CRITICAL METALS

TECHNOLOGY MEETS METAL PRODUCTION TO DISRUPT BATTERY AND OTHER KEY METAL INDUSTRIES
Process solutions for battery and other critical metals

Processing innovation is helping to reduce risks and attract new investment to battery metal projects to ensure competitive and sustained production.

CSIRO’s focus

- Alternative process development
- Characterisation for process development
- Pilot-scale demonstration
- Impurity management
- Geometallurgy for technical marketing of steel-making materials

INSIDE THIS ISSUE

2-3  GRAPHITE
   GRAPHITE GOES GREEN

4-5  FEATURE
   THE BATTERY CHARGE

6  RESEARCH PERSPECTIVE
   A BUBBLE OR THE NEXT BIG THING?

7  VANADIUM
   CAPTURING THE BEST OF THREE

8-9  INDUSTRY PERSPECTIVE
   CREATING VALUE FOR AUSTRALIA

10-11 SENSORS AND DATA
      SMART OPERATOR

12-13 IRON ORE
      SECURING A KEY AUSTRALIAN EXPORT

14-15 FUTURE VISION
      THE NEW MINE MODEL

16-17 GOLD
      A GREEN AND GOLD FIRST

18  LITHIUM
    POWER TO RECYCLING

IF YOU WOULD LIKE TO SUBSCRIBE TO RESOURCEFUL PLEASE VISIT THE WEBSITE:
CSIRO.AU/RESOURCEFUL

RESOURCEFUL is produced by CSIRO Mineral Resources. Views expressed do not necessarily reflect those of CSIRO Mineral Resources management.

MANAGING EDITOR editor.resourceful@csiro.au
DESIGN brand@csiro.com.au
© 2018 CSIRO Mineral Resources csiro.au
All rights reserved. No part of this document may be reproduced, stored in a retrieval system, photocopied or otherwise dealt with without the prior written permission of CSIRO Mineral Resources.

IMAGE CREDITS: Cover: © iStock, pages 2, 4, 10, 13, 14.
LEADER’S COMMENT

FORCES FOR DISRUPTION

Advances in new technology are driving forces for change in mining, and the impact is two-fold: changing the way we mine, while propelling significant shifts in the metal market.

JONATHAN LAW writes

Disruption is happening all around us. New sensors and digital technologies, advances in renewable energy, artificial intelligence and automation are all changing the face of mining, while simultaneously shifting demand in the metal commodity market it serves. And, the landscape is changing fast.

Growing populations (driving volume growth) and changing technology (driving metal usage patterns) are both important forces for change. These pressures are also playing out in an increasingly demanding social, ethical and environmental context.

But, there is also significant inertia in the system – resisting change are well established mining and processing operations that are tied to major investments built on stable and traditional technologies.

Combining shifts in technology, new market opportunities and inbuilt industry inertia provides a perfect opportunity for disruption by those willing and able to challenge the status quo.

In this edition of resourceful, we focus on the impact of technology shifts on metal demand and how processing innovations are transforming resources into valuable materials and products to give producers – and Australia – a competitive edge.

Smaller volume metals like vanadium, lithium and rare earths, together with other mined products like graphite and silica for the battery and electronics industries, are predicted to grow as high as 50 per cent annually by the mid to late 2020s. There are currently two lithium hydroxide plants being built in Western Australia to produce a range of value-added products for use by battery makers. High tech metal applications often have strict specifications linked to their performance, and while meeting these criteria is challenging, it adds significant value to the bulk raw materials.

Even traditional bulk commodities are experiencing significant market shifts in response to changing metal use. Copper is in higher demand for electric cars, consumer products, and renewable energy infrastructure is growing rapidly. Similarly, refined nickel products required by the battery industry are driving value-added product development. BHP’s Nickel West recently announced the successful demonstration of their nickel sulphate process with CSIRO in Perth and is enjoying such strong demand from battery makers for nickel sulphate that it is likely to overtake demand from stainless steel-makers who have been the traditional market for Australian nickel.

Here at CSIRO, we take an integrated value chain approach to ensure Australia is at the forefront of technology trends. We’re helping to keep Australian resources competitive in global markets, in order to leverage our nation’s outstanding resource endowment to deliver long term commercial opportunities.

Security of metal supply is also critical. Australia is well regarded as a reliable provider of strategic metals with great opportunity to grow the range of commodities and market share. In the relatively small volume, high value tech metal markets, green and ethical credentials and a stable supply can out-perform price – with manufacturers looking to their product bands and supply security.

We’re working with a range of different producers on solutions to unlock and add value to a range of key commodities. For example, with TNG – a local strategic metals developer – we improved their vanadium process at pilot scale to help develop a new mine project. We also worked with Kibaran Resources on a faster, more environmentally-friendly approach to graphite purification that could be deployed in deposits around the world.

These are practical examples of why Australian resources can, and should be, a cornerstone of Australian innovation opportunities in a rapidly changing world.

JONATHAN LAW
Director, CSIRO Mineral Resources
+61 3 9545 8316
jonathan.law@csiro.au
Market demand for greener commodities has propelled an Australian miner to work with CSIRO on a more environmentally-friendly way to produce battery-grade graphite. The result is a more cost-effective, efficient and environmentally-friendly graphite production process. 

LOUISE POBJOY reports:

As demand soars for lithium-ion batteries to power new technology, including electrical vehicles, smart phones and laptops, so does demand for battery-grade minerals, like graphite, to make them. However, the environmental and financial costs associated with current methods of purifying graphite are high.

