019). Source Risks as Constraints to Future Metal Supply. *Environmental Science and Technology, 53*, 10571-10579.

Lebre, E., Owen, J., Corder, G. D., Kemp, D., Stringer, M., & Valenta, R. (2019). Source risks as constraints to future metal supply. *Environmental Science and Technology.*

Lebre, E., Owen, J., Stringer, M., Kemp, D., & Valenta, R. (2021). Global scan of disruptions to the mining life cycle: price, ownership and local impact. *Environmental Science and Technology, 55*(8), 4324.

Lèbre, É., Stringer, M., Svobodova, K., Owen, J. R., Kemp, D., Côte, C., Valenta, R. K. (2020). The social and environmental complexities of extracting energy transition metals. *Nature Communications, 11*(1), 8.

Li, B., Deng, R., Shi, F., He, Z., Ku, J., & Zuo, W. (2021). Effect of feed quantity on breakage degree of ore particles subjected to high voltage pulses. *Minerals Engineering, 160*. doi:10.1016/j.mineng.2020.106693

Li, Yuansheng, Liu, Jun, Feng, Bingyang, Zhang, Xingru, Zhang, Mengyu, Xiao, Haolong, He, Mengbing, and Shi, Fengnian (2020). Numerical modeling and simulation of the electric breakdown of rocks immersed in water using high voltage pulses. Geomechanics and Geophysics for Geo-Energy and Geo-Resources 7 (1) 1 . www.doi.org/10.1007/s40948-020-00190-w

Littleboy, A., Keenan, J., Ordens, C. M., Shaw, A., Tang, R. H., Verrier, B., Vivoda, V., Yahyaei, M., and Hodge, R. A. (2019). A sustainable future for mining by 2030? Insights from an expert focus group. *The Extractive Industries and Society 6*(4), 4.

Littleboy, Anna, Keenan, Julia, Ordens, Carlos M., Shaw, Andrea, Tang, Roger H., Verrier, Brunilde, Vivoda, Vlado, Yahyaei, Mohsen, and Hodge, R. Anthony (2019). A sustainable future for mining by 2030? Insights from an expert focus group. *The Extractive Industries and Society 6* (4) 1086-1090. www.doi.org/10.1016/j.exis.2019.11.005

Lois-Morales, P., Evans, C., & Weatherley, D. (2021). Characterising tensile strength and elastic moduli of altered igneous rocks at comminution scale using the Short Impact Load Cell. Powder Technology, 388, 343-356. doi:10.1016/j.powtec.2021.04.091

Lois-Morales, P., Evans, C., Bonfils, B., & Weatherley, D. (2020). The impact load cell as a tool to link comminution properties to geomechanical properties of rocks. *Minerals Engineering, 148*. doi:10.1016/j.mineng.2020.106210

Nkrumah, P. N., Erskine, P. D., Erskine, J. D., & van der Ent, A. (2021). Rare earth elements (REE) in soils and plants of a uranium-REE mine site and exploration target in Central Queensland, Australia. *Plant and Soil, 464*(1-2), 375-389. doi:10.1007/s11104-021-04956-3

Oberle, B. B., D. Mihaylova, A. (eds.). (2020). Towards Zero Harm: A Compendium of Papers Prepared for the *Global Tailings Review.* Retrieved from London: www.globaltailingsreview.org

Ocelík, P., Diviák, T., Lehotský, L, Hendrychová, M., Svobodova, K. Facilitating the coal phase-out: What drives interorganizational cooperation? Under review with *Society & Natural Resources.*

Owen, J. R., Kemp, D., Lèbre, É., Harris, J., Svobodova, K., 2021. A global vulnerability analysis of displacement caused by resource development projects. *The Extractive Industries and Society,* 100877.

