Issue 24 AUGUST 2021

Resourceful

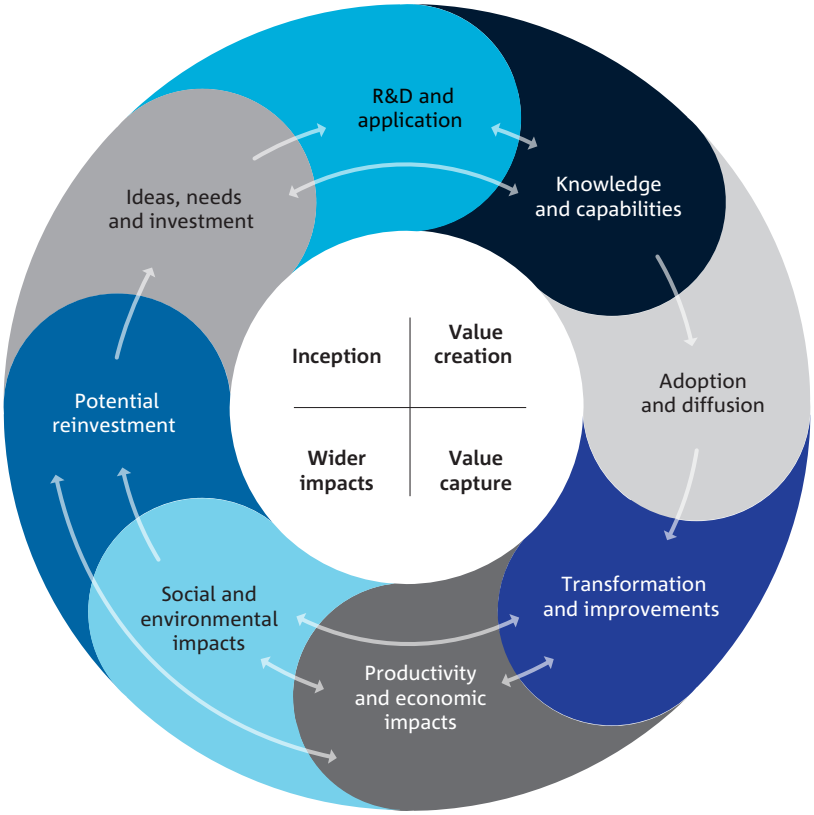
BRINGING CSIRO RESEARCH TO THE MINERALS INDUSTRY

FROM IDEA TO IMPACT

Commercialising innovative Australian technologies

CSIRO Australia's Innovation Catalyst

THE INNOVATION CYCLE



Science and technology have always played a key role in supporting Australia's growth and productivity

Source: CSIRO Futures (2020) Value of science and technology CSIRO, Australia

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COVER
A Chrysos Corporation sample jar ready for its PhotonAssay analysis
Image credit: Chrysos

LEADER'S COMMENT

UNLOCKING VALUE THROUGH INNOVATION

Mr Jonathan Law, Director
CSIRO Mineral Resources

As the list of challenges in the mining industry grows, the industry is focused on R&D to solve key challenges and unlock value through innovation. **JONATHAN LAW** writes

There are plenty of exciting opportunities given the rapid pace of change in technologies in a range of affiliated industries and the new approaches they provide for mining. Rapid sensing and digital technologies linked to automation provide a range of options that simply did not exist even five years ago.

Perhaps the most impactful shift in innovation thinking relates to how value is unlocked through structured partnerships that enable widespread deployment of technology into the market.

In short, innovations are only as good as the commercial delivery vehicle!

CSIRO has a long history in industry focused R&D, however, our focus is increasingly shifting to technology translation through commercialisation, company creation, and how our intellectual property can best add value to our stakeholders and provide returns to fund future innovation.

R&D is traditionally a project-based activity that leaves the end use and delivery mechanism open. In fact, many research activities have no independent line of sight to market as they form a small part of a much broader opportunity. The risk, and common reality, is thus that many technologies or research ideas are stranded.

In this issue of Resourceful, we look at a range of commercial innovations that have been developed with the end use in mind. These innovations look to participate in the new value created for our customers rather than simply provide a product or service that is not well integrated with their operations.

A key enabler in each case is building structured partnerships that offer win-win outcomes for the participants that each add value to delivering the opportunity.

In the case of Chrysos Corporation, CSIRO and our partners created a new spin out company linking capital, market knowledge, manufacturing support and new technology to unlock value in gold processing performance through real time information. There will be many other applications, but the company is focused on unlocking value for customers as opposed to simply providing a cheap and fast analysis.

Our NextORE partnership brings together capital and market knowledge with engineering expertise to deliver an ore sorting solution based on new technology. NextORE aims to provide a fully engineered grade uplift to its customers. This focus on an integrated service, rather than the measurement tool itself, forms a key part of unlocking value for our partners.

Environmental, social and governance (ESG) pressure is a growing challenge for the industry. CSIRO is working to fast-track a suite of environmental solutions through commercial partnerships. Recent examples of successful CSIRO research that delivers both commercial and positive ESG outcomes include the VESI™ groundwater monitoring system; reduced emissions from steelmaking and cement from the dry slag granulation process; and an innovative water treatment process that combines forward-osmosis and reverse osmosis in a unique solution with applications in many sectors. Each of these provide compelling commercial opportunities while focusing on positive environmental outcomes.

Geoscience data is another area of rapid progress. Large data volumes, sporadic data distribution and profound implications across the entire mining lifecycle make this an important area for innovation. In this edition, we also highlight four new technologies on the commercialisation journey and how they will underpin fast and effective decision making in industry.

The number of potential market opportunities is large and so are the potential pathways to unlock these. We look to explore these opportunities with our partners to create value in the most effective way for each specific circumstance.

CSIRO and government have a range of options available for potential partners from support for SME engagement; through commercial accelerators; to access to capital via our venture fund, Main Sequence Ventures.

Perhaps the most important new innovation opportunity, is in the innovation process itself!

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COMMERCIALISATION

FROM IDEA TO IMPACT: COMMERCIALISING CSIRO'S RESEARCH

CSIRO's commercialisation teams utilise a variety of pathways to take the breakthrough work of our scientists and researchers to the world. **JANE NICHOLLS** reports

The work to commercialise CSIRO's science and research relies on modern innovation,yet has its roots in the 1949 act that gave birth to the organisation in its modern form.

As well as decreeing that "there shall be a Commonwealth Scientific and Industrial Research Organisation", there's a clause in the *Science and Industry Research Act* that shows particularly commendable vision, says CSIRO Commercial's Acting Executive Manager, Commercialisation, Dr Werner van der Merwe.

Clause 9.1(b) decrees that the organisation is to "encourage or facilitate the application or utilisation of the results of such research". Dr van der Merwe gets a kick out of the fact that "they wrote that all those years ago".

"We've been on that mission ever since and recently really ramped it up: We've increased our equity portfolio tenfold in the past five years."

To make it happen, business-development and commercial teams work closely with each of the 11 CSIRO business units. "We provide support to the science teams to help them turn their work into products, services, and technologies that will make a meaningful impact through commercialisation" says Julian Reynolds, Director, Business Development and Global (BD&G) for Mineral Resources.

There are numerous carefully designed and complimentary commercialisation programs available in CSIRO to help ensure success. An important part of that is Mr Reynolds and his team (and their equivalents across CSIRO's business units) keeping close to the scientists and researchers they're supporting.

"There's no one size fits all, but a lot of it is about relationships, so that you know what's going on and the more comfortable the science teams are in approaching our team for help," says Mr Reynolds. "And when you go through a commercialisation project together, those relationships get a lot closer. When scientists see a successful initiative, it helps foster a culture of collaboration that surfaces new commercial opportunities."