Graphite is a key component of a range of everyday things from batteries, brakes and refractory bricks, to lubricants, fire retardants, inks and electronics. It is used extensively across the steel, automotive, aircraft, electronics, energy and nuclear industries.

Almost 800,000 tonnes of tiny graphite crystalline flakes, ranging from one to 300 microns, are sold annually. It’s expected that global demand for battery-grade graphite will increase by 300 to 400 per cent by 2020. The automotive industry in particular will contribute significantly to this surge in demand with the rapid move toward electrical vehicles across Europe and Asia.

This means that Australian exploration company, Kibaran Resources, will not only have to find better ways to locate and access more graphite, but also better ways to process it.

“As the market develops for electrical vehicles and energy storage, the awareness of ethical and environmentally-friendly raw materials is becoming more prominent. People want a more environmentally-friendly source,” Kibaran managing director, Andrew Spinks, says.

Kibaran, a company that is focussed on the mineral-rich landscapes of Tanzania in east Africa, wanted to create a more cost-effective, “greener” battery-grade graphite to meet the needs of the growing European market.

“We started working with CSIRO initially to understand the graphite occurrence with respect to the mineralogy and metamorphism. We looked at how we could recover the graphite more efficiently,” Mr Spinks says.

The company then engaged CSIRO and GR Engineering Services to create a better shaping and purification process for this vital mineral.

Processing battery-grade graphite involves two-stages: mechanically shaping natural graphite into small balls – “spheronising” it – then purifying it.
As the market develops for electrical vehicles and energy storage, the awareness of ethical and environmentally-friendly raw materials is becoming more prominent. People want a more environmentally-friendly source.”

Kibaran Resources managing director, Andrew Spinks

Although there are alternate ways of processing graphite, they are not currently competitive. And, with each battery manufacturer having slightly different specifications for graphite, CSIRO and Kibaran had a lot of work to do to optimise the purification process and meet the various specifications.

The biggest challenge for producing battery-grade graphite is the purification process. It’s particularly difficult to remove the resistant minerals. Silica, for example, has several forms and each form must be identified before it can be removed from graphite.

“We were able to use our knowledge that we’ve built up over decades in, for example, alumina processing to understand how the silica species were going to behave while we tried to treat the graphite,” Dr Vernon says.

“It’s that kind of deep know-how around mineral chemistry, phase equilibria and solution reactions that was brought to bear to make this a success.”

Despite CSIRO’s world-class capability and know-how in minerals identification and chemistry, it wasn’t always easy to find the right solution.

“Even with in-depth knowledge of the major impurity minerals, there’s still a considerable amount of experimentation before arriving at the optimum solution,” Dr Vernon says.

“The real enemies are the very low levels of highly refractory, unreactive minerals that you’re trying to coax out of the graphite.

“Instead of hitting them with a big hammer [hydrofluoric acid], we are basically tickling them out with a feather.”

CSIRO scientists used various characterisation tools to identify minerals and understand the different reaction chemistries possible. They then manipulated the chemistry with dilute solutions at modest process temperatures.

“What we delivered for Kibaran was a greener process that’s relatively cheap to operate, and that uses minimal quantities of plentiful and low-impact reagents,” Dr Vernon says.

“We achieved greater than 99.95 per cent purity in the graphite – in a process time of only a few hours – by understanding how impurity minerals are going to react.”

While this exciting new process was bespoke to Kibaran’s mineral chemistry needs, the general principles behind it can be readily adapted to suit other companies – particularly those facing similar issues around producing battery-grade materials.

“The battery industry is going to grow and grow,” Dr Vernon says.

“There’s a strong focus on lithium, that’s for sure. But, we also need all of the other chemicals that act like “vitamins” in the lithium batteries, such as high-purity nickel and cobalt.

“There are also other battery chemistries, requiring high-purity vanadium, manganese and other metals.

“There are quite a lot of approaches from industry at the moment on understanding how to purify their materials to those levels without spending a fortune to do it. A lot of the lessons we’ve learned out of the project with Kibaran are immediately transferable to those other industries.”

Currently, Kibaran is working with several new graphite sources and producers to meet market needs. It has also applied for patents for the new shaping and purification processes that the company recently tested in its new pilot plant in Germany.

“We are very much at the back end of finalising and finishing that pilot work, and we look forward to seeing the results, probably in the next month or two,” Mr Spinks says.

CHRIS VERNON
+61 8 9334 8043
chris.vernon@csiro.au
Battery metals may be shaping up as a major new Australian industry, as innovation aims to add value and gives local companies a competitive advantage on the global stage. TIM TREADGOLD reports.

It is an unusual but handy comparison to picture Australia’s fast-growing battery metals sector as a cooking exercise with the raw ingredients prepped, waiting for the chef to choose a recipe that will produce the best result.

In the case of battery metals, the ultimate result would be the production in Australia of long-life rechargeable batteries to power the world’s growing fleet of electric vehicles, as well as the rapidly-expanding range of devices, such as smartphones and tablets.

That may happen, but a more likely development is an increase in the level to which raw materials such as lithium, graphite, cobalt, vanadium and nickel are converted into semi-and fully-finished products that are sold at a much higher price than basic raw materials to the global battery production chain.

First steps in the upgrading of lithium, cobalt and nickel ore into more valuable forms have already been taken, and finding the best recipe is the focus of the proposed Future Battery Industry Cooperative Research Centre (CRC).

