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CSIRO

Resourceful

BRINGING CSIRO RESEARCH TO THE MINERALS INDUSTRY

AUSTRALIAN RESOURCES FOR GLOBAL TECHNOLOGY

Positioning Australia's mineral resources to drive new technologies, innovation and global electrification

CSIRO Australia's Innovation Catalyst

TOWARDS NET ZERO EMISSIONS

Technology pathways for low emissions industry and agriculture

With a common goal and shared effort, net zero emissions can bring benefits for all

THE GOAL

Reaching a balance between emissions and carbon sinks

Emitters
Agribusiness, Energy, Resource industry

Community

Sinks
Natural sinks, New capture technologies, Agriculture

HOW

Collaboration, new processes and technologies

Multiple stakeholders

A shared vision and shared effort

New innovations and approaches

BENEFITS

Triple bottom line: environmental, economic and social

Sustainability

Transition opportunities
e.g. new workforce to deliver low carbon economy

Decarbonised business

Securing future prosperity

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ISSUE

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LEADER'S COMMENT

AUSTRALIA'S ADVANTAGE IN GLOBAL TECHNOLOGY

The importance of Australia's minerals sector as an 'essential industry' for our country has never been more visible than it is right now during the COVID-19 crisis. **ROB HOUGH** writes

As we saw through the global financial crisis, our resources are and will continue to play a key role to sustain our national economy and our regions. The ongoing operation of the industry and our resource exports and the jobs it provides, at the very least, are softening the economic blow of the pandemic on our economy.

Our resources have placed us at the start of critical supply chains; providing Australia with a global advantage, and one that we can continue to build from. We are incredibly well positioned for the post-COVID global recovery with our world class resources. There are numerous opportunities as the global energy transition progresses, with electrification and digitisation likely to accelerate post-crisis, increasing high-tech demand and with it, a vast increase in requirements for our minerals and metals.

That demand for supply, however, also comes with an increasing demand for sustainable production, efficient with energy, water and overall reductions in the environmental footprint of operations, including emissions. End user preferences are for products with responsible supply chains and resource production, while investors also seek greater social and environmental performance from our companies.

Protecting the ongoing and future prosperity that we expect from our sovereign resources sector, including the contributions to government revenues that provide for essential services, requires us to support the industry to be sustainable, to decarbonise, to lead the world in clean resource contribution into our high-tech future. As demand increases, the scarcity of some minerals and elements, will make them critical or strategic to develop, to ensure that Australian demand and that of our partners can be met. This provides opportunity to create new mines and to shift more of our resource potential into truly economic deposits.

This presents huge opportunity and is a national challenge that we should address – there is surely value to be won for the first movers, those that perform strongly. For Australia, in what is a global race, we are ideally poised to provide technologies and solutions that support our sustainable resource supply.

In this issue of *Resourceful* we feature some of our technologies to support a sustainable resource sector for Australia, to deliver net zero emission resource supply, not just for minerals but also agriculture, another of our essential industries where the challenges are remarkably similar to ours. An example of a pathway to emissions reduction in the mineral sector that we are currently exploring is in the onshore pre-processing of iron ore.

In this issue, we also feature our work to support the development and expansion of our critical minerals industry with a bridge to build a high-tech sector, including value adding to our raw resources here in Australia as well as to guarantee ensuring sovereign supply.

While these technologies and solutions would initially be focused on Australian mines and miners, it ultimately also provides a valuable addition to our, already formidable, mining-related technology and services export sector (METS).

Australia has led the world with technology for exploration for decades, and it is often said that if you visit any mine in the world you will likely find Australians there helping operate the mine. We have the same opportunity now to build jobs, companies and exports from sustainable resource technologies, playing a global role to uplift the social and environmental performance of mining (also critical to supporting the sustainable growth of developing nations economies through their mining industries and uplifting more of the world's population from poverty).

A crisis brings huge disruption, and some companies will thrive post-crisis as they disrupt industries. Australia has another advantage to be seized; a truly sustainable resource industry, value adding our resources into high technology and supplying the global shift to high technologies.

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TOWARDS NET ZERO

HOW CAN AUSTRALIAN INDUSTRIES MEET THEIR EMISSIONS TARGETS?

Collaboration is key, and CSIRO can help.
As told to **RUTH DAWKINS**

CSIRO's Warren Flentje is working with collaborators from across industry, research and government to co-design technology pathways for a low emissions resource industry and agricultural production.

Since the Paris Climate Accords were signed in 2015 – when 195 countries pledged to limit global warming to below 2 degrees – every Australian state and territory has set an ambitious target of net zero emissions by 2050 or sooner.

Many national and international businesses, across mining, agriculture and manufacturing, have set the same goal. These publicly stated pledges have often been backed by a commitment to major financial investment; something which has been especially encouraging in light of the economic uncertainty caused by the COVID-19 pandemic.

Clearly companies don't need to be persuaded that net zero emissions is a worthwhile goal.

The question we now face is how we make that transition to a low-carbon economy while increasing productivity, competitiveness and economic growth. We don't have a lot of time, and we don't have a lot of tools.

That's where CSIRO can help.

Through the new missions program announced by CSIRO Chief Executive Larry Marshall, CSIRO is exploring how we can best support Australian industry to achieve their emissions reduction goals. Currently in development, this particular mission is not all about research. Rather, it is about accelerating the pace and scale at which we can tackle this challenge – increasing not just access to the relevant technology, but the widespread adoption of those tools.

Industry specific challenges

Our conversations with stakeholders have revealed complex challenges specific to resource industry and agriculture.

Take mining operations as an example. We know that one of the key emissions areas in mining operations is the use of diesel. This means there are questions to be explored around remote stationary energy, the electrification of fleets, and the potential use of biofuels and hybrid fuels.

We know that a second area responsible for high emissions is electricity consumption, so we need to be working on efficiency measures and renewables.