Owen, J. R., Kemp, D., Lèbre, E., Svobodova, K., & Pérez Murillo, G. (2020). Catastrophic tailings dam failures and disaster risk disclosure. *International Journal of Disaster Risk Reduction, 42*. doi:10.1016/j.ijdrr.2019.101361

Owen, J., D, K., É, L., J, H., & K, S. (2021). A global vulnerability analysis of displacement caused by resource development projects. *The Extractive Industries and Society, 8*(2). doi:10.1016/j.exis.2021.01.012

Shahbaz, M., Song, M., Ahmad, S. (2022). Does Economic Growth Stimulate Energy Consumption? The Role of Human Capital and R&D Expenditures in China, *Energy Economics* 105. https://doi.org/10.1016/j.eneco.2021.105662

Sharma, V, Greig, C., Lant, P. (2021). What is stopping India's rapid decarbonisation? Examining social factors, speed, and institutions in Odisha. *Energy Research and Social Science,* 78 102117, 1-11. doi:10.1016/j.erss.2021.102117

Shi, F. R., K. Antonio, C. Valenta, R. (2019). Unlocking the potential of advanced high voltage pulse comminution technology for the mining industry. *Mineria*, *506*, 26.

Sonter, L. J., Dade, M. C., Watson, J. E. M., & Valenta, R. K. (2020). Renewable energy production will exacerbate mining threats to biodiversity. *Nat Commun,* 11(1), 4174. doi:10.1038/s41467-020-17928-5

Stringer, M. (2021). *HyLogger Summary and Pyrite Estimates: Centre Pit Expansion, Savage River Mine, Tasmania.*

Maher, R., Buchan, R., Littleboy, A., MacLean, K., Molyneaux, L., Stringer, M., and Valenta, R. (2021). Mining transitions and climate change: a research synthesis to inform CRC TiME strategy. Perth, WA, Australia: CRC TiME.

Su, C.-W., Sun, T., Ahmad, S., & Mirza, N. (2021). Does institutional quality and remittances inflow crowd-in private investment to avoid Dutch Disease? A case for emerging seven (E7) economies. *Resources Policy, 72.* doi:10.1016/j.resourpol.2021.102111

Svobodova, K., Everingham, J-A., Mackenzie, Witt, K. Public participation in mine closure and social transitions: why it matters. Under review with *Journal of Environmental Management.*

Svobodova, K., Owen, J. R., & Harris, J. (2021). The global energy transition and place attachment in coal mining communities: Implications for heavily industrialized landscapes. *Energy Research & Social Science, 71.* doi:10.1016/j.erss.2020.101831

Svobodova, K., Owen, J. R., & Harris, J. 2021. The global energy transition and place attachment in coal mining communities: Implications for heavily industrialized landscapes. *Energy Research & Social Science, 71,* 101831.

Svobodova, K., Owen, J. R., Harris, J., & Worden, S. (2020). Complexities and contradictions in the global energy transition: a re-evaluation of country-level factors and dependencies. *Applied Energy, 265.* doi:10.1016/j.apenergy.2020.114778

Svobodova, K., Stringer, M., Lèbre, É., Owen, J.R., Kemp, D. A mine-town systems approach for assessing impacts of climate change mitigation on resource regions. Under review with *Nature Climate Change.*

Svobodova, K., Vojar, J., Yellishetty, M., & Janeckova Molnarova, K. (2020). A multi-component approach to conceptualizing the reputation of the mining industry from a stakeholder perspective. *Resources Policy, 68.* doi:10.1016/j.resourpol.2020.101724

Valenta, R. K., Kemp, D., Owen, J. R., Corder, G. D., & Lebre, E. (2019). Re-thinking complex orebodies: Consequences for the future world supply of copper. *Journal of Cleaner Production 220,* 816–826.

van der Ent, A., Parbhakar-Fox, A., & Erskine, P. D. (2021). Treasure from trash: Mining critical metals from waste and unconventional sources. *Sci Total Environ, 758,* 143673. doi:10.1016/j.scitotenv.2020.143673

Vaughan, J., Tungpalan, K., Parbhakar-Fox, A., Fu, W., Gagen, E., Nkrumah, P., Valenta, R. K. (2020). Toward Closing a Loophole: Recovering Rare Earth Elements from Uranium Metallurgical Process Tailings. *Journal of Metallurgy,* www.doi.org/10.1007/s11837-020-04451-7.