The CRC is strongly supported by industry and has been shortlisted for consideration in the 2019 round.

Bringing business, the research sector and government together is an important step in harnessing the potential of a business that is a natural extension of what Australia has been doing for some time, albeit without a formal plan to maximise the value of battery metals.

The need for a concerted effort around what could become a major new business for Australia as the world reduces its reliance on fossil fuels, is explained by the sudden acceleration of interest in batteries.

In many cases, batteries will get their initial charge of electricity from renewable sources, such as wind and solar farms.

Mark Woffenden, chief executive of the Mineral Research Institute of Western Australia, says that Australia has most of the raw materials needed to produce batteries and is ready to take the next step and find ways to add value rather the export unfinished or part-finished products.

“If we do that right, we should see battery metals processed locally, all the way to battery-grade material and perhaps even battery production and battery recycling.”

Most battery metals exported from Australia today are in a largely unprocessed, or part-processed state, which Mr Woffenden says is a lost opportunity to add value.

Demand for energy products using new energy materials has been forecast to grow 10-fold by the year 2030, as countries seek to reduce their carbon emissions.

AUSTRALIA HAS AN ABUNDANCE OF MINERALS THAT ARE NEEDED TO FUEL BATTERY AND OTHER GREEN ENERGY TECHNOLOGIES, INCLUDING LITHIUM, VANADIUM, NICKEL AND COBALT.
The opportunity is for Australia to participate in all stages of the value chain for these commodities to provide supply security, quality, reliability, affordability and sustainability.

In lithium, which is the cathode in a rechargeable battery, Australia exports a variety of material ranging from ore with less than two per cent lithium, to part-processed concentrate which grades around six per cent. There are two lithium hydroxide plants being built in Western Australia (WA) to produce a range of value-added products, which can grade up to 99 per cent lithium for use by battery makers.

Graphite, which can be used as the anode in a rechargeable battery, is produced in a number of places around Australia but not generally to battery grade.

That said, a number of Australian companies are moving up the value chain with plans to upgrade their graphite ore to a material (spherical graphite) custom made for battery makers.

Cobalt, another important battery metal is produced in Australia, though primarily as a by-product of nickel mining. The bulk of the world’s cobalt comes from the central African country of the Democratic Republic of Congo with battery makers keen to obtain more reliable supplies.

Nickel, which has been an Australian specialty since the late 1960s, is the metal undergoing the most significant change in the way it is sold. For example, BHP is enjoying such strong demand from battery makers for nickel sulphate that it is likely to overtake demand from stainless steel makers who have been the traditional market for Australian nickel.

In the past year there has been a rapid increase in demand from battery players in Asia for nickel sulphate.

When its plans to expand exposure to the battery metals sector were first outlined, BHP estimated that demand was sufficiently strong that within five years 90 per cent of sales from its Kwinana nickel refinery would be to the battery sector.

However, producing a specific product for battery makers is only part of the challenge. Maximising quality is equally, if not more, important because the battery production process requires material of the highest purity to achieve best electricity storage quality.

BHP has worked with the CSIRO to construct a mini-plant which replicates all aspects of the final nickel sulphate plant that is under construction at Kwinana, with the aim being to extract maximum value from the process.

Apart from getting a higher price by converting nickel mined at a number of projects in WA, the work at Kwinana will give BHP greater exposure to the battery metals business, something it already enjoys with its copper production.
A BUBBLE OR THE NEXT BIG THING?

The battery metals market is charging ahead. Director of CSIRO's mineral processing research, CHRIS VERNON, writes about the prospects of capturing a long-term opportunity and how Australian industry needs to secure its advantage through processing innovation.

The key difference is that interest in rare earths was created by an artificial shortage in a slow-growing market that could have been filled by a handful of new projects coming on stream. Whereas the current battery surge is being driven largely by an almost entirely new industry for lithium-ion batteries undergoing rapid growth.

Typical predictions are that the electric vehicle (EV) market will grow 10-fold by 2025 and at least 50-fold by 2030. EVs are of course not the only use of lithium, and the energy storage market demand is expected to well exceed what is required for EVs.

Current total world lithium production (on a carbonate basis) is approximately 500,000 tonnes per annum. By 2025, the EV market alone is predicted to consume 2.7 million tonnes per year, and potentially 15 million tonnes per year by 2030.

In context, the new lithium refining capacity planned in Australia over the next two to five years will only double world supply to about one million annual tonnes. Other lithium projects around the world may add another million or so tonnes.

It’s safe to say that lithium extraction and refining are anything but a bubble, and are set for a long period of growth to meet predicted demand.

Lithium ion batteries also contain other metals. Popular formulations include cobalt, nickel, graphite and manganese, and indeed, there are also lithium-free chemistries, as well as lithium chemistries that do not rely on these metals.

There are many new mining projects being established to produce the gamut of battery materials in demand. But, what differentiates a “battery mining project” from any other mining project?

Nothing, except for the technology to remove most of the last few thousand parts per million of impurities. The difficulties in achieving this economically shouldn’t be underestimated and it is crucial to project success. There are a range of technical challenges, often unique to a project, that need to be overcome in order to make them commercially viable and competitive.

Australian companies are, however, showing themselves to be innovative in this space and already we are seeing successes from companies such as BHP, Kibaran Resources, TNG and a host of others.

But, Australia isn’t alone in recognising the upcoming opportunity and there is plenty of competition. Embracing more efficient processing technology is one of the factors giving imaginative Australian producers the edge.