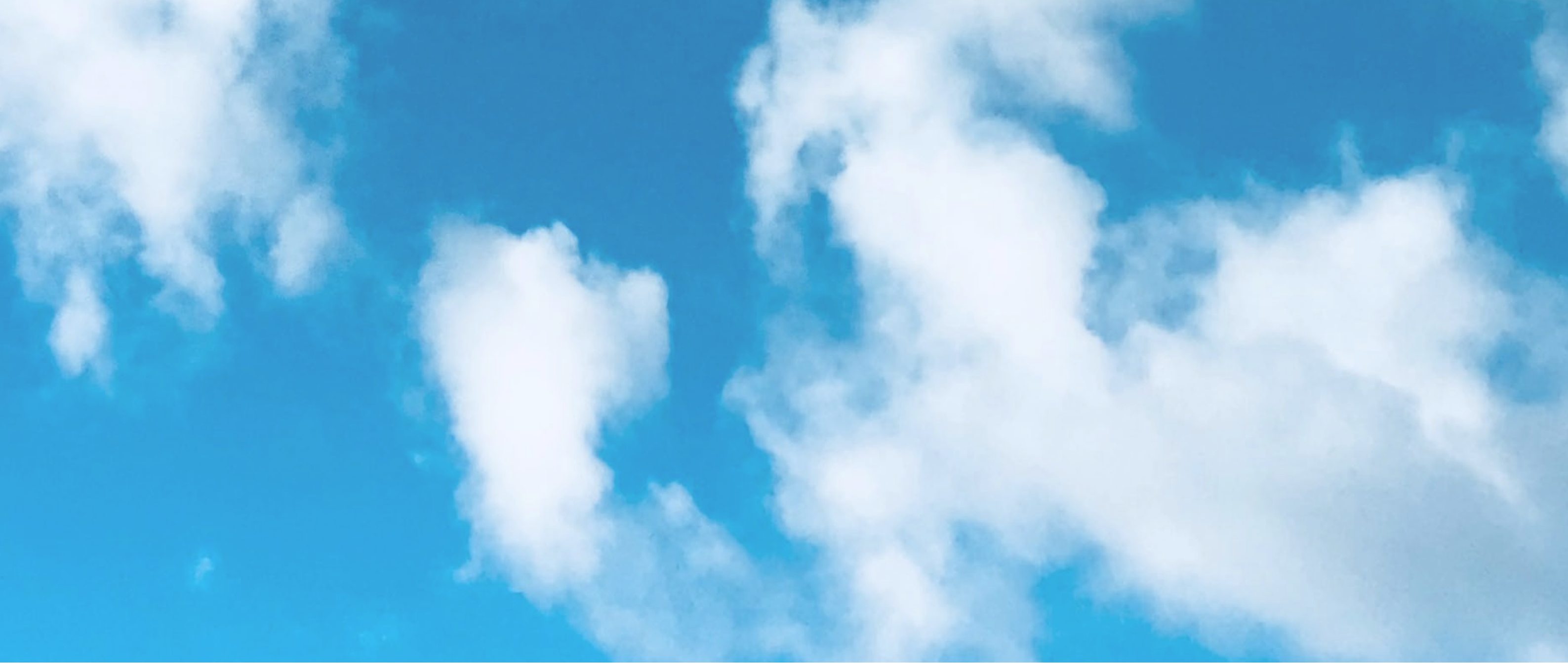
In coal mining, one of the main challenges is fugitive emissions, which currently account for around 5% of Australia's total annual greenhouse gas emissions. CSIRO is conducting research into fugitive emissions abatement in order to make our mining industry safer, more efficient and cleaner.

But increased emissions abatement potential lies in new processes. Pre-processing of iron ore can reduce overall value chain emissions significantly. More efficient use of waste heat and solar thermal resources can reduce energy consumption. In the future, making green steel using hydrogen and our abundant renewable resources has significant potential to make Australia a competitive manufacturing centre in a global low-carbon economy.

Exploring every opportunity for decarbonisation is critical. But no matter how much we decarbonise there will be remaining emissions from hard-to-abate sectors and addressing these will require negative emissions processes – locking up carbon through biological processes in forests, soils and new agricultural practices. CSIRO is working to establish new methods for carbon storage in the compliance and voluntary carbon market. We are also working on novel, high-abatement potential technologies such as Direct Air Capture, carbon mineralisation and bioenergy with carbon capture and storage.

Australia has much to gain from domestic and international carbon markets. Our vast land area, high-quality renewable energy resources and geological sequestration opportunities present opportunities to build new revenue streams for farmers, land managers and new industries.

To capitalise on Australia's natural advantages, we must close the technology gap. There is a significant gap in the availability of cost-effective, scalable technologies. Not only do we need to develop the tools that will help us to reach net zero, we need them to be demonstrable, cost-effective and adopted at an unprecedented scale.



The challenge of Scope 3 emissions

A further significant challenge is the need to reduce Scope 3 emissions – indirect emissions that occur across the entire value chain. These are much harder to track and manage, and they require large companies to change not only their own practices, but to influence the behaviour of their customers and consumers.

An integrated approach is required to reach net zero. It is not enough to consider just one company or one industry. Instead, a coordinated effort must be made by a wide range of related but independent stakeholders. CSIRO can help to address the many complexities, develop new technology and lead the conversation about putting these skills to use.

If Australia gets this right, decarbonisation can present opportunities for businesses and economic growth. Scope 3 emissions goals for international supply chains mean that Australian producers who reduce their emissions will find it easier to access international markets and supply chains. Those business innovators will also benefit from access to low cost global capital as investors move to sustainable options.

For the mining industry in particular, there are enormous opportunities. The shifting demand for minerals that accompanies the growth of low carbon technologies like wind turbines, solar photovoltaics and hydrogen fuel cells means that Australia's mining industry can become part of the decarbonisation solution by providing raw materials.

A trusted organisation

There is significant pressure on the mineral resources industry to reduce emissions – from governments, from investors, and from society. Meeting this challenge and ensuring that the mineral resources and agriculture industries remain internationally competitive will require the development and deployment of technology solutions at scale.

As Australia's pre-eminent scientific organisation, CSIRO has experience working in this space. We have long-standing collaborative relationships with all the relevant stakeholders: universities, where primary research is taking place; local, state and federal governments, who determine the policy and legislative frameworks we need to work within; and businesses themselves, who need to see tangible outcomes.

Additionally, our relationships across all sectors of the economy mean that we are uniquely placed to identify any barriers to adoption that aren't related to technology. We know it's not just about developing the tools – it's about making those tools cost-effective, scalable, and easy-to-adopt.

Preparing for the future

Action on climate change is growing at a rapid pace across Australian industry, and CSIRO is here to help you prepare for the future.

We cannot be doing the same things in 2050 as we are at the moment. We cannot even be doing things the same way in ten years. To hit those critical emissions targets, we need a large-scale coordinated effort. CSIRO has an important role to play in that effort, and we are putting our research to work.