The BD&G teams work with the science teams from the early stages of ideation. "We can help test and validate ideas in the marketplace, and with help from CSIRO's IP area check to see what else is out in the market, via patent landscape searches."

It's important to validate the novelty of the CSIRO research or technology and its market appeal in order to understand the value proposition. "We define the problem we're solving and put the idea or technology through its paces. Then we recommend the best way to proceed to get it out to market, by the various pathways we have available."

TAKING A WIDE VIEW

A lateral approach is part of the process, too. "We try to think beyond where the technology was born," says Mr Reynolds. For example, sometimes the research is a solution to a particular problem, but could well have wider applications. "You think more broadly and see where it could fit in other areas."

Mr Reynolds points to a Mineral Resources example where the Hard Rock Mining Group's 4D Internet team developed a novel way to "fuse big, clunky data sets and manipulate them so they are manageable". The work was to solve a problem for the mining industry. "But when you think about where that technology can be applied, mining is only a small chunk of where it could go."

The role of the BD&G teams and CSIRO Commercial is, he explains, "to help the teams look beyond what's right in front of them in terms of the particular problem they've solve and open up opportunities in other markets or other industries."

Mr Nick Pagett is Business Development and Global director, overseeing the BD teams across all of CSIRO's business units. "Together with the Commercialisation teams and industry, we work to take the world's best science and technology that's being created through CSIRO's research activities and turn it into applied form, to create impact and value for communities, industry, governments, in Australia and globally," says Mr Pagett.

Revenue from CSIRO commercialisation is reinvested into future science and commercialisation

"CSIRO Mineral Resources has a lot of great examples of doing just that; and they're also investing directly with partners to create future disruptive technologies," says Mr Pagett.

"They take a portfolio view of science capability and develop a strong pathway to take it to market. Is it a joint venture, a startup, a spin out, a pure licensing transaction? We have defined eight different pathways to market, and the Minerals team has done a really good job of identifying the best pathway to create sustainable and scalable returns."

THE JOURNEY TO COMMERCIALISATION

CSIRO employs various pathways to ensure that we maximise the impact from our research. These include selling or licensing intellectual property rights, forming joint ventures with industry to bring the technology to market, or in some cases setting up new ventures that can grow into future industries.

CSIRO also has a bespoke model for employee founder led start-ups. There is also the possibility of a 'spin-in' to grow a proto-business.

If none of those pathways is quite right, a special-purpose vehicle can be designed to meet unique opportunities and take CSIRO's ground-breaking science and research to market.

Dr Werner van der Merwe, Executive Manager Commercialisation, CSIRO

PULL UP A STOOL – HERE'S HOW CSIRO COMMERCIALISES ITS INNOVATION

As executive manager of the Commercialisation team, Dr van der Merwe says the team operates like a three-legged stool.

The first is the team of Commercialisation managers who work with our researchers, BD managers, industry partners and entrepreneurs to originate new opportunities, and then helps to structure, execute and manage deals across the different business models described above.

Each manager is a specialist in one of CSIRO's 11 business units; Dr van der Merwe, who has a PhD in engineering, doubles up as the Manufacturing commercialisation specialist. "Fundamentally, they're the people who guide the end-to-end process of how the deals are made," he says.

The second leg is the Equity Portfolio Management team. "We currently have 40 companies in that equity portfolio," says Dr van der Merwe. "Chrysos and NextOre [see pages 5–6] both emerged from CSIRO's Mineral Resources business unit."

Equity Portfolio managers look after CSIRO's shareholding in a company, and work closely on governance and administration, and when required finding and nominating a CSIRO director for a board. "Sometimes we just take an observer seat," explains Dr van der Merwe. "We decide based on what's best for the company and commercialising the technology."

The final leg of the commercialisation stool is the Licence Portfolio team. "CSIRO has around 500 active licences."

"So we have the deal-making team and then CSIRO collectively manages the portfolios that result from the deals."

The revenue that flows from CSIRO commercialisation is reinvested into future science and commercialisation.

"CSIRO wants to grow its portfolio substantially, and we're investing it back into more research and accelerated commercialisation," says Dr Nick Cutmore, Commercial Advisor to CSIRO Mineral Resources and a director of NextOre. "There are large amounts of money starting to flow."

Mr Nick Pagett, Director Business Development and Global, CSIRO

> Together with the Commercialisation teams and industry, we work to take the world's best science and technology that's being created through CSIRO's research activities and turn it into applied form, to create impact and value for communities, industry, governments, in Australia and globally.
> **Mr Nick Pagett, CSIRO**

SUPPORTING INNOVATION ALL OVER

But wait, there's more. CSIRO has a host of programs to help get novel science and technology to market, including SME Connect, for Australian companies that have a breakthrough idea but need some help – funding, resources, support or all three – to get it off the ground.

"It's often the case that they need some R&D when they don't have those resources in house," says Mr Reynolds. "They come to us with the problem and the opportunity and together we figure out something that they can take back into their business as part of their market offering. A great example of that from Mineral Resources is detectORE."

Beyond SME Connect, there's a variety of accelerators and innovation funds, including Main Sequence Ventures.

There's also the CSIRO Market and Community Discovery program, "the high-level analysis, where teams are taken through a process to inform ideal pathways to impact," says Mr Reynolds. "It helps them think about the best way to take their technology to market. There's such demand for these programs that we're setting up more internally."

One more step along is ON Prime. "This is where we start to dig a bit deeper, build up value propositions and begin to look for potential partners in the market as we start the planning phase for commercialisation."

For situations where there's compelling technology but no clear pathway to market, there's the Commercialisation Marketplace.

"It's like a shopfront where we list all sorts of technologies that we're looking for interest in," says Mr Reynolds. "Investors looking to back novel technologies can have a look on the website. A couple of recent examples from Mineral Resources are Vesi and MagSonic."

Mr Pagett explains that cross-pollination and strong communication across CSIRO business units and strategic partnerships with industry are vital to the organisation's fast-growing commercialisation ecosystem. "We're building a balanced portfolio that spans from the startup and spin-out commercialisation models all the way to sustainable, recurring long-term partnerships," he says.

"There's not always the required level of investment from the startup community available to develop a technology from scratch, which is when we partner with large organisations who have deeper pockets and for whom a particular solution is applicable."

For the scientists, researchers and the BD teams that support them, the growing emphasis on commercialisation is inspiring. "Helping the science teams to get their great work out to market and for them to see the impact it can have is really exciting," says Mr Reynolds.

Dr van der Merwe adds that those sentiments hold true for him and his team, too. "I cannot imagine a more exciting and more challenging job than being a commercialisation person for Australia's national science agency at this moment in time," he says.

"There is a huge upswell of interest in the area, and there's also an enormous level of support – from government through to our executive, through to our universities and to industry. They all want to see more of this activity, and I can't imagine being anywhere else."

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Mr Julian Reynolds, Director Business Development and Global, CSIRO Mineral Resources

CSIRO TECHNOLOGY USED BY INDUSTRY

COMMERCIALISATION IN ACTION: THREE SUCCESS STORIES

CHRYSOS PHOTONASSAY

An experiment that Dr James Tickner conducted for CSIRO Minerals around two decades ago ultimately led to the creation of Chrysos Corporation.

The young physicist found a paper from the 1960s about X-ray activation processes. He and his CSIRO colleagues used a hospital's radiotherapy suite out of hours to try to activate ore samples. "It wasn't very sophisticated, but it was where we first figured out that we could build something."

It went on the backburner, but when gold prices started to climb around 2012, Dr Tickner decided to have another look at it. "There was renewed interest in finding better ways to detect and measure gold."

They came up with a concrete demonstration that high-powered X-rays could be used to excite the nuclei of gold atoms, allowing gold samples to be measured "quickly and with great precision", explains Dr Tickner.

The PhotonAssay process eliminates the need for fire assay at 1200-degree Centigrade temperatures and hazardous chemicals, improving both environmental outcomes and workplace health and safety.