As a world-leading mining nation, Australia is fortunate to have the wealth of mineral resources, industry track record, and innovation know-how to capitalise on and capture growth in the expanding battery metals market.

The challenge now is for Australia to attract sufficient investment in battery metals projects – from mining through to processing and battery-grade product – and the required innovation to make them economically viable and competitive on the world stage.

Let’s hope that we can develop our industries fast enough, and with the edge that they need, to position Australia as a major supplier of battery metals.

CHRIS VERNON
+61 8 9334 8043
chris.vernon@csiro.au
Improvements to a new more energy-efficient vanadium process will enable an Australian resource company to market three products instead of one, while significantly reducing costs at a proposed new mining development.

LOUIS WHITE reports

Vanadium, a malleable transition metal predominantly used for steel alloys, is gaining traction for its potential use in the battery market. Australia is home to world-class vanadium deposits, and TNG, a local strategic metals developer, is gearing itself up to lead the charge globally.

Over the past few years, TNG has been developing its Mount Peake vanadium asset – a titanomagnetite deposit – in the Northern Territory, with the aim of turning it into a productive new mine with a 17-year lifespan.

Having developed a new, patented vanadium recovery process, TNG approached CSIRO to test the process at pilot scale and explore further improvements that could be made.

The TIVAN process promised to be less energy and capital-intensive than conventional processes for titanomagnetite deposits.

“The market price for vanadium is relatively volatile and the financial risks of a titanomagnetite deposit are higher when based solely on this commodity,” CSIRO hydrometallurgical expert, Ron Pleysier, says.

“Because titanomagnetite deposits are also rich in titanium and iron, we looked at ways to capture these additional minerals using the new TIVAN process, in a way that made economic sense.”

Working with TNG and Mineral Engineering Technical Services (METS), CSIRO developed an additional treatment stage to remove the bulk of the iron as a by-product prior to leaching.

Adding a step to remove iron significantly reduces reagent consumption, resulting in substantial savings on capital and operating expenditure. Reducing the iron content means that vanadium can be recovered directly from the leach solution, and expensive solvent extraction – which is used to separate vanadium from the iron – is no longer required.

“We built and operated a pilot plant at CSIRO’s Perth-based facilities, incorporating the additional iron removal stage, to prove the concept and identify further potential refinements,” Mr Pleysier says.

The CSIRO team then turned their attention to the TIVAN leach residue.

“We showed that once the vanadium has been extracted, it was possible to produce a titanium dioxide concentrate at 65 per cent purity,” Mr Pleysier says.

“Conventional pigment technology could then be used on the concentrate to recover titanium dioxide at greater than 90 per cent (TiO2) purity.”

TNG is now looking to enter the titanium pigment market to increase revenue from the mine. Titanium pigment currently sells for approximately US$3000 per tonne.

Overall, the potential to capture two additional saleable products – titanium and iron – has helped to minimise the associated financial risks of the mine plan and increase its net present value.

Recently, TNG received in-principal approval for a Native Title Mining Agreement that brings the company a promising step closer to developing the Mount Peake mine.

The proposed plan is to establish a three-million-tonne concentrator onsite at the Mount Peake mine and link it by rail to an advanced TIVAN hydrometallurgical metal refinery in Darwin.

MR PLEYSIER SAYS THAT COLLABORATION WITH TNG, METS, SMS SIEMAG AND OTHER INDUSTRY EXPERTS FROM THE VANADIUM AND TITANIUM PIGMENT INDUSTRIES WAS KEY TO THE SUCCESSFUL DEVELOPMENT AND REFINEMENT OF THE TIVAN PROCESS.

But CSIRO’s work hasn’t stopped there, with the organisation already expanding its horizons across the industry.

“CSIRO already works with the broader vanadium industry to evaluate titanomagnetite deposits by hydrometallurgical routes and the more traditional salt roasting techniques,” Mr Pleysier says.

Many companies, and ultimately end users, will benefit from this work into the future.

RON PLEYSIER
+61 8 9334 8923
ron.pleysier@csiro.au
CREATING VALUE FOR AUSTRALIA

Why is Australia’s mining equipment, technology and services (METS) sector considered central to innovation?

One of the most important factors of the Australian METS sector is that it is globally competitive and a world leader. It’s one of our nation’s core industries in terms of innovation. Unsurprisingly, Australia ranks like that in mining too.

Australian METS is central to innovation and it’s not necessarily the research itself, but the commercialisation of it that converts and creates value in a monetary sense long-term. METS companies are really good at commercialising innovation, which helps create jobs and export opportunities for the Australian economy.

Australian METS are globally competitive and we can see that in the data. For example, 20 per cent of all mining equipment-related innovation by METS companies in Australia are exported. To export, a company must be competitive globally.

That correlates to the fact that the METS sector in Australia is worth $86 billion to the economy, and of that, $16 billion is in manufactured goods. Compare that to automotive manufacturing which is worth $9 billion. While we are, of course, sad about the decline of the nation’s automotive industry, we have a globally competitive manufacturing industry in Australia in the METS industry that we believe can fill the gap.

How can Australia’s METS sector create additional value for Australia?

When you have a globally competitive industry, you can also transfer capability from METS to other industries. If we don’t have globally competitive channels, then we’re not going to be able to maintain a world-leading status. Particular areas of importance for the future are data analytics, sensing, automation and artificial intelligence, for example.