Vaziri, V., Sayadi, A. R., Mousavi, A., Parbhakar-Fox, A., & Monjezi, M. (2021). Mathematical modelling for optimized mine waste rock disposal: Establishing more effective acid rock drainage management. *Journal of Cleaner Production, 288*. doi:10.1016/j.jclepro.2020.125124

Verrier, B., Smith, C., Yahyaei, M., Ziemski, M., Forbes, G., Witt, K., & Azadi, M. (2022). Beyond the social license to operate: Whole system approaches for a socially responsible mining industry. *Energy Research & Social Science, 83.* doi:10.1016/j.erss.2021.102343

Ya, C., Usama, A., Shabbir, A., & Zhixiong, T. (2021). How do technological innovation and fiscal decentralisation affect the environment? A story of the fourth industrial revolution and sustainable growth. *Technology Forecasting and Social Change, 162,* 6.

Zuo, W., He, Z., Shi, F., Rao, F., Guo, B., & Deng, R. (2020). Effect of spatial arrangement on breakdown characteristics of synthetic particle in high voltage pulse breakage. *Minerals Engineering, 149.* doi:10.1016/j.mineng.2020.106241

Zuo, W., Li, X., Shi, F., Deng, R., Yin, W., Guo, B., & Ku, J. (2020). Effect of high voltage pulse treatment on the surface chemistry and floatability of chalcopyrite and pyrite. *Minerals Engineering, 147.* doi:10.1016/j.mineng.2019.106170

Conferences and commentary

Svobodova, K., Owen, J., Lebre, E., Edraki, M., & Littleboy, A. (2019). *The multi-risk vulnerability of global coal regions in the context of mine closure.* Paper presented at the 13th International Conference on Mine Closure. *(Kamila Svobodova, postdoctoral research)*

Svobodova, K., Everingham, J. A., Mackenzie, S., & Witt, K. (2021). *Public participation in mine life cycle transitions.* Paper presented at the Life of Mine Conference 2021, Brisbane, Australia. *(Kamila Svobodova, postdoctoral research)*

Eleonore Lebre accepted an invitation to give a keynote speech at the 3rd annual WA Mining Conference and Exhibition (WAM) on the topic of critical minerals and circular economy in mining. *(Source risks to future mineral supply, presentation)*

Presentation provided to the Prospectors and Developers Association of Canada for their March 2021 Annual Conference, for the Cutting Edge program: Sustainable Extraction of REE (Paul Gow, plus others). *(Increased efficiency processes for Rare Earth Elements, presentation)*

Lebre, E. Presentation of Nature Communications paper at the 2021 Basel Peace Forum organised by SwissPeace. Topic of session: 'Transitioning to a Low Carbon World – Urban Decisions, Local Impacts'. *(Source risks to future mineral supply, presentation)*

Eleonore Lebre presented at the International Industrial Ecology Day 2021 on June 21st. Online conference organised by the International Society for Industrial Ecology. Eleonore spoke during slot 1: 'Securing material base for carbon neutrality'. *(Source risks to future mineral supply presentation)*

Eleonore Lebre accepted an invitation to give a keynote speech at the 3rd annual WA Mining Conference and Exhibition (WAM) in Perth, 2021, on the topic of critical minerals and circular economy in mining. *(Source risks to future mineral supply, presentation)*

Presentation at the Responsible Raw Materials online conference in May 2020 *(Source risks to future mineral supply, presentation)*

Cote, C., Everingham, J.-A., Svobodova, K., Worden, S., Asmussen, P., Shaygan, M., Paz, A., Pagliero, L., Edraki, M., & Erskine, P. (2020). Moranbah post-mining land use collaborative project: Baseline works. Brisbane: Sustainable Minerals Institute. The University of Queensland *(Kamila Svobodova, postdoctoral research, presentation)*