We are actively engaging with partners to identify opportunities to develop and demonstrate pathways to net zero. We invite you to join us on the journey.

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“ An integrated approach is required to reach net zero. It is not enough to consider just one company or one industry. Instead, a coordinated effort must be made by a wide range of related but independent stakeholders.
Warren Flentje, CSIRO

REDUCING CARBON IN THE IRON-MAKING VALUE CHAIN

Increased scrutiny over greenhouse gas emissions in iron and steel production have prompted all parties involved in its value chain to invest significant resources into reducing their carbon footprint. **ROBERT HOBSON** reports

Miners, in particular, also view it as a risk to their social licence to operate despite the bulk of the carbon emissions weighted on the manufacturing end of process.

This poses a challenging situation for the Australia resources industry as, according to CSIRO research scientist Keith Vining, the heavy industries which turn iron ore into iron and steel are largely located overseas.

"The majority of the work and the carbon-intensity is in the steel making process at the other end of the chain in Asia, for example in China, Japan and South Korea," he said.

"It's difficult for us to influence what goes on there and the energy used is significantly higher in the smelting process than it is in the mining process."

The main source of carbon emissions comes from the use of metallurgical coal as fuel or coke to melt the waste material – also known as gangue – from the ore to extract the iron.

Downstream, however, Vining said miners could contribute to limiting the emissions at the other end of the value chain by essentially improving the quality of the ore before it is shipped to the smelters through the processes of drying, beneficiation, agglomeration and pre-reduction.

"One of the biggest emitters of carbon in the iron making value chain is the use of metallurgical coke in the blast furnace, and the simplest way we can influence how that is reduced is by upgrading the material prior to shipping it overseas," he said.

"In order to beneficiate any kind of ore, regardless of what it is, you need to do some sort of size reduction –crushing and grinding – so you can liberate the good stuff from the bad and effect the separation,"

"However, in doing that you negatively affect the size distribution of the material and it becomes problematic for the consumer,"

"The iron ore agglomerates, can then be charged into a blast furnace along with the metallurgical coke to separate the metal from the gangue avoiding the sintering process." Vining said.

As there is less waste material to melt, there would also be less metallurgical coke needed in the furnace per tonne of iron metal.

He also points out that another way in which beneficiation and agglomeration can reduce carbon in the value chain is in the transportation of the materials.

"It is important to remember the scale of the mining operations because you're talking about hundreds of millions of tonnes of material being transported from Australia to Asia," Vining said.

"In a wet tonne of iron ore, more than 50 per cent may be comprised of water, oxygen and gangue content, which is a significant amount of 'packaging' for the product."

He believes water and gangue removal is something Australian iron ore producers can do onshore to lower the carbon intensity associated with out iron ore exports.

Also, a higher quality ore would impart a further economic benefit to iron ore producers through their products commanding higher prices as well as spurring jobs growth in this part of the iron and steel value chain.

Although doing this may increase Australia's carbon emissions in the near term, Vining said it was important to take into account the bigger picture, which is the overall carbon-reduction in iron and steel making process.

For example, Japan's COURSE 50 program– the world's third largest steel producer – is actively researching the reduction of carbon intensity in its iron and steel industry by introducing hydrogen into the blast furnace.

It won't entirely replace metallurgical coke but rather reduce the reliance on metallurgical coke which, according to the COURSE 50 website, will generate water as opposed to carbon dioxide emissions.

The program also goes a step further to develop 'chemical absorption' technologies which aim to capture carbon dioxide from blast furnace gasses.

"They're still using metallurgical coal or coke, and that's to maintain the permeability of the blast furnace," Vining said.


Train loading of direct shipping ore in the Pilbara bound for port. Image credit: Fortescue Metals Group.

"And this is because the coke does a couple of things – it's very, very stable at very high temperatures and it maintains the integrity and permeability of the blast furnace burden,"

"So, it performs a physical function and you need that material in there. But the concept is to introduce more hydrogen to limit the carbon they need to use and to capture what carbon they do produce."

Again, it is at the 'bigger picture' level where the cumulative effect of these types of carbon reduction measures can be seen.

It also raises the possibility of the iron and steel value chain going that step further to produce 'green steel', particularly if hydrogen can be harnessed in its manufacture.

Despite some of the technical and commercialisation challenges faced by a latent hydrogen industry, Vining believes it is a promising, albeit a longer-term goal.

"It opens up a pathway to asking, 'Well, if we have gone this far in the process, should Australia be making its own iron and steel?', and that's a much bigger challenge because that will be a structural change in the way iron and steel is made," he said.

> It's important to take into account the bigger picture, which is the overall carbon-reduction in iron and steel making process.
> **Keith Vining, CSIRO**

"The blast furnace has been refined over centuries and it is an extraordinarily efficient process. But, of course, it uses carbon,"

"If you want to a process that can compete with blast furnaces in terms of efficiency and productivity, you have got to produce the hydrogen in a competitive way."

However, Vining suggests that pairing up renewable energy sources like solar and wind farms with beneficiation and agglomeration activity can spur iron ore producers to consider further opportunities to reduce their downstream carbon footprint in the short term.

"There might be a bit of reluctance from iron ore producers to start doing these sorts of things in the absence renewable energy," he said.

"But everything changes with the availability of renewable energy to power beneficiation and agglomeration processes. Cheap renewable energy can really change the landscape,"

"I believe (hydrogen) is a long-term solution, but beneficiation and agglomeration using conventional renewable energy sources is something we can do right now.".

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ZERO CARBON FUEL

HYDROGEN'S KEY ROLE IN DECARBONISING THE MINING INDUSTRY

Hydrogen has risen to dizzy heights in recent years as a promising zero-carbon fuel across the world, and although many hydrogen energy systems are in the demonstration phase, the mining sector is set to be an early adopter. **FRAN MOLLOY** reports

IMAGE: CSIRO's metal membrane technology converts ammonia to high-purity hydrogen at the point of use, enabling the safe and low-cost transport of hydrogen as fuel in the form of ammonia (NH_3).

In 2019, the Australian government announced the National Hydrogen Strategy, setting a path and committing substantial funding to accelerate the commercialisation of hydrogen energy and build a strong domestic hydrogen sector.

And in March 2020, four mining giants – BHP, Fortescue, Anglo American and Hatch – formed the Green Hydrogen Consortium, pledging to work together to accelerate renewable energy-powered hydrogen production and its application to the resources sector and other heavy industries.