We spoke to Elizabeth Lewis-Gray – deputy chair of METS Ignited and managing director of leading Australian METS company, Gekko Systems – on how Australia can capitalise on its leading METS sector to drive innovation and benefit the nation’s resources sector more broadly.
While we are, of course, sad about the decline of the nation’s automotive industry, we have a globally competitive manufacturing industry in Australia in the METS industry that we believe can fill the gap.

How do you bring innovation to the Australian economy, unless you’re operating at world-class level? Having world-class sectors like METS and mining are key to attracting talent and knowing how to do the nation.

For example, my company Gekko Systems is world-class at modular plants and we’re transferring that knowledge to turn waste into energy technology. So, unless you’re operating at a globally competitive level, it’s hard to create new value for the economy that’s sustainable long-term.

That is what the purpose of the METS Ignited Growth Centre is; to grow the METS sector’s competitive advantage and productivity, globally, in order to grow business and jobs within the sector, as well as for Australia’s mining industry.

What are some of the top innovations being born out of Australia’s METS sector that we can offer the world, particularly in minerals processing?

Australia’s national science agency, CSIRO, very much plays a role around sensing and analytics. CSIRO is particularly strong in this space and in many ways leading the world in this for the mineral processing industry.

Australia is also leading in mining contracting services, mine remediation and environmental services, as well as occupational health and safety. We provide a world-class service in these areas to emerging economies and nations, for example, helping operations understand how to best run their safety systems on-site and what the process should be for remediation.

Another top innovation example out of Australia, is the creation and export of mining-related hackathons, engineering, geological software, mineral processing, autonomous vehicles and remote operations.

Is the minerals and mining industry ready for disruption?

I think the mining industry is ripe for disruption and it’s going to happen in the digital space first. It’s likely to come out of the technology sector with companies that have the market capitalisation and who may want to secure commodity supply, in particular a more socially-conscious supplier.

Social licence is one of the most significant factors at play, and arguably our industry’s biggest challenge. Unless the mining industry addresses this head on, it will result in significant disruption.

What do you think is the opportunity for Australia in the growing battery market?

If we are producing battery materials like lithium and cobalt here, there’s a real opportunity to firstly process, and then, lead the way in battery manufacturing. METS Ignited is working on bringing together organisations to realise this opportunity.

How can industry, government and the research sector come together to create more value for Australian mining and METS?

There is an enormous value to be made from collaboration. When we undertook our first industry sector competitiveness plan, collaboration was the single most cited factor and identified as the biggest opportunity.

Australia is ranked poorly globally on collaboration and it’s certainly not a characteristic genome of the mining industry. Particularly in Australia, we like to do it alone. Greater collaboration is the big opportunity.

METS Ignited’s Project Funds are designed to help teach researchers, METS and miners to work together and collaborate to achieve research outcomes.

The collaborative Project Funds involve finding a problem that a mining company is looking to resolve, working together to solve the problem, and splitting the funding 50/50.

What are the barriers to collaboration from your perspective?

In my view, one of the big factors is current procurement practices. Based on longstanding culture, miners tend to compete down to the lowest possible price, the standardisation of a product, and pay in arrears rather than in advance. Procurement systems do not encourage innovation or collaboration.

Most of the major western mining nations have very rigid and tight procurement practices, I don’t believe that companies in China operate in the same way, for example. The risk is that we fall behind. The more flexibility companies have with pathways to purchasing, the greater capacity they have to innovate.

One company that is demonstrating speed of innovation and is making an impact in mining is Sumitomo. They are one of the largest companies in the world and are using lean principles. They’ve recently started to run their own operations rather than be a joint venture partner.

Another good example is Fortescue Metals Group who are driving costs down faster and getting faster results. They are not trying to strip every supplier of every cost, but rather, are finding the partners that add value and funding them to speed up innovation.

We want to encourage miners to benefit by working opening and collaboratively, without arrogance, with Australian METS companies. Our nation and METS companies have hands-on operational experience, long-standing knowledge and skills that they could leverage.
The high-tech vision for the world’s first smart processing plant will see integrated data technologies enable automated production. **TIM THWAITES** reports

Satellite navigation and mapping, autonomous processes, robotic excavators, mineral sensing equipment, smart safety devices, intelligent control of metal extraction – that’s where Australia’s mining industry needs to be headed.

It’s a long way from digging a hole in the ground in the right place and shipping the contents overseas; the future is in investing in smart technology.

As Australia’s Chief Scientist, Dr Alan Finkel, said recently in an Australian Institute of Mining and Metallurgy lecture: “good luck building an intelligent mine in a data black hole.”

It’s a black hole that CSIRO has been working on for decades to plug. CSIRO’s efforts have started to bear fruit in the processing space, with smart sensing technology solutions such as their magnetic resonance ore sorter, which within seconds, can distinguish productive copper ore from waste.

CSIRO has also developed gold analysis techniques, including an alternative to fire assay that can determine the levels in ore of gold and many other metals of low natural concentrations within a few minutes; and the Online Gold Analyser (OLGA), which can determine gold concentrations in process streams to less than one part per million.

“This sort of technology could rewrite the whole triple bottom line equation.”

CSIRO Mineral Resources director, Jonathan Law
The potential impact of these sensors, and other digital advances on the way could be revolutionary, CSIRO Mineral Resources director, Jonathan Law, says.

“This sort of technology could rewrite the whole triple bottom line equation,” he says.

“The benefits flow right through the value chain – defining what resources really look like in situ, mining them in a more focused way, sorting the material before it gets processed, and making sure the processing is controlled and efficient. And, finally these tools can be used to understand, monitor and control environmental outcomes.