A conference presentation – Kamila Svobodova, Jo-Anne Everingham, Sarah Mackenzie, Kathy Witt: 'Public participation in mine life-cycle transitions' presented at the LOM conference on 30 April 2021 *(Kamila Svobodova, postdoctoral research, presentation)*

Guest comment on future copper demand and implications for the mining industry to be published in the Global Mining Review. Authors: Rick Valenta, Eleonore Lebre, John Owen, And Deanna Kemp. *(Source risks to future mineral supply, comment)*

Eleonore Lebre had an interview with TDi Sustainability, who are preparing a white paper commissioned by the World Economic Forum. The paper will be about the potential of deep-sea minerals to support advancement toward global economic and social goals. *(Source risks to future mineral supply, comment)*

Changing societal values and the mine/mining company of 2030: Briefing note was reviewed by the Master Class on Wednesday, 28 November. *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, briefing notes)*

SMI strategic positioning at UQ: Initial comparative document linking SDGs and SIC classification completed and forwarded to Neville and Anna. Neville raised the idea of a retreat with the full leadership team to discuss related ideas in terms of the identity of SMI. This idea is now with Neville for initiation *(Visiting Fellow: Tony Hodge assisted with outreach, strategy, research and teaching, briefing notes)*

Svobodova, K., Everingham, J-A., MacKenzie, S., Witt, K.: Public participation in mine life cycle transitions. Life of Mine Conference 2021. April 28 – 30, 2021, Brisbane, Australia. *(Kamila Svobodova, postdoctoral research, conference presentation)*

Verrier, B., Smith, C., Ziemski, M., Witt, K., & Yahyaei, M. *System Dynamics for a Sustainable Mining Industry,* 3rd Asia Pacific System Dynamics Conference in Brisbane, 4 February 2020. *(Creating tools to quantify the impacts of production on ESG risk, conference presentation)*

Verrier, B., Smith, C., Ziemski, M., Witt, K., & Yahyaei, M. (2020). S*ystem Dynamics for a Sustainable Mining Industry.* Paper presented at the 3rd Asia Pacific System Dynamics Conference, Brisbane, Australia. *(Creating tools to quantify the impacts of production on ESG risk, conference presentation)*

Appendix. Our outputs

Shi, F., Huang, W., Christian, A., & Runge, K. (2018). *High Voltage Pulse Pre-treatment of Ores*. Paper presented at the XXIX International Mineral Processing Congress, Moscow, Russia.

Lay, D., Shi, F., & Antonio, C. (2021). *Factors Influencing Ore Breakage in High Voltage Pulse Pre-Treatment*. Paper presented at the International Minerals Processing Congress, IMPC 2021, Cape Town, South Africa.

Klawitter, M., & Valenta, R. (2019). *Automated Geological Drill Core Logging Based on XRF Data Using Unsupervised Machine Learning Methods.* Paper presented at the Geomin-Mineplanning 2019, Santiago, Chile.

Huang, W., Shi, F., Christian, A., & Runge, K. (2018). *High Voltage Pulse Pre-concentration Study Using a Low Grade Copper-gold Ore.* Paper presented at the The 14th AusIMM Mill Operators' Conference 2018, Brisbane, Australia.

Gow, P. (2021). *Sustainable Extraction of REE.* Paper presented at the 2021 PDAC Conference, Cutting Edge Session. Video submission.

Forbes, L., Runge, K., & Plint, N. (2019). *Collaborative Research on Coarse Particle Processing.* Paper presented at the 15th International Minerals Processing Conference, Santiago, Chile.

Demir, K., Whiten, W. J., Morrison, A., Runge, K., Evans, C., & Kohmuench, J. (2019). *Developing a Semi-empirical Model of the HydoFloatTM Cell: Part 1 A Hindered-Settling Classification Model.* Paper presented at the Flotation '19, Cape Town, South Africa.