"There are a whole range of opportunities for hydrogen in the mining sector," says Dr Daniel Roberts, who is the Director of the CSIRO Hydrogen Energy Future Science Platform.

"There's a strong drive to decarbonise mining operations. Hydrogen can be used to store renewable energy to generate electricity, it can power equipment and trucks and cars, and it can even be used in certain mining processes as a reductant," Dr Roberts says.

Roberts' group is part of a wider CSIRO effort to support the emerging hydrogen industry, which includes a $20 million partnership between CSIRO and Fortescue Metals Group to develop industry applications of CSIRO's metal membrane technology, which can rapidly convert hydrogen from ammonia, used to easily transport and store hydrogen.

Announcing the partnership in 2018, Fortescue's chair Andrew Forrest said, "We are at the beginning of an energy revolution and Fortescue intends to be at the forefront of this once-in-a-generation opportunity."

Future Science Platform

CSIRO's Hydrogen Energy Systems Future Science Platform is a key research centre working on new science and technology which will allow industry – including the mining sector – to decarbonise operations, transport and production processes.

"Much of our work involves the foundational science and the technology development that's not yet ready for our industry partners to invest in, but which has the potential to grow the hydrogen energy industry," says Dr Roberts.

The group works with low-readiness level hydrogen technologies, he explains. This involves creating new capabilities and new technologies around hydrogen production, transport, and use from a variety of renewable sources, and bringing these to demonstration stage.

CSIRO business units then work with industry partners to kick off the technology commercialisation pipeline to bring these innovations to market.

The push to decarbonise

The mining industry plays a crucial role in Australia's economic future. According to the World Economic Forum, however, the sector's ongoing viability will rely on its ability to meet expectations from governments, investors and wider society to reduce greenhouse gas emissions.

In June 2020, the Minerals Council of Australia released its Climate Action Plan which spelled out a range of actions to decarbonise the industry, including the use of renewable hydrogen.

A January 2020 report titled 'Climate risk and decarbonization: What every mining CEO needs to know,' produced by McKinsey & Company notes that the resources sector contributes around one per cent of greenhouse gas emissions globally through its mining operations and electricity. (Fugitive-methane emissions from coal mining contribute a further three to six per cent of global emissions, the report adds.)

"Mines theoretically can fully decarbonise through operational efficiency, electrification, and renewable-energy use," the report states, also noting that, while hydrogen fuel-cell technology is not yet mature, it has the potential to fully decarbonise on-site emissions from mines.

Opportunities for hydrogen in mining

Dr Roberts says the use of 'green' hydrogen energy is currently a hot topic in the resources sector. There are already numerous examples where renewable-sourced hydrogen is actively used as an energy source and as a means for storing renewable energy in the mining industry.

Since 2015, Glencore's Raglan mine, in northern Quebec, Canada, has run on a micro-grid powered by an arctic-rated wind turbine generator connected to a hydrogen energy storage unit.

"By producing and storing energy on site, rather than transporting diesel to a very remote site, they saw a big reduction in diesel use and cost, with associated carbon emissions," says Roberts.

Once the initial investment in renewables-to-hydrogen is made, the gas can be used as fuel in a range of different applications, from operations, to refining and transport.

CSIRO's high purity hydrogen derived from ammonia (using hydrogen membrane technology) is used to refill a hydrogen fuel cell vehicle.

> The key message for mining now is that much of the technology exists, and in many cases is proven – the next step is just doing it.
> **Dr Daniel Roberts, CSIRO**

In October 2019, Anglo American announced the development of the world's largest hydrogen-powered mine haul truck, a 290-tonne giant which will be trialled at the Mogalakwena platinum group metals mine in South Africa later this year.

Also in South Africa's platinum mines, Impala is using hydrogen fuel cells for forklifts and refuelling stations within its refinery operations.

Hydrogen driving green steel

One of the most interesting areas emerging for renewable-sourced hydrogen is in traditionally hard-to-abate sectors, Roberts says – and "green steel" is a much-talked about example.

"Steelmaking commonly occurs in a blast furnace, using coke which is made from coal through a highly carbon-intensive process," he says. Coke has a few roles to play in the blast furnace, providing heat and structure, as well as acting as a reducing agent, removing oxygen from the iron ore.

As well as being a useful energy carrier, hydrogen is also a good reducing agent. "There's enormous interest in developing technologies that can use both the heat and the energy from hydrogen along with that reducing power," Roberts says.

"At the moment, hydrogen is only used as a part-replacement for coal or coke in steel operations, but in these large-scale undertakings, even a partial replacement of a large amount of carbon can make a significant impact."

Future of hydrogen in mining

Roberts says that the focus of mining operators considering hydrogen is often on cost-saving around diesel consumption and transport, which can be considerable on remote sites.

"There's also a push towards creating products domestically that have a real environmental and sustainability advantage, which can differentiate Australia from some of our international competitors who don't have access to the same level of renewable energy resources."

He says the key message for mining now is that much of the technology exists, and in many cases is proven – the next step is just doing it.

"It's a great time for the sector to start deploying some big electrolysers out there, demonstrate some utilisation pathways, and be the leaders who revolutionise the industry and get that competitive advantage." ♦

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Scientists from the CSIRO Hydrogen Energy Systems Future Science Platform group examine the innovative metal hydrogen membrane.

WHAT YOU MAY HAVE MISSED

In-Pit Sensing Using Magnetic Resonance – The Magnetic Resonance Group at Lucas Heights recently commenced a new project with NextOre for the development of a highly novel magnetic resonance-based sensor for mineral grade measurement on in-pit mobile mining machinery.

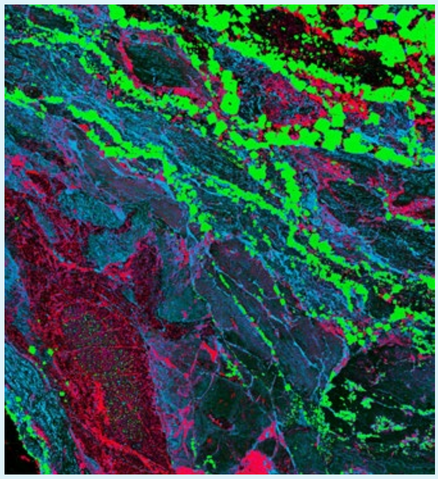
Recovering Clean Water from Mine Wastewater using Integrated Forward and Reverse Osmosis (FO-RO) Process – Dr Ramesh Thiruvenkatachari has been developing a novel integrated FO-RO process. A modular, transportable integrated FO-RO prototype unit, able to produce up to 10,000L clean water per day, has been developed. It is being trialled at the Centennial mine, treating different qualities of mine water and produce consistent quality clean water.