“So, you spend less capital by building smaller processing plants because you are more efficient, and you reduce environmental impacts because you know exactly what you are putting out there and in smaller volumes.”

Mr Law envisions an industry improving its efficiency initially by introducing smart technology into individual processes (industry 3.0). And then, combining and integrating these processes into automated production (industry 4.0) – similar to the manufacturing industry but with the orebody rather than the manufactured product being the key driver. But, he recognises there are still significant barriers to negotiate.

Manufacturers can specify their feed materials within precise tolerances and design their factories to suit; they can measure all their inputs and reject anything out-of-specification.

“In mining, every mineral, every ore and every minesis is different. We can't be like manufacturing until we can measure key things,” Minerals Consultants senior minerals industry adviser, Joe Pease, says.

CSIRO fellow Dr Ray Shaw, another industry insider, says the needs of bulk ore miners – such as iron ore, bauxite and coal producers – are very different from those who produce metals such as gold, copper and platinum where natural concentrations are low. The processing of bulk materials focuses heavily on grade control through blending, and therefore, technologies that determine the composition of the ore are important. Extracting precious metals, however, puts the emphasis on controlling the process itself, as well as the ore feed.

The flexibility of the latest developments in digital technology and in analysis, have allowed CSIRO to come up with a whole range of helpful sensors. For example, Wi-SED automatically tracks progress of sedimentation and sends the results via Wi-Fi to a computer or smartphone; whereas InterFloat monitors froth depth in mineral floatation units.

They have also developed SENSEI technology, which incorporates robust, solid-state electrochemical sensors that can be embedded in materials being processed in order to transmit measurements of properties, such as temperature, conductivity, pH or levels of dissolved metal ions.

“All of these are at least at the prototype demonstration stage and are being tested on mining operations around the world,” Mr Law says.

The CSIRO-developed magnetic resonance technology for ore sorting – commercialised through NextOre – heralds big changes. It analyses and sorts without interruption to a flow of 5000 tonnes an hour of copper-bearing rock from mine to stockpile or process plant.

This technology fires short pulse radio waves into the rock and within seconds, using magnetic resonance technology similar to a medical MRI, it can determine the form and amount of copper moving past. Once identified, a separate diverter can reject the gangue before it enters the processing chain, saving energy and water otherwise wasted on unproductive ore.

NextOre’s ore sorting solution can save in the order of 20 per cent of costs, which equates to a lot of money for a plant costing tens or hundreds of millions of dollars a year to operate.

It is already on the market, sold not simply as sensing equipment, but as a packaged solution that can undertake the analysis and provide information for rapid decision-making. It can be added or bolted on to existing operations.

However, other new sensors for mineral processing may enable different plant designs, and different organisational approaches.

“If we don’t know what is coming into the plant, then natural ore variation is harmful. So the best strategy is to smooth out the variation by lumping everything together to get average performance,” Mr Pease says.

“With real-time knowledge of input, we could put the variation to our advantage and optimise the plant for each kind or ore. This would change the way we design and operate mines and plants.”

According to Dr Shaw, one problem is that many companies have cut down on the number of people dealing with the technical side of their business and have contracted out these skills, so they might need to buy in knowledge to assess and handle the new technology. And, new technology is always a risk.

“Added to all the geological, political, social and approval risks of a mine, is it reasonable to ask the Board to assume another risk – that of technology? Once an early adopter demonstrates that the technology is robust, can be applied and makes money, it will be adopted quickly,” Mr Pease adds.

The next big gains, probably lie in data management, particularly in the development of packages that integrate sensors to produce a more comprehensive picture of what is happening, allowing finer control and better optimisation.

“CSIRO Mineral Resources is beginning to look at that in conjunction with CSIRO’s data innovation powerhouse Data61,” Mr Law says.

“There is huge opportunity to transform the industry.”

JONATHAN LAW
+61 3 9545 8316
jonathan.law@csiro.au
Iron Ore

Securing a Key Australian Export

With a total annual revenue of some AUD$63 billion, iron ore is one of Australia’s most important export commodities. However, a range of local and international factors are affecting the market on both the supply and demand sides. Advanced research and development is helping to secure the value of the nation’s iron ore exports.

David Simpson reports

Fortunately, Australian iron ore exporters have some advantages. One is geographical – being closer to Asian markets reduces the cost of shipping, which is significant when one purchase can involve millions of tonnes. The second is access to the expertise and resources of Australia’s national science agency, CSIRO. CSIRO has a team of specialists who can develop product testing research programs to address key challenges faced by iron ore producers.

Working with Australian mining companies, CSIRO is providing material analysis that gives valuable information on ore quality. This information enables exporters to modify their ore blends to suit steelmaker needs, along with valuable information to inform decisions around the most cost-effective and environmentally-friendly processing methods. It can also help producers decide whether a deposit is currently worth extracting, or best left in the ground.

China’s slowing economy, has in turn, reduced the demand for commodities such as iron ore – and China is Australia’s most important market. At the same time, Australia’s supply of high grade ore is being depleted, while resource-rich Brazil is ready to step up and dominate the high grade iron ore market.

This is the challenge facing Australian exporters. Effectively, it is how to replace naturally high grade iron ore exports with alternative products that meet the needs of international buyers. Considerations include the cost of processing, the quality of the resultant product and the environmental impacts. Smelting lower grade ores requires more energy, which adds to the financial costs and increases environmental emissions associated with the process.