A mixture of the commercialisation pathways have been deployed: Chrysos Corporation is part spin-out, part employee start-up, part investor JV, and CSIRO still holds substantial equity. Licensing is also in the mix: the equipment is leased and the technology is licensed to customers, creating a sustainable revenue stream.

> In June 2021, Chrysos announced that it had completed analysing 1 million samples using its PhotonAssay technology.

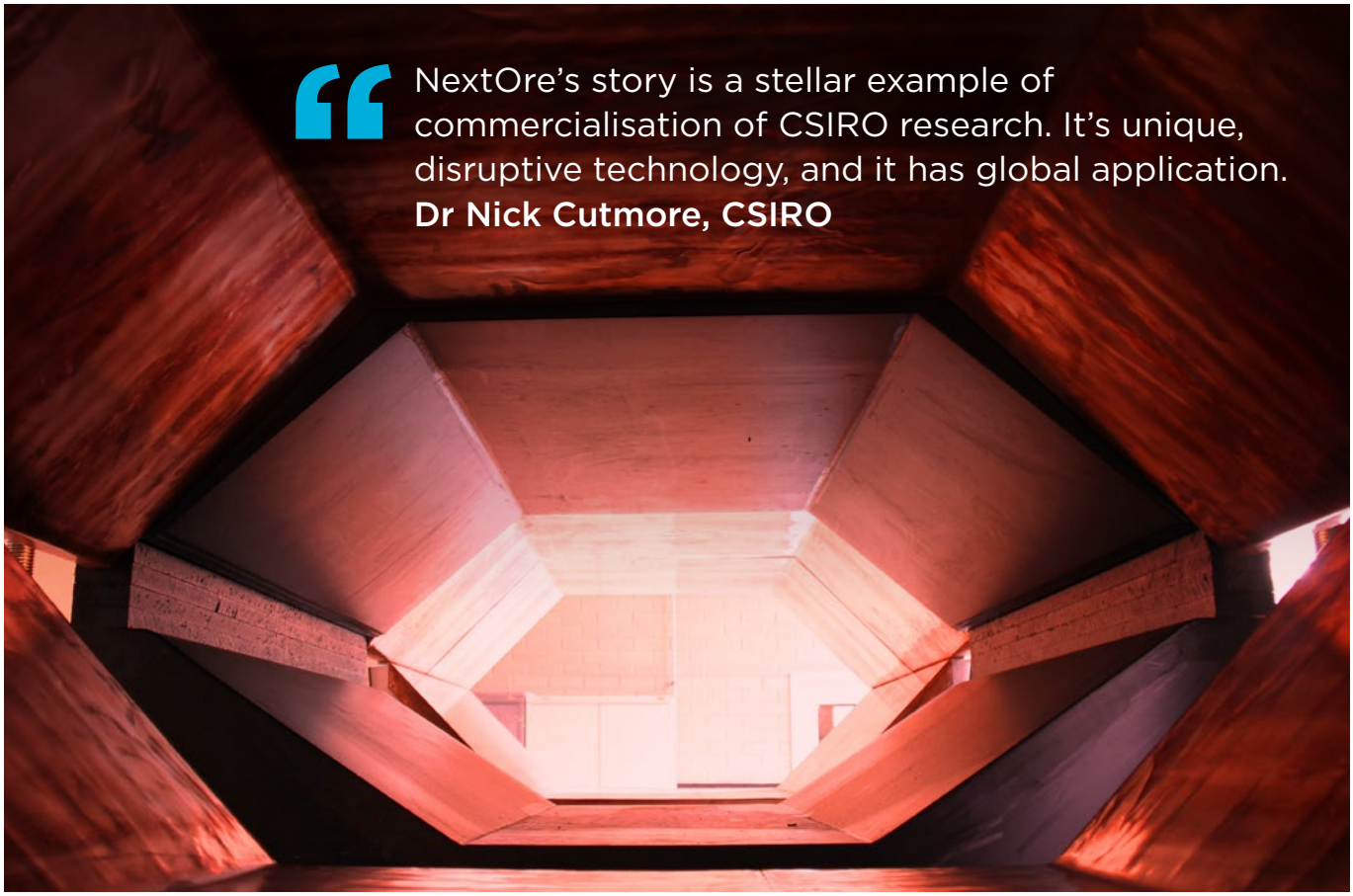
Chrysos Corporation recently announced an intention to list on the ASX in the next few years. Dr Nick Cutmore, who chairs the advisory board of Chrysos. "In the past nine months, Chrysos has significantly grown their installations around the world."

For Dr Tickner, the path to Chrysos also tells the story of his own scientific journey. "I joined CSIRO from a very academic background in high-energy particle physics – I was absolutely a lab nerd," he says. "Over the years, my role inside CSIRO evolved. I was leading teams and increasingly focused on external projects – I've always been very interested in talking to industry and understanding how our technology could solve real-world problems."

In June 2021, Chrysos announced that it had completed analysing 1 million samples using its PhotonAssay technology.

Says Dr Tickner: "I love the intersection between science, engineering and practical application – that's what motivates me."

Chrysos PhotonAssay delivers fast and accurate gold analysis
Image credit: Chrysos



Inside NextOre's magnetic resonance analyser

NEXTORE

The idea behind the technology that drives NextOre was born inside CSIRO's Mineral Resources business unit and is based on around 15 years of research on developing an analysing technique using magnetic resonance technology (MRT).

The focus was to find a sustainable, fast and accurate way of 'bulk sorting' ore, rather than the conventional approach of digging it up, transporting all of it to a processing plant, and then grinding and crushing it in order to extract the valuable elements.

"Grinding and crushing ore consumes huge amounts of energy and water," says Dr Nick Cutmore, Commercial Advisor to Mineral Resources and a director of NextOre. "There are figures that suggest that the crushing and grinding of rock in mining operations is responsible for 3–4% of energy consumption globally, and up to 56% of the mining sector's energy use."

The problem has been accurately defining the greatest concentration of target minerals in a mined ore prior to the processing step.

"A resource is a bit like sultanas in a pudding – it's not uniform," says Dr Cutmore. "There's high-grade ore in one spot, low-grade in another, but the traditional mining process is to process it all."