Book published: Modelling Rock Fracturing Processes: Theories, Methods, and Applications 2nd edn. Shen, Baotang, Stephansson, Ove, Rinne, Mikael (Eds.) (2020), Springer International 2020. This book is the second edition of the well-known textbook Modelling Rock Fracturing Processes.

A new three-year space mining technology In-Situ Resource Utilisation (ISRU) project has commenced. Led by Dr Jonathon Ralston and funded through CSIRO's Space Technology Future Science Platform, the project will target the development of new capability, build relationships and profile, and conduct technology demonstrations for ISRU.

Defining the Chemistry of the Jundee Mine Sequence project (Renee Birchall) – In early 2018, Australia's largest diamond drill hole, 3.217 km through the Jundee Gold Camp stratigraphy, was characterised at the CSIRO's Advanced Research Characterisation Facility in Western Australia. The core was analysed with multiple techniques at multiple scales, including over 3 km of continuous X-ray fluorescence (XRF) data and 400 Scanning Electron Microscope (SEM) mineral phase maps.

This provided new insights into the chemical architecture of the deposit and a practical template for navigating the stratigraphy, which can be implemented on site by the client using portable-XRF technologies.



LOOKING FORWARD

Structural geophysics for exploration through cover, Tanami Region (Teagan Blaikie) – CSIRO Mineral Resources and the Northern Territory Geological Survey (NTGS) recently completed a collaborative project to interpret the geology and structural architecture of the Tanami Region and northwest Aileron Province from newly acquired airborne magnetic data. Data and reports will be released by the NTGS in the coming months.

New Mining Geoscience and Space Technology Future Science Platform multi-resolution 3D scanning project – A collaborative project led by CSIRO Mineral Resources (Marc Elmouttie) and Data61 (Paul Flick) bringing together CSIRO's 3D scanning technologies for space applications (international space station and lunar surface scanning).

New Australian Coal Industry's Research Program (ACARP) project 'The Remotely Operated Longwall' (Jonathon Ralston) – This new two year $2M Sustainable Mining Technology project targets new H2 technology for longwall operations. Significantly, this project has advocated a new, flexible delivery model where project tasks are chosen at quarterly intervals through direct engagement with the ACARP industry monitors to respond more dynamically to industry priorities.

Geological Survey of South Australia (GSSA) – CSIRO Sedimentary Cu mineral systems, Stuart Shelf Project 2020-2023 (Susanne Schmid) – CSIRO Mineral Resources Discovery is partnering with GSSA to create an exploration framework for sedimentary-hosted Cu exploration in the Stuart Shelf. The project team comprising GSSA and CSIRO staff will deliver a robust understanding of the basin architecture, basin evolution and a sedimentological sequence stratigraphic framework. The results will be presented as workshops and digital data packages.

Ardea Resources and CSIRO Mineral Resources, SME Innovation Connection project: Gold behaviour in nickel-cobalt laterite at Goongarrie, North Kalgoorlie (Walid Salama) – The regolith team will determine whether gold and pathfinder anomalism in the Ni-Co profile at Goongarrie, North Kalgoorlie represents dispersion from primary mineralisation below. This knowledge will form a basis for Ardea to use elsewhere in its tenements to define the primary source of the gold mineralisation.

Cloncurry Multi-Element Toolkit and Laboratory (METAL) 2018-2021 (James Austin) – Bringing together expertise across ore deposits knowledge, structural geology, remote sensing and geophysics, the project collaborates with the Geological Survey of Queensland and industry partners to create a world first scale integrated dataset for the Cloncurry mineral system. The integrated dataset will provide quantitative insights into the geochemical evolution of a range of ore deposits, their structural controls, chemical footprints and geophysical expression, and will be optimised for big data approaches.

CRITICAL ENERGY METALS

WHAT IS A CRITICAL METAL ANYWAY?

Fashionable as it might be to talk about critical metals in a world migrating towards a clean-energy future it is equally important to ask why some metals are considered critical and others not. **TIM TREADGOLD** writes

Knowing what is genuinely critical in an economic sense, and not simply rare with limited economic value, could save industry from wasting time and money looking for metals which might not have a big future market.

The critical label applied to some metals can be confusing because scarcity could actually reflect a situation where demand is so small that there is little incentive to explore for more – but when the hunt does start the scarcity factor fades.

Lithium is a classic case of a metal which had a small market a few years ago when it was mainly used in making glass, ceramics and as a lubricant – and even as a medicine to treat bipolar disorder.

Today, lithium is a key ingredient in rechargeable batteries of the sort used in electric vehicles with a rush into EVs initially sparking fear of a shortage – until explorers discovered that lithium is relatively abundant, it's just that no-one was actively looking.

The net result is that while the future for lithium is bright a series of new mines in Australia and South America have filled the market and killed the price, with the result being the mothballing of newly-constructed projects before they could even start production.

Sorting out the facts from the popular understanding of what makes a metal important is a challenge currently under development as part of CSIRO's new portfolio of "missions" to better understand critical energy metals headed by CSIRO innovation and strategy leader, Dr Jerad Ford.

"Our starting point is to focus on metals needed in the energy transition," Ford said.

"There are a lot of metals that have unique uses in exotic technologies such as night-vision goggles which means we could look at all sorts of minerals."

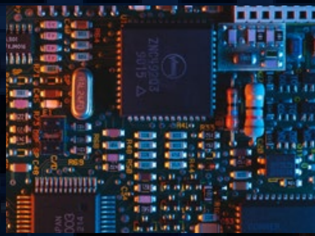
"But we see the number one critical-metals issue being ensuring sufficient supply to make a successful global energy transition, and that means understanding exactly what metals will be required, and where they are going to come from."

Most newcomers to the issue of critical metals are influenced by the geopolitical debate around rare earths which, in simple terms, means China controls the market and other countries, especially the U.S., want them.

The debate has also been influenced by the publication two years ago of a U.S. Government list of 35 minerals which its Commerce Department deemed to be critical minerals and a similar list published five years ago by the British Geological Survey of 41 elements it believe could face future supply risk, largely because production is dominated by China.