To stay competitive, iron ore producers need to understand their iron ore grades in near-real time to adapt to an evolving market that’s becoming more complex and fragmented. They also require an understanding of their ore for value-in-use calculations.

According to Keith Vining who leads CSIRO’s iron ore and carbon steel research, there are two main ways that they assist mining companies.

“One is to look at the potential for upgrading the material,” Dr Vining says.

“So, for instance, removing the deleterious elements, assessing whether material has the potential to be upgraded or figuring out an appropriate way to do that, as well as how to achieve that upgrade for the minimum cost possible.”

Dr Vining explains that typically, the materials that dilute the ore are silica and alumina. These are the impurities that cause processing difficulties downstream, so buyers focus on them and put cost penalties on the ore.

The CSIRO team looks for ways to cost-effectively reduce, or remove, the silica and alumina, which then leads to an improvement in the iron grade.

Another method to upgrade lower grade deposits of materials, such as magnetite and hematite – which usually contain around 30 per cent iron – is to grind them to a fine powder from which it is then relatively easy to separate the iron and produce a high grade product.

“While it’s not an asset that we’ve traditionally relied on very heavily because of the processing costs, calculating grinding costs and determining the metallurgical properties of the resulting product, is helping to shift the thinking to put more emphasis on magnetite concentrates,” Dr Vining says.

“It’s making people consider whether now is the right time to begin exploiting these resources.”
If reduction or removal of unwanted materials is not practical, the CSIRO team has a second strategy.

“If you can’t get it out, well, let’s find a way that we can effectively use it. These are technical marketing activities to establish the real value-in-use of the material.”

In practice, this involves looking beyond the chemical composition of a sample to its structure – the way in which the elements and minerals are linked or positioned.

“With this information, we can show that an ore with an unimpressive sounding chemical composition, but a beneficial structure, can deliver processing advantages to the end user,” Dr Vining says.

“That’s an important factor that can influence saleability and other decisions, such as whether or not to mine the deposit.”

The key to being able to analyse and treat ore samples and determine the effect of the composition on their processing is CSIRO’s world-class pilot processing plant. The plant batch processes ore samples of as little as one to two tonnes, and can replicate a traditional continuous process.

“We work at a scale where we can use international standards to establish the quality of the material, which is exactly what the end customers would use to measure in a continuous large-scale process,” Dr Vining says.

“So, our test results are directly applicable to the real world.”

A major benefit of CSIRO’s team is that they have end-to-end expertise. From strong ore characterisation capability, through to extensive beneficiation experience and pilot scale processing for determining the metallurgical properties of the materials.

In practice, this means the team can work with small samples from undeveloped resources to assist in determining their viability, through to helping inform their clients’ investment decisions and sales process as they take their product to market.

When asked about the potential of the CSIRO team’s approach, Dr Vining is enthusiastic.

“Personally, I believe the whole concept of textural ore classification is applicable across much of the mineral processing industry,” he says.

“There’s a lack of understanding from industry about the importance of ore texture on processing, so we need to educate the market that texture is an important factor to measure. Doing so, can give a miner valuable information that can have significant impacts on operation costs.”

And, looking to the future?

“Right now, we’re pretty busy working with the iron ore sector, but the next natural extension would be to look at similar opportunities with bauxite,” Dr Vining says.

“I think we could add value to that industry too. It feels like the next logical step.”

KEITH Vining
+61 7 3327 4761
keith.vining@csiro.au
Emerging science that takes the geology of a deposit and combines it with metallurgy and other statistics to provide a predictive model of processing options, can shed light on the economic potential of a resource to inform planning and development. **ADAM COUR TENAY** reports

These days many would argue that understanding ore at the micro scale is as important as the mine process itself. New technologies are transforming the small scale world with profound implications.

The extractive potential of a given deposit is about knowing its chemistry, mineralogy and texture, and how these impact processing. It’s also about knowing what the ore might be mixed with, as well as its petrophysical properties – such as density and hardness.

All these things can be deciphered before a mine is even considered and it’s why improvements in the science of geometallurgy are changing the landscape of mineral extraction.

“Geometallurgy can now reliably inform economic models around a mine that can help you to decide on its viability” CSIRO’s research director for minerals processing, Chris Vernon, says.

Dr Vernon gives the very simple example of two similar copper deposits of roughly the same size and grade: are they of equal value and of equal interest to a mining company? Not necessarily.

“If one is tied up in chalcopyrite, which is a copper iron sulphide, and the other is an oxidised copper that is easily dissolved in acid, the geometallurgy will tell you to ignore the one that is harder to process and go for the one which is much easier,” Dr Vernon says.

He offers another example: determining the viability of aluminium extraction from bauxite mines. The ore extracted from two potential sites might show similar elemental analysis, but this may not be enough information on which to base a decision to extract.

“Some alumina phases are quite refractory and need very high temperatures to extract the aluminium,” Dr Vernon explains.

For example, at bauxite reserves in the Darling Range in Western Australia, aluminium can be extracted at low temperatures, making it a highly economic process.

One of the reasons that these bauxites were ignored when first discovered was a belief that the high silica level would make extraction too expensive.
Among the specific new developments is the CSIRO-developed, one-of-kind Maia Mapper technology that can produce a detailed picture of a drill core of up to 50 centimetres with a pixel size of 30 microns (less than the breadth of a human hair), looking at the sample’s texture and chemical composition using an intense, focused x-ray beam.

“It’s a chemical mapping approach that has previously been deployed at a synchotron. We have brought that into a laboratory setting, to create an instrument that allows us to chemically image drill cores with unprecedented scale (length) and with very high resolution.”

