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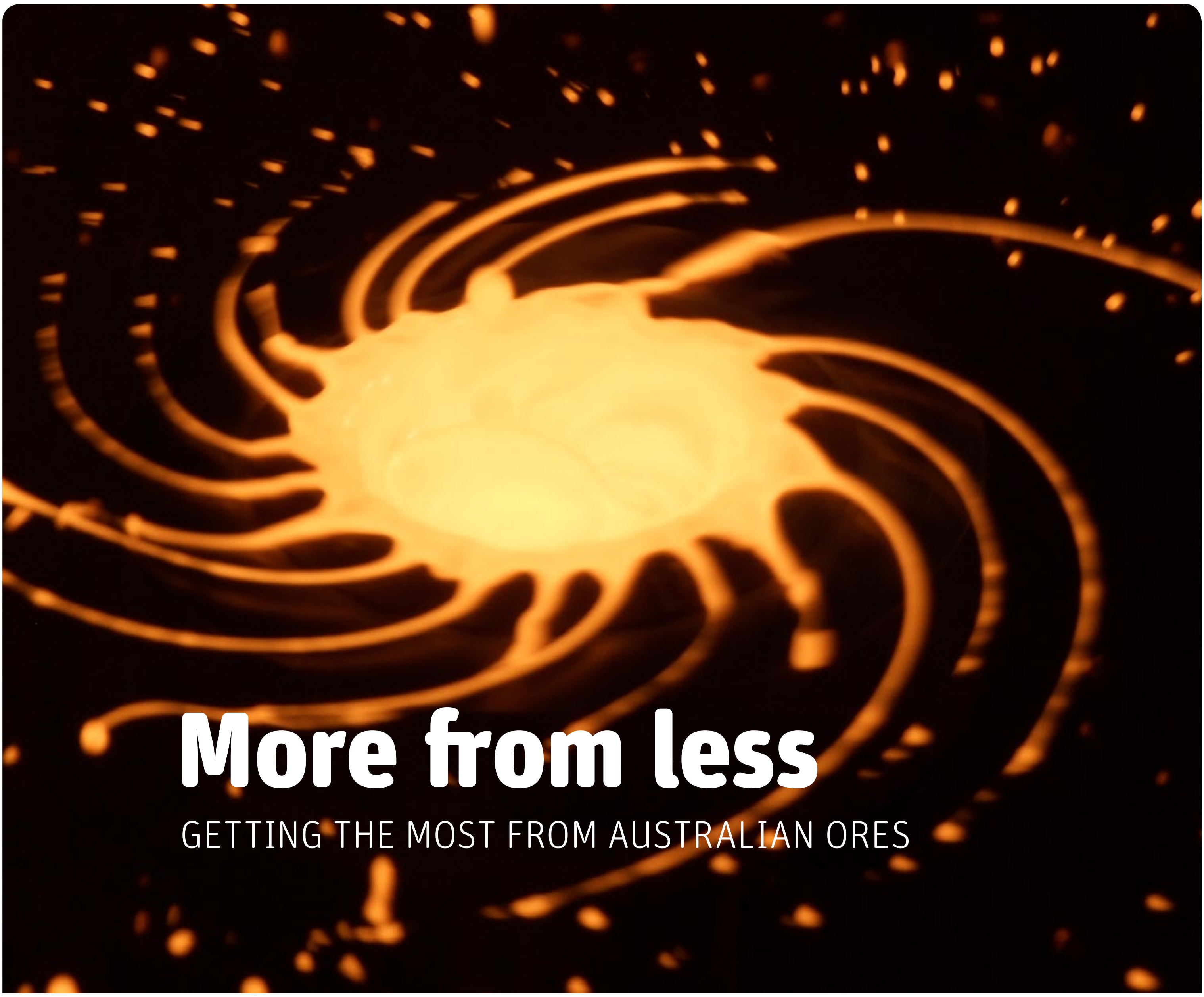
BRINGING CSIRO RESEARCH TO THE MINERALS INDUSTRY



More from less

GETTING THE MOST FROM AUSTRALIAN ORES

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INSIDE

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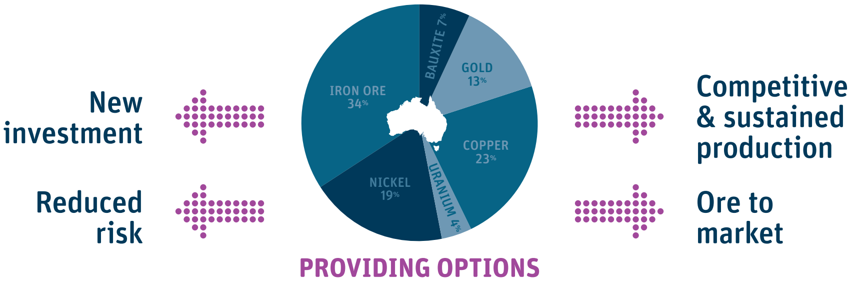
CHALLENGES THAT ACCOMPANY AUSTRALIAN ORES

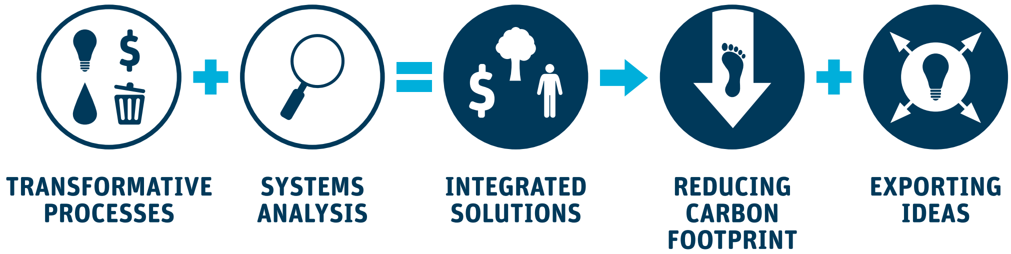
In CSIRO's Mineral Resources Flagship, two areas of research focus specifically on addressing challenges that accompany Australian ores:

- **Processing Australian ores** targets innovation across our ores types that helps: get ore to market, improve production flow and competitiveness, attract new investment and reduce risk.
- **Responsible metal production** focuses on the transformative processes and systems that provide solutions for more sustainable and environmentally friendly production.