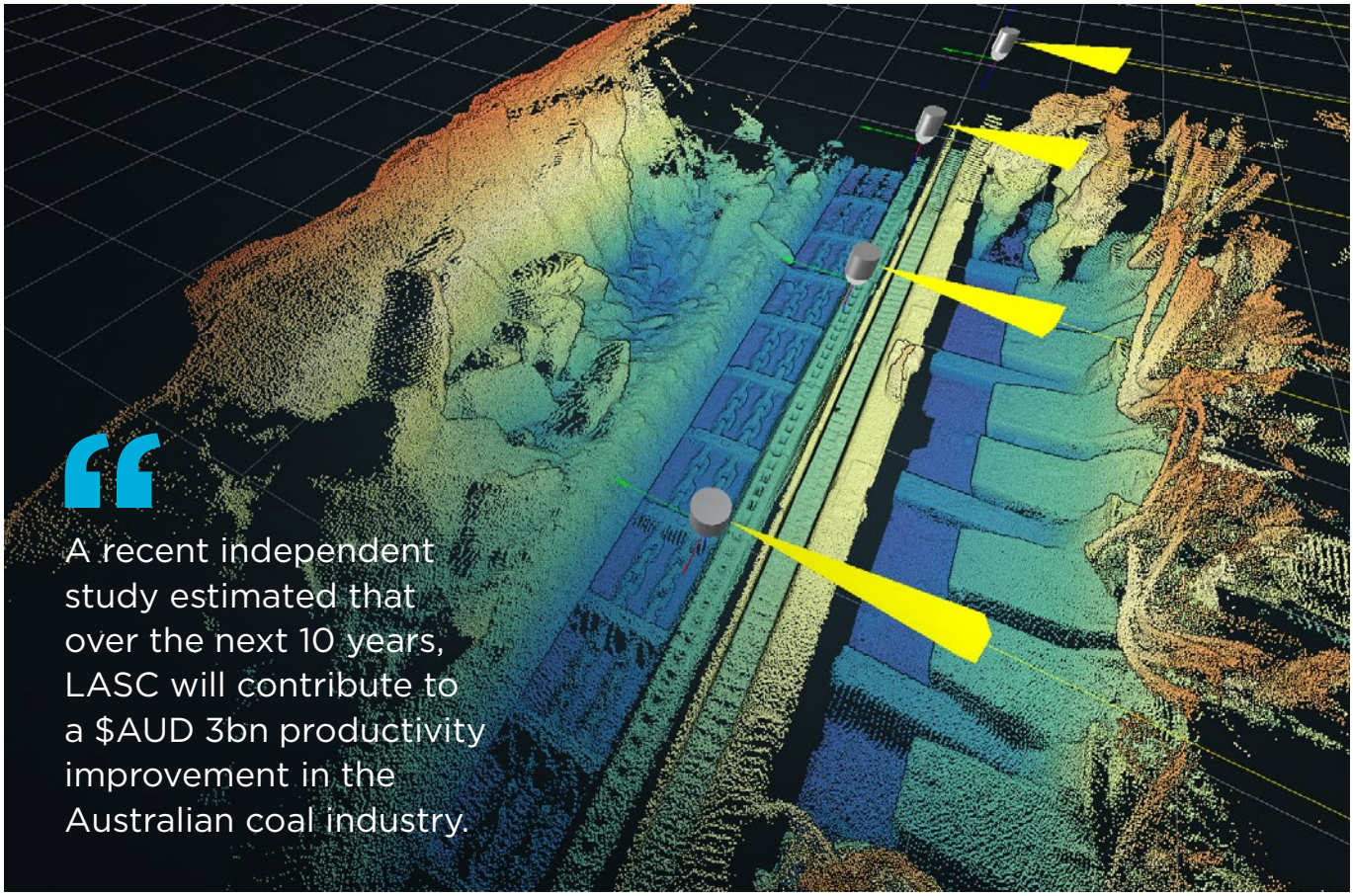
NextOre works "a bit like an MRI machine in hospitals, but without the magnets," says Dr Cutmore. "We send radio waves into the mined ore and excite the elements; the signals we get back allow us to accurately analyse how much of the valuable element is there."

This minimises the use of energy and water in the processing step, because the low grade ore can be discarded at the bulk stage and only the high-grade ore processed. "The NextOre process is a more sustainable approach and can positively impact the profitability of a mine by between 10 and 30 per cent," says Dr Cutmore.

The company was formed in 2017 with three partners: CSIRO, global engineering giant Worley, and RFC Ambrian, an investor advisory group (which is also a partner in Chrysos Corporation).

NextOre follows the JV partner pathway, and, like Chrysos, licenses rather than sells its IP to generate ongoing revenue. NextOre also plans to list on the stock exchange in the next two-three years.

With NextOre demonstrations and projects already underway in mines from Zambia to the Philippines, Dr Cutmore says NextOre's story is a stellar example of commercialisation of CSIRO research. "It's unique, disruptive technology, and it has global application."



The ExScan laser scanner can generate detailed maps of the underground environment with can assist in navigation along the longwall

LASC LONGWALL AUTOMATION AND EXSCAN

CSIRO's Mineral Resources business unit is constantly researching ways to develop technologies that improve workplace health and safety, as well as productivity. The longwall automation system known as LASC was developed by CSIRO in partnership with the Australian Coal Association Research Program.

Most underground coal mines involve longwall mining, where traditionally a mechanical shearer cuts along the coal seam beneath a roof, supported by hydraulic jacks. In that scenario, miners operating the machinery are exposed to multiple risks, and it's been a long-term industry goal to improve the safety of longwall mining.

The LASC system uses remote-guidance technology to steer the machinery, plotting its position in three dimensions and enabling workers to distance themselves from hazardous situations. The real-time progress of the longwall can be monitored from anywhere in the world.

LASC technology is used at most underground coal mines in Australia (older mines retrofitted their operations). Since being launched commercially in 2009, several mines in the US and dozens in China have licensed the system, as have the major international suppliers of coal-mining equipment, including Caterpillar, Joy Global and Eickhoff. A recent independent study estimated that over the next 10 years, LASC will contribute to a $AUD 3bn productivity improvement in the Australian coal industry.

Building upon the global success of LASC, CSIRO went on to develop ExScan, a laser-scanning system that provides real-time data for enhanced navigation in underground mines and 3D mapping capability.

Housed in an innovative and certified enclosure to make it safe to use in volatile underground environments, the ExScan system's powerful sensing platform allows it to be remotely deployed. The unit can be mounted in any orientation, even upside down.

ExScan's laser scanner and software generate real-time 3D maps of tunnels, walls and cavities deep underground, where GPS cannot penetrate. These maps can then be used for locating, steering and navigating mining machinery and vehicles.

ExScan is already in use in six Australian mines, and can be integrated with LASC information systems or used as a standalone sensing and scanning solution.

Glencore, one of the world's largest mining companies, successfully trialled ExScan to remotely monitor and manage the coal seam shearer and conveyor system at its Oaky Creek North Mine in Central Queensland. Glencore now has more than 60 ExScan units in use underground.

The innovative technology is attracting global interest and new commercialisation pathways are being explored.

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SENSING FOR STEP-CHANGE IMPACT

Cutting edge sensing and sorting technologies are delivering step-change improvements across a range of industries, and CSIRO is at the forefront of this exciting research. **RUTH DAWKINS** reports

In the mining industry, CSIRO researchers are developing Gamma Activation Analysis (GAA) methods to enable bulk ore sorting on gold mines; and in the security industry, work is taking place to adapt Magnetic Resonance (MR) techniques, originally developed for mineral detection, to identify security-sensitive substances such as explosives and narcotics.

Both these innovative applications of sensing technology demonstrate the significant real-world impacts that can be achieved – human, environmental and economic – when science moves beyond the lab.

Coarse gold ore sample in position for linac activation tests

USING SENSING TECHNOLOGY FOR EFFICIENCY IN GOLD MINING

Gold is one of Australia's most precious commodities, with annual production of more than $20 billion. But with ore grades declining, there's an appetite within the industry for a rapid analytical technology that can work at scale to improve productivity and reduce costs.

THAT TECHNOLOGY MAY BE GAMMA ACTIVATION ANALYSIS (GAA)

GAA uses high-energy x-rays to bombard ore samples and activate any gold contained within them. A detector then picks up the unique gamma-ray signature from the gold and determines its concentration.

The method was originally used for small-scale assay analysis in laboratories, and has been successfully commercialised by CSIRO spin-off company Chrysos, which was established in 2016 and has since marketed the technology as PhotonAssay.

Leveraging off this expertise, researchers now believe that GAA could also be an effective method for sorting bulk ore. In contrast to particle-based ore sorting, bulk sorting involves the measurement of conveyed material in real time, on site, and at much high quantities: up to 1000 tonne/hr.

According to Dr Peter Coghill, Group Leader for Magnetic Resonance at CSIRO, the technology offers the potential to capture significantly more value in the processing stage.

"Using GAA for bulk ore sorting – directly and rapidly measuring the concentration of gold at ppm levels as it's coming down the conveyer - represents a major breakthrough for gold processing. It could potentially remove 30–40% of unviable rock from being processed, which equates to a saving of $80–$110 in mill costs for every ounce of gold produced. You're cutting back on unnecessary time, money, water and energy use, which makes it a very appealing prospect."