DR FISHER SAYS IT ALLOWS A FULL UNDERSTANDING OF THE VARIABILITY OF THE SAMPLE, GUIDING SUBSEQUENT SAMPLING AND INVESTIGATION. ONE UNIQUE APPLICATION OF THE TECHNOLOGY IS THE ABILITY TO LOCATE RARE, MINUSCULE PARTICLES OF PLATINUM AND GOLD IN-SITU WITHIN THE DRILL CORE AND UNDERSTAND WHERE THEY SIT WITHIN THE MINERAL ASSEMBLAGE.

“We can see what minerals these particles are in contact with and that information allows geometallurgists to assess processing options and determine whether the commodity is viable.”

One might argue that the “art” behind the science of geometallurgy is having the foresight to collect all of the required data, and in ways where the datasets are connected enough that there is easy overlay between different properties.

There are still challenges to be overcome, says Dr Fisher, and most of these reside in receiving reliable data. There is plenty of legacy data that’s not easily accessible.

For scientists to have “the full picture” it’s important to have information from a number of different sources, processes and characterisation tools, over multiple scales, she says.

“We need these to be made available in ways that are acceptable to any potential user,” Dr Fisher says.

“We need inter-operability of data and we need to make sure we can get it on an ongoing basis.”

LOUISE FISHER
+61 8 6436 8664
Louise.Fisher@csiro.au
The first “green” gold pour using CSIRO’s non-toxic gold recovery process has been achieved with a small Australian gold producer, showcasing how innovation could create niche market opportunities for more sustainable commodities.

**EMILY LEHMANN** reports

To meet growing consumer expectations, some technology companies are seeking to secure greener, more sustainable supplies of metals for their products. Some mining companies are already stepping up to the challenge.

CSIRO believes this market demand will grow in future and that it’s an opportunity for producers to embrace innovation and turn raw commodities into higher value, uniquely Australian products.

A great example of what’s possible, is CSIRO’s work developing a non-toxic thiosulphate-based recovery process for gold. The technology called “going for gold” offers a more environmentally-friendly way for recovering gold than traditional cyanidation, and could open up niche market opportunities for smaller gold producers or help them overcome regulatory barriers.

The CSIRO team recently reached a significant milestone when they poured the first “green” gold using the technology at demonstration scale as part of early industry trials.

The first gold was produced in partnership with small gold miner Eco Minerals Research at a demonstration plant in the Western Australian goldfields town of Menzies.

Eco Minerals Research hopes to be the first Australian gold producer to go cyanide free.

“The first gold pour is a major milestone in our progress towards becoming one of the world’s first green gold producers,” Eco Minerals Research managing director, Paul Hanna, says.

Cyanide is used in more than 90 per cent of global gold production, but producers are facing increasingly tough regulations that prevent or restrict its use due to environmental and health concerns.

In response to recent spills of toxic cyanide, several regional agencies in the United States, South America and Europe have banned the use of cyanide for gold extraction.

The project was accelerated through CSIRO’s ON program where the team identified that there are a lack of opportunities for miners with smaller deposits that do not fit into the large-scale economics of gold processing plants using cyanidation.

“We’re not proposing a replacement for cyanide,” CSIRO team leader, Paul Breuer, says.

“Instead, what we’re offering is a process that could potentially allow production of gold from stranded gold deposits where cyanide can’t be used, or is not economic to be used.”

To reduce economic barriers to entry for small producers, CSIRO’s vision is to deliver the alternative process technology direct to mine sites via a mobile service.

The $2.1 million demonstration project was made possible through $860,000 in funding from the Science and Industry Endowment Fund (SIEF). The project was also supported by the Australian Government Department of Industry, Innovation and Science as part of the Entrepreneur’s Programme.

The demonstration plant is expected to provide key information and lessons that will aid commercialisation of the technology.

The CSIRO team behind the innovation have already had commercial success with another tailored cyanide-free gold solution developed with Barrick Gold specifically for their Goldstrike Mine in Nevada where it has been used for nearly four years to maintain production rates.

**PAUL BREUER**
+61 8 9334 8074
Paul.Breuer@csiro.au
The first gold pour is a major milestone in our progress towards becoming one of the world’s first green gold producers.

Eco Minerals Research managing director, Paul Hanna
POWER TO RECYCLING

Right now, only two per cent of Australia’s annual 3300 tonnes of lithium-ion battery waste is recycled, and this waste is growing by 20 per cent a year.

According to a new CSIRO report, Australia is well placed to tackle this waste and could lead the world in the re-use and recycling of lithium-ion batteries.

The report, *Lithium battery recycling in Australia*, addresses growing demand for lithium-ion technology, currently used in vast quantities in electronic and household devices.

Low battery recycling rates can be overcome through better understanding of the importance of recycling, improved collection processes, and by implementing ways to efficiently recycle materials.

An effective recycling industry could also stabilise global lithium supplies to meet consumer demand.

The report found that, if recycled, 95 per cent of components can be turned into new batteries or used in other industries.

The majority of Australia’s battery waste is shipped overseas, and the waste that remains left in landfill, poses potential fire, environmental contamination and human health risks.

The report also concludes that research, government and industry must work closely to develop standards and best-practice solutions to this issue.

CSIRO research is supporting recycling efforts with research underway on processes for recovery of metals and materials, development of new battery materials, and support for the circular economy around battery reuse and recycling.

To access the report, visit: csiro.au