The two lists are not identical but both have a number of common elements including rare earths which Ford said undoubtedly had a role to play in the development of new-energy technologies, but it was also important to consider the case for industrial metals such as copper and nickel because they are required in large quantities as the world switches to low carbon forms of energy.






> The impact the critical energy metals mission is trying to make in the world, is to create more value from our resources.
>
> **Jerad Ford, CSIRO innovation and strategy leader**

Copper, which is used in everything electrical, is not often seen as being critical to a clean-energy future but without a substantial increase in supply it will be harder (and more expensive) to wean the world off fossil fuels.

The easiest example which explains the importance of copper is to consider the demand for the metal in an EV which is three-times that of a conventional petrol-powered car.

Explosive future demand projections make the case for criticality easy. "Lithium is an obvious candidate for the critical designation, and right now the same can be said of cobalt," Ford said.

"But there are already questions being asked of cobalt as battery makers develop new products that do not require as much, if any, cobalt- particularly Lithium Iron Phosphate (LFP) batteries which are the choice of Battery Electric Vehicle (BEVs) manufacturers – as well as Tesla – in China we need to understand the way the market is changing."

"Copper is a safer bet because it is used in almost every clean-energy technology the world is looking at."

Indium is another example of a metal topical today because of its uses in semi-conductors and photovoltaics which has triggered a number of exploration programs and the resampling of old drill cores, Ford said.

"But gross demand for indium is very small and there's also the question of whether projections of a sharp increase in future indium demand are correct."

While there could be strong growth for indium in next generation photovoltaics there will be greater demand for other metals, including silver, silicon and aluminium for silica-based photovoltaics which currently dominate the market.

"The focus of our research is to try and assess the level of metal demand in the global energy transition in the longer term, and determining exactly what metals will be needed," Ford said.

"Consuming more metals might have an environmental cost but there is more to gain in an environmental sense from the impact of new-energy technologies in reducing the need for fossil fuels in power generation and transport."

As far as the impact the "mission" is trying to make in the world, it's all about creating more value from our resources and convert more of those resources into economic production, we can grow the sector.

"We also want to identify where the best economic opportunities lie in higher-value manufacturing over the next five-to-10 years, areas such as metal alloys and precursors for batteries which will create jobs and long-term growth," Ford said.

"We're trying to create a critical energy-metals road map which will help identify the targets we need to aim for.

A better understanding of what makes a metal critical includes the development of a clearer picture of where those metals can be found and how they can be commercialised.

To this end, demand analysis and forecasting is part of the road map as is understanding the future sources of metal supply.

Ford said another of the aims of his mission was to identify how Australia could leverage some of its competitive advantages into creating future value from its critical metals.

Rare earths for example could theoretically be extracted from some types of iron ore as they could from the fly ash produced by burning coal.

In closing, Ford said the mission aims to be a flexible and a multi-year collaborative effort to help navigate these waters, and attract industry partners and funding to prove up technologies and help create new Australian companies, jobs and industries.

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BATTERY WASTE

CLOSING THE LOOP ON ENERGY METALS

Technology is hungry for energy metals and minerals, many of which are becoming increasingly scarce. Efforts to recycle these critical materials from e-waste and batteries have so far had disappointing results. CSIRO is working on solutions. **JANE NICHOLLS** writes

One of the world's biggest impending environmental problems is battery waste, which is set to explode globally in the next 10-15 years – and it's already in a bad state.

In Australia today, more than 3,300 tonnes of lithium-ion batteries (LIBs) end up as waste, with a shocking 97% of the batteries we buy going to landfill rather than being recycled. But the next-problem will be a lot bigger – literally – than the AAs and AAAs we're dealing with right now.

"The large-scale batteries being sold today will start coming offline in a decade or so," explains Dr Anand Bhatt, Team Leader for Electrochemical Energy Storage and CSIRO Energy in Clayton, Victoria. "As an example, we're talking about between 150,000-180,000 tonnes of electric-vehicle [EV] batteries, based on the very small scales of EVs sold currently in Australia. That's *just* Australian waste."

Add to that, explains Dr Bhatt, "the power-utility battery systems in South Australia, Queensland and Victoria, and suddenly we're talking about *millions* of tonnes of battery cells coming offline in the next 20 years or so. This is going to be a massive environmental problem in the future if we don't start working on it now."

A crushing waste

Even the most advanced approach to recycling batteries in Australia is "let's smash them up," says Dr Chris Vernon, Leader of CSIRO Green Minerals Technology initiative. Even then, 'recycling' is something of a misnomer. "They get crushed up, and the bulky base metals are recovered, but the high-value, functional, 'magic powders' inside the battery end up being exported to be recycled elsewhere." These valuable precursor materials are either fed into a furnace or dissolved in vats of acid for recovery of only the nickel and cobalt value "and the other materials just get dumped," he says.

"The problem with recycling LIBs is also that we've got to change consumer behaviour and get people to stop throwing them away, but rather collect them and every few months take them to a recycling centre," says Dr Vernon. "We also need to stop sending them overseas. Right now, some are smashed up to make them safe for transportation and to standardise them, maybe some basic metals are recovered before they're shipped off. Mostly they are sent as whole battery units, which is a fire risk – in fact one container load of batteries from Sydney caused a fire in the Port of Colombo and that port no longer accepts battery waste."

A 2018 report from CSIRO (Dr Bhatt is one of the authors) estimated that a combination of Australia's historically poor collection of LIBs combined with the offshoring of the 'recycling' could by 2036 represent an economic loss to the Australian economy of between $813 million and $3 billion, an estimate based on the potential recoverable value of the materials at current-day commodity prices. These projections are only for EV wastes – when the household batteries and grid utility batteries are factored in the potential recoverable value is a lot higher.
The valuable resources in LIB waste include cobalt, lithium, base and other metals and graphite, which could instead be recovered onshore and reused for new products.

> We're talking about *millions* of tonnes of battery cells coming offline in the next 20 years or so. This is going to be a massive environmental problem in the future if we don't start working on it now.
>
> **Dr Anand Bhatt, CSIRO**

CSIRO's value proposition for battery recycling

Reduce by 30-100% batteries in landfill sites → Make batteries fully viable and sustainable → Stop mining dwindling and finite resources → Make the world a sustainable place

Inventing technologies to give batteries another life

Dr Vernon says Dr Bhatt and his team are developing world-leading innovations to recover and re-use battery materials. "That's an important distinction: the *recovery* and *reuse* of materials," says Dr Vernon. "Recycling is that big loop where the nickel you take out of an old battery becomes nickel in something else. With recovery and reuse, it's always going to be a battery."