The team working on the development of GAA for bulk ore sorting have completed a full-scale static bulk ore sample laboratory trial in China; a trial that was designed to validate the performance of the GAA measurement system, meet the performance hurdles for sorting, and reduce the risks for further investment.

Looking to the future, they are hopeful that CSIRO's ability to demonstrate proof of concept will attract strong partners who bring manufacturing capabilities and bulk ore sorting capabilities to the table. That combination will provide a clear path to market and a meaningful opportunity to support Australia's gold mining industry.

"One requirement for GAA sorting to be successfully deployed on a mine is that there must be low levels of uranium and thorium," says Dr Coghill. "Western Australia fits the bill from that perspective, and is one area we would certainly be keen to explore the potential for implementation and trial at a mining site."

USING MAGNETIC RESONANCE TO BOOST GLOBAL SECURITY

Magnetic Resonance (MR) technology is a form of spectroscopy in which radio waves are used to excite materials, and the resulting signals are analysed to detect or identify the composition of the material.

A similar technique will be familiar to many of us from our experiences in the medical sector, where MRI scans are commonly used to try and achieve the best clinical outcomes.

Over the last fifteen years, CSIRO has developed MR technology for use in the mining industry.

"It can't detect the magnetic resonance signature of every mineral," explains Dr David Miljak, Research Program Director for Sensing and Sorting at CSIRO. "But copper minerals are especially amenable to the technique, which allows bulk measurement through many metres of rock. When we worked that out back in 2005, it was a very exciting discovery."

> "We have discovered that we can use similar techniques to identify security sensitive substances, such as explosives and narcotics.
> **Dr David Miljak, CSIRO**

Hand-held magnetic resonance sensor for rapid high-explosive detection

Since that initial breakthrough, significant work has taken place to advance the technology within the mining sector: first by taking what was essentially a lab technique out into the field, then by trying to improve the accuracy of the measurements and by analysing ever larger volumes of material.

The MR mineral sensing technology is now commercialised through NextOre: a joint venture established in 2017 between CSIRO, leading advisory firm RFC Ambrian and global engineering company Worley.

More recently, researchers have been examining whether MR may have a role to play in other industries, such as security.

"We have discovered that we can use similar techniques to identify security sensitive substances, such as explosives and narcotics," says Dr Miljak.

"It's a great opportunity to build on the expertise that we have gained through applying the technology in the mining sector. One area we're focusing on is de-mining. Land mines are a huge issue in some parts of the world: they compromise the safety of communities and restrict travel across many areas. MR allows us to detect those mines deep below the surface."

Throughout its history, CSIRO has built a culture around the idea of impact: investing in research and using science to deliver real-world, tangible improvements to the economy, environment and people. In some cases, that means investigating models for the most efficient way to get technology out of the laboratory and into the hands of the people who can use it.

It also means that an application designed with one purpose in mind can sometimes be adapted for another: such as in the case of a technology that was developed for more efficient mineral extraction and is now being developed for saving lives.

"It's been a long path, but it's very rewarding to know there is going to be a value to this work beyond the environmental and financial," says Dr Miljak. "A humanitarian value. It's really nice to be associated with it."

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MAKING DECISIONS EASIER

Data-informed decision making is rapidly driving innovation in the resources industry and CSIRO is at the forefront with several projects in the commercialisation pipeline. **IAIN COPP** writes

Project concepts are often born out of a need to solve longstanding problems in exploration, metallurgy or mine planning. Increasingly, however, they are now addressing issues that come with the advent of big data and envisaging the next generation of products that can add value to these datasets. And of course, industry partners are essential for the subsequent development and testing stages before commercialisation is plausible.

Here are four recent CSIRO innovations – from concept to their current commercialisation stage.

GEOPHYSICS PROCESSING TOOLKIT

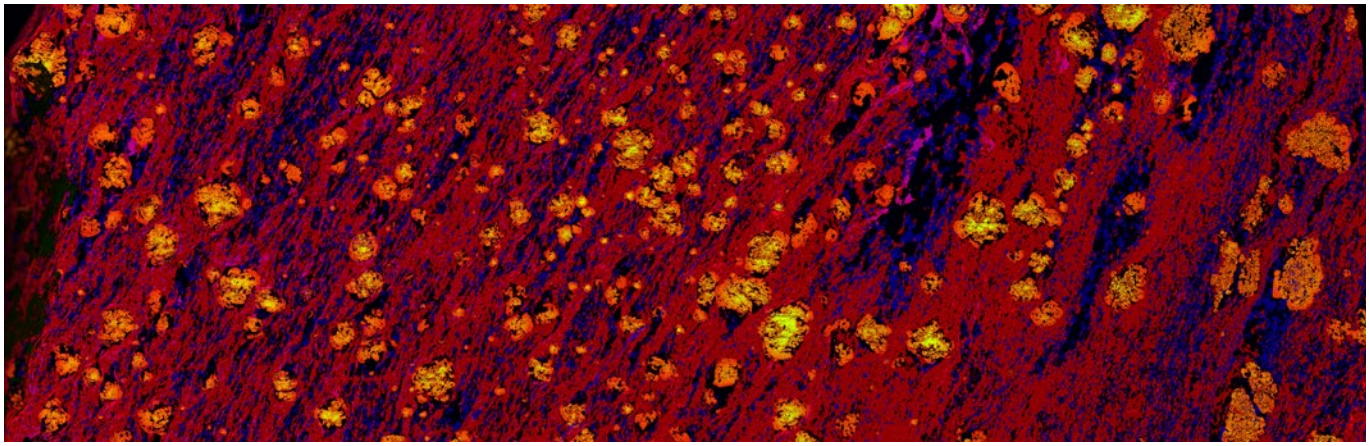
The Geophysics Processing Toolkit (GPT) is a Cloud-based and Web-serviced program that provides interactive visualisations of large datasets, together with suites of tools that assist inspection, processing and modelling of geophysical survey data.

Currently GPT is in the concept and technology evaluation stage and will initially be designed for electromagnetic (EM) data, which are large in volume, dense in time and space, and have many dimensions. EM surveys are widely used in mineral exploration, groundwater resource detection, soil mapping and geotechnical hazard assessment.

Research Director Dr Sandra Occhipinti remarks that CSIRO has a long history of involvement with EM, including the development of the Tempest system, SiroTEM, LandTEM and SQUID sensors for EM applications.

“Our team has strong EM expertise and several processing and inversion codes developed over the last 30 years,” says Dr Occhipinti.

“GPT will provide a streamlined workflow for geoscientists to follow and to more easily load, visualise, process, invert and export the data. Commercial geophysical processing software is quite limited for EM data, so we are building a Web-based, Cloud-processing solution that is much more accessible.”



Maia Mapper dataset of a garnet schist from Cannington Ag-Pb-Zn mine, Queensland (Fe in red, Mn in yellow, K in blue)

A typical EM survey contains hundreds of thousands of individual data locations, with millions of measurements. Before this data can be inverted for conductivity–depth information, it must undergo a laborious QA/QC process to remove the noisy and inferior data. GPT is envisioned to greatly accelerate this process.

The time is also ripe for GPT's development – the entire Australian continent will soon be covered by airborne EM data through an acquisition program by Geoscience Australia and State and Territory geological surveys. It will be the largest EM survey in the world.

Initially a platform for EM data, GPT will also incorporate existing tools developed by CSIRO's Deep Earth Imaging Future Science Platform.

"We envisage that within two years, GPT will have grown beyond an EM toolbox and will incorporate other geophysical techniques such as gravity and magnetics."

"Testing of the platform will be needed and so we are currently interested in talking to potential service providers," says Dr Occhipinti.

ROSETTA

Rosetta is a software platform designed for exploration and mining companies to help understand and predict orebody characteristics. It pulls together analytical data from a range of sources and provides predictions of ore quality for processing evaluation and mine planning.