Media

Industry Queensland, Consortium seeks energy edge in coarse particle processing *(Integrating coarse particle flotation into processing – a research consortium)*

Sonter, L. J., Watson, J. E. M., & Valenta, R. (2020). Renewable energy can save the natural world - but if we're not careful, it can also hurt it. *The Conversation.*

Australia's Mining Monthly, Coarse particle processing consortium *(Integrating coarse particle flotation into processing – a research consortium)*

Australian Mining, New consortium to improve future processing efficiencies *(Integrating coarse particle flotation into processing – a research consortium)*

The Pick, UQ and industry to tackle energy efficiency in mineral processing *(Integrating coarse particle flotation into processing – a research consortium)*

Tech Invest, UQ and industry to tackle energy efficiency in mineral processing *(Integrating coarse particle flotation into processing – a research consortium)*

National Resources Review, Consortium formed to tackle energy efficiency in mineral processing operations *(Integrating coarse particle flotation into processing – a research consortium)*

The Conversation. Sharma, V, Greig, C., Lant, P. 2021. India's wicked problem: how to loosen its grip on coal while not abandoning the millions who depend on it. *(Kamila Svobodova, postdoctoral research)*

Australia's Mining Monthly, January 2021. Heavy industry attachment key to coal mining communities *(Kamila Svobodova, postdoctoral research)*

Ian Morley Prize news release: Daniel Lay named as 2020 Ian Morley Prize recipient. *(High Voltage Pulse comminution: more effective and efficient?)*

Published interview – 'Pioneering research and PhD realities – a conversation with Daniel Lay', Inside SMI September 2020. *(High Voltage Pulse comminution: more effective and efficient?)*

Press release from the QLD Minister for Resources: Native plants used to extract rare earth metals as part of trailblazing Queensland research. 11 August 2021. *(Increased efficiency processes for Rare Earth Elements)*

News article on IQ Industry Queensland site, Niche processing models for rare earth minerals *(Increased efficiency processes for Rare Earth Elements)*

The Conversation. Clean energy? The world's demand for copper could be catastrophic for communities and environments. Co-authored by Deanna, John, Rick and Eleonore. *(Source risks to future mineral supply)*

Forbes, L., Runge, K., Mankosa, M., Kohmuench, J., & L, V. (2021). Reducing the Daily Grind. *The Chemical Engineer.*

Lebre, E., Kemp, D., Owen, J., & Valenta, R. (2021, 8 April, 2021). Clean energy? The world's demand for copper could be catastrophic for communities and environments. *The Conservation.*

The Signal. Eleonore Lebre was interviewed (pre-recording) for ABC's daily news podcast The Signal (Sydney) by journalist Stephen Smiley. *(Source risks to future mineral supply)*

Focus, Radio Adelaide. Eleonore Lebre was interviewed (live) for the Focus, Radio Adelaide, weekly current affairs program, by journalist Dr John Bruni. *(Source risks to future mineral supply)*

Eastside. Eleonore Lebre was interviewed live on Eastside 89.7 FM – Monday Drive 4:00pm (Sydney). Journalist: Ruth Hessey. *(Source risks to future mineral supply)*

102.1FM. Eleonore Lebre was interviewed (pre-recording) for 102.1FM Community Radio Brisbane by journalist Kloe Phelan. *(Source risks to future mineral supply)*

ABC journalist Nick Kilvert wrote an article titled 'Where and how will we get the metals to feed our future technology needs?' Eleonore quoted. *(Source risks to future mineral supply)*

Short interview for video about the SUCRE UQ-UL collaboration. 'Sourcing Unconventional Critical Resource Elements', ongoing collaboration with University of Lorraine *(Source risks to future mineral supply)*

Complex Orebodies Program
Sustainable Minerals Institute

smi@uq.edu.au
smi.uq.edu.au
+61 7 3346 4003

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

CREATE CHANGE

CRICOS Provider 00025B