Dr Vernon says to his knowledge no one is successfully doing this yet and Dr Bhatt's Electrochemical Energy Storage group has already applied for patents on some of the technologies they've developed. "One of the most expensive components in the battery is the electrolyte," he explains. "At the moment we're throwing that value away."

The current process to capture lithium from batteries (if it is recovered at all), Dr Bhatt explains, is to convert it using a hydrometallurgical or pyrometallurgical process back to lithium hydroxide or lithium carbonate – essentially the same product that was originally mined – which is worth up to around $10,000 a tonne.

In order to use this for battery manufacture, it has to be converted to lithium hexafluorophosphate ($LiPF_6$). "The price for $LiPF_6$ is sitting at around $50,000 a tonne," says Dr Bhatt. "We looked at that and thought it seemed silly: It's in the battery already in the form that's needed to make more batteries. Why are we going backwards?" He also points out that the process to manufacture lithium PF_6 "takes a *lot* of hydrofluoric acid, so it's not the kind of process that you want going on everywhere".

The CSIRO team came up with the idea to develop a process for the first step of the recycling process. "Once it is crushed down into a powder for processing, our idea is to capture the lithium PF_6 right then as it is, recuperate it, clean it up and put it straight back into batteries." The process of charging and discharging batteries intrinsically causes chemical change and some damage to the electrode materials. "You can't get away from that," says Dr Bhatt.

But even at the end of a battery's useful life, there is more than 90% of undamaged battery materials left; 'cleaning it up' separates these materials out for reuse.

This recovery of the precious electrolyte – using a chemical process to extract it and then converting it into a powder ready for reuse in batteries – is the kind of technology that will help us close the loop on energy metals. "It's a powder which can then be dissolved into a liquid electrolyte and then that liquid is injected into the new battery," says Dr Bhatt. "We don't want to be redesigning recycling plants or battery manufacturing plants, so this is the most cost-effective way of getting it happening," he says.

A bold vision

Dr Bhatt has his eyes on a broader mission than dealing with only Australia's battery waste: He sees a future where Australia could become the Asia-Pacific hub for this circular battery recycling. "We can take China's battery waste, India's battery waste, all the Asian waste and turn it into a large-scale industry generating thousands of jobs for Australians," he says. "Obviously we have to do a lot of economic calculations to show it's viable, but from our perspective as scientists that's where we would like to see this go."

He and his team hope to have the PF_6 recovery technology ready for pilot-scale in the next five years, and to have it commercialised for industry five years after that. "That puts us into the timeframe of 10-15 years when the batteries being sold today will be coming into the waste stream. The key for us now is to make sure the technology's ready."

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IMAGE: Waste batteries at an Australian battery-recycling plant.

RESEARCHERS TARGET EFFICIENCY AND INDUSTRY FOOTPRINT

Striving to increase efficiency – doing more with less by working smarter to make discoveries while reducing its footprint and emissions – is how the Australian minerals exploration industry will thrive. **TONY HESELEV** reports

Efficiency is the ability to avoid wasting materials, resources, energy, effort, time and money in delivering or producing a desired result.

Technological developments, such as those the MinEx Cooperative Research Centre (MinEx CRC) is working towards in its nine projects, are driven by efficiency. These developments centre on:

- More productive, safer and environmentally friendly drilling methods to discover and drill-out deposits, including coiled tubing drilling technology
- New technologies for collecting data while drilling, bringing forward mine production
- Drilling in under-explored areas of potential mineral wealth in Australia through a partnership of geological surveys and researchers, known as the National Drilling Initiative (NDI).

"The CRC now in its second year of a ten-year life, is not afraid to borrow from other industries, including defence, telecommunications and information technology, to adapt and apply ideas such as fibre-optic cables in downhole and surface exploration and computing advances to better process large amounts of data to enable 3D modelling for exploration," says Chief Executive Andrew Bailey.

A key part its work is helping the industry reduce its environmental footprint by developing more efficient drilling rigs.

The CRC and its predecessor organisation[1] developed the RoXplorer®, a lightweight, mobile drilling rig that uses coiled tubing technology, adapted from the petroleum industry. Drilling with a continuous coil removes the need to connect and disconnect drill rods as a drillhole deepens, making it faster, cheaper and safer than conventional drilling – and reduces the environmental footprint by drilling smaller holes with a lighter and more mobile drilling platform.

The first generation RoXplorer was capable of drilling to a depth of 500 metres. A second generation RoXplorer, which can drill to 1000 metres and has been fitted with additional fluid processing capability, will be tested in the field at Kapunda, South Australia, early next year. This follows field trials of the original RoXplorer in Nevada, Port Augusta and Horsham.

"The second generation RoXplorer®, has a longer coil and deeper reach as well as sensing and steerable drilling," Mr Bailey said. "This is more efficient, more rapid and smaller footprint drilling that is a cheaper method of testing through thick cover sequences which traditionally have been very difficult to drill through."

The RoXplorer®, will be used in the South Australian and West Australian geological surveys' drilling and research programs next year as part of the NDI. The South Australian drilling will focus on the Delamerian basement in the Murray Basin beginning in autumn. The Western Australian drilling will begin in spring, focused on unlocking greenfields terranes in the remote desert country in the east of the state.

These programs are expected to deliver significant pre-competitive data to the market, resulting in a better-informed exploration environment in Australia, and improve understanding of a wide range of mineral systems, including those associated with critical metals.

Mr Bailey said the CRC's aim is to better understand the systems beneath the blanket of deeply weathered rocks and transported sediments that covers about three-quarters of Australia, to enable companies to explore for specific minerals including critical metals that will help deliver technological advances such as enhanced energy storage.

"Australia has a large percentage of critical metals but understanding where they are is key to be able to efficiently exploit them," Mr Bailey said. "We need to develop an understanding of where these critical metals are so that we can meet society's needs when required."

The $218 million MinEx CRC is the world's largest mineral exploration collaboration, bringing together a total of 38 industry, government and research organisations. Its work ranges from undertaking fundamental research to commercialising research projects.