Rosetta is in the early prototype and development stage, building on a proof-of-concept program that commenced in 2016 on the Olympic Dam deposit in a collaboration between CSIRO and BHP.

"During this next stage we plan to build a portfolio of case studies to further test and develop Rosetta. We want to be open with what we are doing and not have Rosetta seen as a 'black box' where data goes in and predictions come out," says Research Group Leader Dr Yulia Uvarova.

The Olympic Dam project was born out of a need to process and incorporate vast amounts of hyperspectral data created during exploration and mining. It was also at a time when machine learning and AI possibilities were being explored by the mining industry.

Dr Uvarova explains, "Partial mineralogy was being collected by hyperspectral scanning, but we wanted to see what value we could add to these datasets using data analytics and machine learning."

"Was it possible to predict properties such as lithology, chemistry and mineralogy that were being generated by traditional laboratory-based analyses?" asks Dr Uvarova.

Using a supervised machine-learning approach to predict the properties was a perfect test case and proved to be very successful. However, the uncertainties between predicted and actual values were high.

"Since then, machine learning has significantly progressed and so by refreshing the original code with a few improvements we have shown that the results are now actually much better," says Dr Uvarova.

"Rosetta technology has proved that it works as a robust predictive tool. We now need to use large datasets from different ore bodies to increase the confidence in the predictions made, and we are looking for companies to work with to help achieve this".

MAIA MAPPER

Aimed at research across the geological, biological, environmental sciences, as well as material science and medicine, the Maia Mapper is a high-throughput X-ray fluorescence (XRF) detector system that produces high-definition, quantitative elemental images with microscopic or nanoscopic detail in real-time.

The technology was first developed in 2014 for use on the synchrotron, but the need to analyse large samples drove development of the laboratory-based Maia Mapper. After several years in the proof-of-concept stage, the Maia Mapper has now progressed to the prototype and development stage.

"Although other techniques, such as laser ablation systems may have similar or even better detection limits, the Maia Mapper's real strength is its combination of good detection limits, fine resolution and its ability to analyse samples over a large spatial extent, for example in drillcore up to 50 cm in length," says Research Group Leader Dr Mark Pearce.

"It fills a well-needed gap between the much broader sampling of drillcore that mining and exploration companies carry out, and the very detailed microanalysis of small samples that researchers carry out using lasers and microprobes."

The Maia Mapper fits neatly within CSIRO's drillcore laboratory facility, which includes the Minalyze XRF line scanner and the HyLogger spectral scanner.

"We are able to scan many hundreds of meters of drillcore, and then use that data to move down a scale and determine which 50 cm samples are representative of the drilled intervals and analyse them using the Maia Mapper. Once we've done that, we can move down a further scale and cut thin sections and carry out micro-analyses," says Dr Pearce.

Mel Linton, Simon Bolster and Wayne Robertson

Since early development, Maia Mapper has increasingly been used in CSIRO projects and is now also being incorporated into research projects for mining companies.

"We've recently been involved in projects looking at the geometallurgy of gold, that is, where the gold sits in the samples, if it's hosted within sulphides or if its free gold that's going to be easily extracted. This kind of data is extremely useful at a very early stage of exploration by helping determine how the gold will be extracted during later mining and processing".

DETECTORE™

detectORE™ is one of CSIRO's most recent success stories of technology commercialisation for the minerals industry. It was developed primarily to help gold explorers find deposits, faster.

The detectORE™ system comprises sample preparation, sample processing and use of a portable X-ray fluorescence device to obtain low-level gold results in the field. Commercial partner Portable PPB Pty Ltd won the technology license contract in 2019 to use and further develop detectORE™.

CSIRO Principal Research Scientist Mel Linton invented the detectORE™ technology and went on to become Portable PPB's Chief Technical Officer after leaving CSIRO in 2018. Portable PPB now employs up to 19 people at various times and is working towards full commercialisation by the end of 2021.

The ability to analyse gold in the field has great advantages for exploration companies, particularly cost and time savings.

"detectORE™ is changing the way that traditional drilling campaigns are carried out, allowing companies to adapt on-the-fly and modify exploration plans and activities while still in the field. Cost savings are also substantial as the number of traditional laboratory-based analyses required is significantly reduced," says CSIRO's Business Development and Global Manager Wayne Robertson.

> detectORE™ is changing the way that traditional drilling campaigns are carried out, allowing companies to adapt on-the-fly and modify exploration plans and activities while still in the field.
> **Wayne Robertson, CSIRO**

Results to date are extremely encouraging. Managing Director of Portable PPB Simon Bolster has been working with several companies in the Kalgoorlie region.

"We tested detectORE™ over a large area of interest and confirmed anomalies identified by traditional sampling and drilling. We also found an additional area that fell between drillholes that they weren't aware of. By reducing the sample grid, detectORE™ then identified a very coherent gold anomaly, which was later confirmed by laboratory assays that came back after nine weeks," says Bolster.

Being able to analyse soils and drill chips for gold in the field can lead to the identification of deposits faster and at lower cost. detectORE™ has a quick assay turnaround of just eight hours, compared with potentially weeks from a laboratory, and most significantly can identify gold down to less than 20 parts per billion (ppb).

Being able to rapidly identify areas with higher gold levels compared with low background levels without sending samples to the laboratory, means that real-time decisions for soil sampling and drilling campaigns can be made during the field exploration campaign.

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ENVIRONMENTAL SOCIAL GOVERNANCE

COMMERCIALISING INNOVATION: THE KEY TO MEET ESG EXPECTATIONS

There's growing pressure on organisations across industry sectors and around the world to meet environmental, social, and governance (ESG) expectations set by investors, governments and communities. **FRAN MOLLOY** explores

In the highly-competitive resources industry, CSIRO innovations have helped fast-track ESG outcomes for a number of organisations through ongoing commercial partnerships to develop innovative technology that can deliver high-value outcomes and positive ESG contributions.

Three examples of successful CSIRO research that delivers both commercial and ESG outcomes include the VESI™ groundwater monitoring system; the revolution in steelmaking and cement from the dry slag granulation process; and a remarkable water treatment process that combines forward-osmosis and reverse osmosis.

> The next stage is new field trials with companies keen to explore the efficacy of the VESI™ monitoring system for their surface water, closed mine and mine tailings treatment.
> **Daniella Caruso, CSIRO**

GROUND ZERO FOR WATER MONITORING

Monitoring and managing mine-site groundwater is a critical part of safe, efficient and legally compliant mine operations, and plays a crucial role in a mine's ongoing social licence to operate.

Traditionally, groundwater has been monitored via a lengthy, complex and labour-intensive process where surrounding groundwater samples are manually collected and tested, leading to a time-lag between the detection and remediation of any leaks.

CSIRO's VESI™ system is a world-first automated groundwater monitoring and reporting system which can rapidly and continuously survey the state of mine groundwater and its surrounds remotely, and operates for extended periods with little maintenance, even in harsh conditions.

Commercial Manager Mick Wade and Project Lead Daniella Caruso are part of the VESI™ team who are in the process of turning years of research into a commercially viable outcome.

Dry slag granulation plant built by the Beijing Research Institute of Metallurgical Equipment (MCCE) for the industrial demonstration

COMMERCIAL OPTIONS

"CSIRO is a research and development organisation, so we don't manufacture or distribute products, or compete with companies that make high-volume products and provide services for a market," Wade says.

Wade says that CSIRO projects typically take a product from idea to proof of concept, and will look for commercial partners when it reaches an appropriate technology-readiness level.

"CSIRO's goal is to create impact; whether that's generating revenue to support future research or delivering a public good like improved safety or better environmental outcomes," he says.

"The range of CSIRO commercialisation pathways includes licensing new technology to generate ongoing revenue, or generating value via equity in a new company," he says. "We look at what's the most appropriate pathway for each project,".