CSIRO is a major research partner in the CRC, along with seven Australian

MinEx CRC Program 2 Researcher Steve Tassios (CSIRO) calculating LIBS measurements

> The $218 million MinEx CRC is the world's largest mineral exploration collaboration, bringing together a total of 38 industry, government and research organisations. Its work ranges from undertaking fundamental research to commercialising research projects.

universities. CSIRO Principal Research Scientist Yulia Uvarova, who leads the MinEx CRC 'Data from Drilling' program, and her team are developing sensing technology based on laser-induced breakdown spectroscopy (LIBS).

The LIBS technology had been used to sense and analyse the relatively few elements found in alloys, pharmaceuticals and other non-geologic materials. But Dr Uvarova's team is developing a downhole tool that is so versatile that it can sense elements across the periodic table and provide chemical analysis in situ.

"The conventional method is to extract the core and send it to the lab for chemical analysis," she says.

"Of course, that takes time and is very costly, especially if you are drilling in remote areas.

"Our idea was to build a tool that can be deployed right after drilling the hole – maybe the same day – collect the downhole chemistry onsite through a deep, slim drillhole and get results almost immediately, providing practical information to geologists and drillers in real time."

Using LIBS downhole assay tool will require fewer drillholes, reducing rock cutting, grinding and crushing, and saving transport and fuel costs, although exploration companies will still want to send samples to the lab to verify the initial analysis.

The MinEx CRC also works to improve the efficiency of conventional drilling rigs by, for example, placing sensors on the rigs to measure and analyse flow and pressure data, and applying advanced seismic and petrophysics capabilities to the rigs.

"Not all advances can be giant leaps," Mr Bailey said. "We've got to accept that drilling has been done in that manner for 150 years and we don't expect to throw all that out at once and come in with a totally new technique."

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1 The Deep Exploration Technologies CRC, which was wound up in September 2018 at the end of its federal funding period.

COLLABORATING WITH INDUSTRY

MAKING THE RIGHT CONNECTIONS CAN UNLOCK A GOLD MINE

Kalamazoo Resources is an Australian junior gold and base metal explorer, with interests in the Castlemaine region of Victoria. Working with CSIRO for the last year, Kalamazoo have gained access to vital research and development (R&D) resources and expertise to grow and shape their business. This collaboration was part-funded by an Australian Government Innovations Connections grant. Interviewed by **KEIRISSA LAWSON**

Hayley McGillivray, CSIRO

Hayley is a Facilitator in the Innovation Connections element of the Australian Government Department of Industry, Science, Energy and Resources (DISER) Entrepreneurs' Programme.

My work is focused on connecting small to medium businesses (SMEs) with experts in the research sector. I am based in Perth and work across Western Australia.

The Innovation Connections Grants are designed specifically to help SMEs access research expertise to take forward an idea or innovation.

My role is to help SMEs find the right researchers from universities, CSIRO and other research organisations. Finding the right match is a crucial step to success. The Innovations Connections grant provides a dollar-for-dollar funding match to successful R&D projects and collaborations.

Kalamazoo Resources successfully applied and received an Innovations Connections grant in 2019 for work at their Wattle Gully gold mine within the Castlemaine project near Bendigo in Victoria.

I was introduced to Kalamazoo Resources before their Castlemaine project commenced. They were facing a regolith challenge on one of their other project areas. My role was to understand the businesses' needs and support them in identifying and engaging with the right researchers.

When Kalamazoo's priorities changed, it was my job to understand what they were seeking to achieve at Castlemaine and to connect them to Adam Bath who I knew had the right expertise and tools to address these challenges.

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Adam Bath, CSIRO

Adam is a Mineral Systems Scientist at CSIRO, specialising in mapping hydrothermal orebodies, particularly gold and copper, using microscopy, mineralogy and geochemistry techniques.

Hayley made the connection between my expertise and what Kalamazoo wanted to achieve. They were seeking greater understanding of the underground footprint of their gold-bearing orebody at Wattle Creek, located in their Castlemaine project.

Kalamazoo had access to 80,000 metres of historical drill core located in the project area. I was able to examine diamond drilled cores and, using scanning electron microscopy (SEM) and minerology, map different mineral zones (zonation) across the site.

Victorian gold systems are quite narrow. The Wattle Creek deposit is characterised by narrow gold shoots emanating throughout the underground geology. We were looking for alterations in the soil geology associated with gold mineralisation which could be used to direct future exploration.

L to R: Katie Woodall, John Walshe, Adam Bath and Tina Shelton. Mineral Systems team sampling drill core from the Wattle Gully deposit, central Victorian goldfields

Interestingly, we found an association between white mica chemistry and distance to the gold orebody. We discovered that white mica chemistry changed closer to the orebody, creating a detectable 'alteration halo'.

Concentrating on white micas and mapping these alternation haloes is helping unlock new gold mining target. The next stage is taking this knowledge and applying it to a larger scale.

This is not just limited to gold exploration. This approach can also be adopted for the discovery of other metals distributed by hydrothermal fluids, such as copper, lithium, zinc, lead and rare earth elements.

Kalamazoo have been a great industry partner to work with. They were responsive and keen to see the results of the project at every stage.

For me, it was a rewarding opportunity to see real world impact between science and business. These findings have been crucial in determining the next strategic step the company are undertaking to mature their Castlemaine interests.

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Luke Mortimer, Kalamazoo Resources

Luke is Exploration Manager at Kalamazoo Resources; an industry professional and experienced geoscientist.

I was introduced to the Innovations Connections scheme through work contacts. We were about to embark on a new exploration project in Victoria and wanted to involve CSIRO.

The Innovations Connections grant was important to be able to initiate our first project. However, whilst the funding is one helpful part of this process it was the opportunity to collaborate with CSIRO which was more important to us.

WE WOULD NOT NORMALLY HAVE ACCESS TO THIS LEVEL OF EXPERTISE AND RESOURCES AS A JUNIOR COMPANY AND SME AND THE FUNDING MADE IT EASIER FOR US TO COMMIT TO THE PROJECTS.

The connection between Hayley to Adam was crucial in the acquisition of the grant and ultimately to the success of the project.

The outcome of the first project at Wattle Creek was so useful, we initiated a second project. We have now received a second Innovation Connection grant based on those learnings and are looking on how we can apply it practically in the field of gold exploration here in Victoria.

From our experience, Kalamazoo would recommend working with CSIRO. CSIRO brings a certain level of respect and credibility to the R&D process, which is something we are able to promote to our shareholders and investors.

The Innovation Connections program has been of great benefit and value to us as a junior company and we greatly appreciate the opportunity to work with the CSIRO.

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