CSIRO is currently exploring a range of commercial options and partners including deployments in industries outside the mining domain. Systematic and reliable water monitoring provides many exciting opportunities that we are keen to explore with potential partners.

THE ROAD TO PATENT

Project Lead Daniella Caruso says that in 2008, CSIRO Senior Principal Research Scientist Dr Miao Chen came up with the concept of immersible solid-state electrochemical sensors for on-going monitoring of chemicals in liquids, when Chen was researching mineral ore processing.

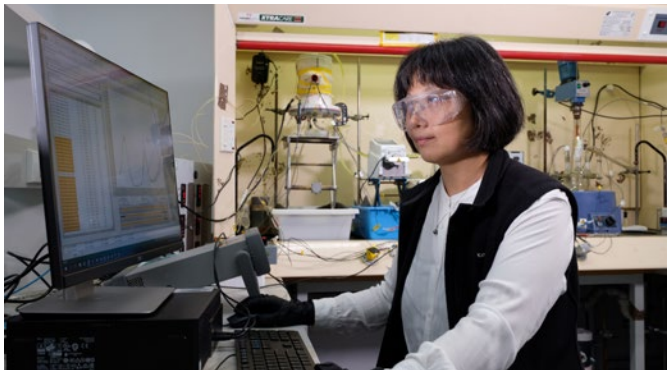
This led to the VESI™ team's development of a robust solid-state reference electrode, now expanded with sensors to measure temperature, pH, oxidation reduction potential (ORP) and conductivity.

The VESI™ team took the product through the CSIRO ON program. Here, discussions with industry progressed the technology for use in groundwater monitoring of in-situ recovery (ISR) operations, where mining fluids escaping the site could cause mineral loss and environmental harm.

The patented VESI™ solid-state probe is permanently immersed into groundwater wells at the site perimeter to wirelessly transmit continuous data, quickly identifying any change, in real-time.

In 2018, VESI™ (then named SENSEI) began an on-site trial at Heathgate Resources' South Australian mining operation in a collaboration between National Energy Resources Australia (NERA), Heathgate Resources, Boss Resources and CSIRO.

"The next stage is new field trials with companies keen to explore the efficacy of the VESI™ monitoring system for their surface water, closed mine and mine tailings treatment," she says.



CSIRO's Dr Miao Chen co-invented the solid-state electrochemical sensor technology (Vesi™) for in-situ monitoring of aqueous chemistry

FORWARD OSMOSIS – REVERSE OSMOSIS WATER TREATMENT TECHNOLOGY

Senior CSIRO Researcher Dr Ramesh Thiruvenkatachari, from CSIRO's Centre for Advanced Technologies in Pullenvale, Queensland, heads a CSIRO project currently trialling an innovative process that was developed to recover fresh water from mine wastewater.

But this forward-reverse osmosis technology has very broad potential beyond the mining sector. For example, a trial is currently underway in an industrial water treatment plant processing abattoir wastewater.

Thiruvenkatachari says the forward-reverse osmosis water treatment unit will reduce the quantity of wastewater that the plant must treat and also recover reusable water at source.

Traditionally, reverse osmosis water treatment uses hydraulic pressure to force impure water through a partly-permeable membrane that traps the concentrates – whether that's salt, mining ore, or other impurities – leaving fresh water to pass through.

But membranes separating concentrates from fresh water often become blocked and must be repaired or replaced.

His team's novel process reduces membrane maintenance by combining the reverse osmosis process with forward osmosis – where fresh water moves naturally to a body of water in what Thiruvenkatachari calls "the natural physical desire of water to flow and equalise the highest concentrated solution."

"In some of our trials we have been able to completely eliminate the need for pre-treatment by combining forward and reverse osmosis," he says.

The innovation is in the know-how and applies the team's engineering knowledge of the integration of a forward and reverse osmosis system, to commercially available membranes.

Thiruvenkatachari says that participation in the CSIRO ON program enabled the team to work with different industry representatives to discover some of their major challenges.

"Our solution helps industry safely meet the discharge requirements of wastewater, and also facilitates more efficient recovery of usable water for various other beneficial purposes within the industry operation and in the wider environment."

After establishing the process in several mine wastewater applications, the team was approached to investigate its use outside mining, for other industrial applications.

"The process we have developed can be applied in a number of different ways to recover water from industrial processes, and there is growing understanding that water is a very valuable resource, especially in remote inland locations," says Thiruvenkatachari.

CSIRO Business Development Manager Stephen O'Dowd says that CSIRO is currently exploring partnership options and welcomes enquiries from industry with potential applications for the FORO technology.

DRY SLAG GRANULATION

Steelmaking worldwide produces over 300 million tonnes of iron blast furnace slag every year, dissipating incredible amounts of heat in the environment. CSIRO's innovative Dry Slag Granulation (DSG) technology has the potential to combine these heat and slag waste streams into valuable resources.

DSG turns the waste slag from blast furnaces into a high-value additive for cement production, while recovering heat energy and making enormous reductions in water use and greenhouse emissions.

"Traditionally, this waste is crushed and used as base aggregate in road and civil construction, but DSG has potential to convert the slag into a sustainable substitute material for a key component of cement, whose production emits eight per cent of global CO_2," says Adrien Guiraud, Principal Research Consultant in CSIRO Mineral Resources Processing, who has led the CSIRO DSG project for several years.

The technology began development in 2002, and early support from the Australian steel industry helped kick off the project and bring the technology to further maturity. By 2013, the technology had been demonstrated at pilot-scale in CSIRO's high temperature laboratories in Melbourne and was ready to move to industrial demonstration.

Despite the Australian steel-making industry's support for the DSG technology, the move to industrial scale deployment wasn't feasible in Australia.

CSIRO canvassed likely international engineering collaborators and a landmark research and commercial deployment collaboration was agreed with Beijing Research Institute of Metallurgical Equipment (MCCE) in 2015.

The success of this partnership is underpinned by CSIRO's long-standing collaboration with China says Professor Gang Wei, Director of China Engagement for CSIRO Mineral Resources, who is managing the relationship with MCCE.

CSIRO Research Technicians David Macedo and Dylan Marley deploying Vesi™ sensor unit in the field

In early 2019, another milestone was achieved with the start-up of a 20 tonnes per hour semi-industrial demonstration plant in China, allowing CSIRO researchers and MCCE engineers to collect data, build know-how and optimise the process, with encouraging results.

CSIRO and MCCE have extended their partnership and plan to scale up the technology to full commercial capacity within the next three years.

"Our objective is to bring the DSG technology to the Chinese market by 2025, before expanding to the rest of the world," says Guiraud.

He says the project has great potential to reduce the environmental impacts of the steel industry and will allow CSIRO to move into non-ferrous and other slag producing industries which have already shown strong interest in DSG technology.

"Developing and commercialising a technology to significantly reduce the negative impact of steelmaking on the environment will be a major achievement for CSIRO, and an exceptional example of product stewardship for the Australian iron ore industry," says Guiraud.

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ADVANCED CONTROL IN PROCESSING

THE REVOLUTIONS WILL BE COMMERCIALISED: TAKING SWIRLFLOW® AND MORE TO THE WORLD

The Queensland Alumina Limited refinery in Gladstone has been integral to the SWIRLFLOW® commercialisation success story.
Image credit: Queensland Alumina Limited

Of all the items on Mick Wade's wish list in his job at CSIRO, he says there is one that would, on its own, virtually ensure a win for the organisation and its clients in mineral processing.

It can be captured in two words: "industry standard". That is Mr Wade's commercial aspiration for SWIRLFLOW®, a piece of CSIRO technology already used in mineral processing across three continents and counting. He believes that soon, those in mineral processing who don't have it will wish they did.

AGITATING FOR COMMERCIAL SUCCESS

Mr Wade, who is based in Melbourne, swears by the technology. SWIRLFLOW® replaces traditional agitators inside mineral refineries' large mixing tanks with a short shaft system that generates a tornado-like vortex flow.

Its novel impeller design addresses a scourge of mineral processing: agitators getting bogged in settled solids.

It is a problem that routinely leads to shutdowns, expensive clean-ups and dangerous repairs.

Mr Wade is a Business Development Manager with CSIRO Mineral Resources. He focuses on corporate realignments called "spinouts", start-up companies and licencing CSIRO's mineral processing technologies.

Large scale SWIRLFLOW® deployment has started with licensing to the worldwide alumina industry. SWIRLFLOW® has been shown to ramp up efficiency and decrease refineries' eye-wateringly costly downtime. The industry can now upgrade mixing tanks using CSIRO's laboratory-developed mixing technology.

"One of our goals is to increase that part of the business because it generates more sustainable revenue through licensing," says Wade.

"But our bigger goal for SWIRLFLOW®is for it to become the desired industry standard for alumina refineries and beyond. That in a nutshell would be it, because all those other benefits such as saving energy, reducing refineries' costs, generating money for CSIRO; all those things will flow on from that."

HELPING CLIENTS FIND THEIR FLOW

Dr Jie Wu, CSIRO Mineral Resources Technical Director Fluids Engineering, estimates that there are about 80 alumina refineries worldwide each with many mixing tanks. CSIRO has now installed SWIRLFLOW® in about 30 tanks and momentum is building as the industry has praised the technology and its commercialisation.

Dr Wu cites the estimated five-to-ten million dollars a year saved in capital and production costs by Queensland Aluminium Limited (QAL) over a decade as an example of the impact delivered.

"[SWIRLFLOW®] has delivered improved yield through higher operating factor and reduced scale growth, improved

resuspension ability, reduced maintenance cost and lower risks to maintenance personnel," QAL has reported.

"Damaged draft tubes in cone bottom tanks are being routinely replaced with SWIRLFLOW® agitation. The agitation upgrade is less expensive, requires a shorter outage and delivers ongoing process benefits."

Similarly, a joint paper by CSIRO, QAL, LKAB Minerals, Energy Resources of Australia and Rio Tinto notes that, "SWIRLFLOW® technology has attracted attention from processors of other minerals and is now being rolled out across applications including those in the magnetite, uranium and gold industries, on top of growing alumina sites worldwide".

With the scope of SWIRLFLOW®'s commercialisation about to expand outside Australia, Mr Wade and Dr Wu are keen to explore other use cases.

IT'S PRONOUNCED LIKE "MIA"

MEA stands for Mineral and Elemental Analyser. It's a CSIRO tool that Sydney-based research scientist Dr Yves Van Haarlem believes is 99.9 per cent ready for commercialisation using patented CSIRO X-ray diffraction and X-ray fluorescence analysers mounted to an 80-litre slurry delivery tank, the MEA is a real-time analysis system for process stream slurries.

In mineral processing, stream minerology, chemistry and particle size have a critical impact on operations. Being able to monitor these properties at key points in the processing chain enables optimisation of mineral processing based on stream composition and maintaining high plant efficiency.

MEA perfectly meets the requirements for process control. MEA can quantify the grade of commonly mined elements such as copper, nickel down to low levels.

In addition, MEA can also measure a range of mineral phases, such as talc or other problematic gangue minerals and report on average particle size using a newly developed method using X-rays.

CSIRO's new analyser sits within a 'toolkit' of online mineralogical tools for advanced process control developed by CSIRO. Each was developed, says Van Haarlem, in line with the commercial needs of prospective clients. It is a balance that a CSIRO research scientist is frequently called upon to strike.

"What these technologies have in common is that they're all online and can enable real-time process monitoring and control, so they're not as accurate as working in the lab but they are fast and relatively inexpensive," says Dr Van Haarlem.

"To commercialise the technologies, we bring them together in a common platform, up to a point of an advanced prototype, but as simply as possible so that it can be easily adapted for the market by commercial partners to fit their standards and needs."

As with much of the CSIRO technology that has preceded it, the story of the CSIRO MEA's commercialisation success will come down to its ability to meet market needs.

CSIRO is looking to both trial and commercialise MEA and other process monitoring systems with interested partners.

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CSIRO INNOVATION CONNECTIONS

DRILLING DOWN TO THE RIGHT DECISION

Our work with Ardea Resources uncovered evidence to support deeper drilling efforts at their Goongarrie project in the Eastern Goldfields of Western Australia.

CSIRO research scientist Dr Walid Salama and Dr Matt Painter, Ardea Resources

Ardea Resources (Ardea) is an ASX-listed resources company with an exclusive focus on West Australian projects. Aided by funding from an Innovation Connection grant, CSIRO worked with Ardea to understand gold and critical mineral behaviour in their Goongarrie nickel laterite deposit, located 70 kilometres north of Kalgoorlie.

***Dr Matt Painter** is an experienced exploration geologist and General Manager, Exploration of Gold at Ardea Resources Ltd.*

At Ardea we value science and innovation in exploration. Through general discussion with CSIRO at the RIU Explorers Conference in Perth, we explored how CSIRO could add value through an R&D project at our nickel laterite deposit at Goongarrie.

Our Goongarrie tenement is the largest nickel laterite deposit in the world. In historical drilling samples we found evidence of gold in the laterite profile; an unusual phenomena which we wanted to understand the significance of.

With the assistance an Innovation Connections grant we were able to access CSIRO's mineral discovery expertise and were matched with Dr Walid Salama and his team.

Walid's scientific knowledge and experience in understanding weathered terrain combined with his impressive lateral thinking brought new perspectives which have exceeded our expectations.

The studied region showed deep V-shaped laterite mineralisation with associated gold. Walid came up with novel ideas to see through the weathering profile to indicate the primary structure.

These findings have helped us make the decisions for deeper drilling programs but have now led to a further project with CSIRO.

For Ardea, the work is already providing significant competitive advantages that will take our project studies and exploration efforts in new directions for nickel sulphide and gold exploration.

Based on our experience, working with CSIRO provides a great pathway to unlock exploration value in mineral exploration.

***Dr Walid Salama** is a Senior Researcher and Team Leader at CSIRO, with expertise in mineral exploration in weathered and covered terrains.*

Our Innovation Connection facilitators paired up my expertise with Ardea's interest in understanding anomalous features of their nickel laterite deposit at Goongarrie.

In an exceptional finding, gold was found associated with nickel laterite. This has never been described before and presented a fascinating geological puzzle.

Using a variety of microscopy, mass spectrometry and x-ray diffraction techniques, we examined high grade sections of historic drilling samples taken for the site.

We found secondary gold within the samples indicating the gold had been transported from elsewhere into the nickel laterite. We also found indicator minerals and elements for gold and nickel sulphides which suggests the likelihood of gold mineralisation beneath the nickel laterite cap.

These findings were able to help Ardea understand the mobility and behaviour of gold and other metals within their nickel laterite deposit and reveal new drilling targets to further develop their project.

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> Working with CSIRO provides a great pathway to unlock exploration value in mineral exploration.
> **Dr Matt Painter, Ardea Resources**

Would you like CSIRO to be your R&D partner in business?

Sue Robson is a Facilitator in Western Australia for the Entrepreneurs Programme Innovation Connections, working within CSIRO's SME Connect. Sue develops partnerships with companies in WA, connecting them with specialised expertise and access to equipment available within publicly funded research organisations like CSIRO.

Sue can also help you navigate the various funding opportunities available to business to support access to CSIRO R&D, like the Innovations Connections programme used by Ardea. Contact Sue Robson on +61 448 260 476 or sue.robson@csiro.au to explore the options available.

As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

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