PROCESSING AUSTRALIAN ORES



RESPONSIBLE METAL PRODUCTION



MINERAL TO METAL > **Silver (Ag)**

Silver is a relatively scarce element that occupies the 47th position on the periodic table.

The metal occurs in pure or native silver form, in minerals such as tetrahedrite, freibergite, pyragyrite and argentite and also as a lesser part in electrum – an alloy of gold and silver.

Most of Australia's silver is produced from silver-bearing galena but some is also recovered with copper and gold mining.

Australia is the world's fourth leading producer of silver behind Mexico, Peru and the USA, however we have the world's largest economic silver resources, following the discovery of lead-zinc-silver deposits of Cannington, Century and McArthur River.

Silver is soft, white and lustrous and is classified as a transition metal. Silver has long been valued as a precious metal and been used in jewellery, coins, ornaments and silverware since before ancient Roman times. Silver is still used in these ways due to its value, ease of working and shaping and attractive appearance, however use in coins has declined.

Due to its high electrical (highest of all the metals) and thermal conductivity and reflective properties, silver is widely used in electronic applications, solder, brazing alloys, solar panels, mirrors, and the like. It has applications in medicine, dental fillings, photographic paper and film.

World silver production in 2014 topped 877 million ounces with about 59 Moz (or 15%) produced by Australia.

Hard times –
a catalyst for innovation?

Falling iron ore and other commodity prices have made life difficult for Australian resource producers - but challenges and hard times can also be the catalyst for game-changing innovation, writes JONATHAN LAW.

The iron ore price is squeezing margins for Australian producers and industry has responded by reducing costs through removing inefficiencies throughout the value chain.

While having a lower profile in the media, most other commodities are affected by the reduced global demand and falling prices.

Many commentators have pointed out that, although low relative to the recent boom years, commodity prices remain higher than their long term averages - and yet margins are still being squeezed.

But challenges and hard times can also be the catalyst for game-changing innovation and most companies are taking a fresh look at how innovation can impact on their cost base, productivity and longer term competitiveness.

There is considerable overlap in the views, of various companies and research & technology providers, about what the big challenges are. However, the question of 'how to get there', is now getting more attention.

What are some of the key factors in this shift in focus and some of the barriers in the way?

Firstly, many new innovations being sought by industry involve fundamental changes to the way the value chain operates and impact on things as diverse as equipment design, new sensing and data technologies and changing cost drivers. These innovations are largely beyond the ability of most companies to deliver on their own.

Secondly, the rapid growth in innovation options being delivered by large and small METS companies provides a plethora of solutions for point problems but the integrated solutions required by industry are lagging. Innovations that do not integrate seamlessly are not valued, as they require cost and effort to implement and can result in complexity and unintended consequences further downstream.

Thirdly, the delivery of step change innovation into a somewhat fragmented market is often difficult. Not only do the multiplicity of commodities each have different requirements but individual mining and/or processing operations have been individually designed to tackle orebodies which, as the products of nature, display unique characteristics. So, although there can be a lot of commonality between operations, each tends to think of itself as different. Innovation is a risk investment. Larger investments for more rapid or more impactful developments are enabled when it is possible for the market to behave in a more integrated manner.

Together these issues underpin an urgent need to change how we tackle major innovation changes in a capital intensive industry like mining.

The mining community is taking a lead in this thinking.

At the World Mining Conference in Montreal the Anglo CEO framed an important proposition for innovation in the mining industry:

"..... *although there are many areas of excellence in our individual companies, we could do so much more if we were able to make a step-change by co-operating in mining technology. And if that sounds a bit fanciful, take the example of the process-control industry, where we benefited from collaboration with the chemical and petrochemical industries. In the early days of process control you had to buy a single-source solution from instruments all the way through to controllers. Now you select the best instruments from the best suppliers and connect them to the best control solution appropriate to your specific need, through common interfaces. Even more importantly perhaps, we need to co-operate within our sector because in a number of important areas we have effectively ceded control of the mining technology space to our OEM suppliers. An ideal outcome is a progressive, competitive ecosystem where players compete on adding value to the mining process – and not by developing closed, insular, proprietary components.*"

These remarks were made in 2013 but there is a growing view in the industry that collaboration and more open innovation are poised to change how we innovate to address the big challenges facing the mining industry.

At CSIRO, we invest around $80 million in innovation across the mineral resources value chain each year. This reflects a mix of industry and Australian government funds and is an important resource for the mining community to tackle these challenges.

A shared research vision and commitment to the major challenges, raises the opportunity to change the pace and scale of innovation in the mining industry, the METS sector and R&D providers.

How we collaborate on the major challenges may be the single biggest game changer for innovation in the mining industry.

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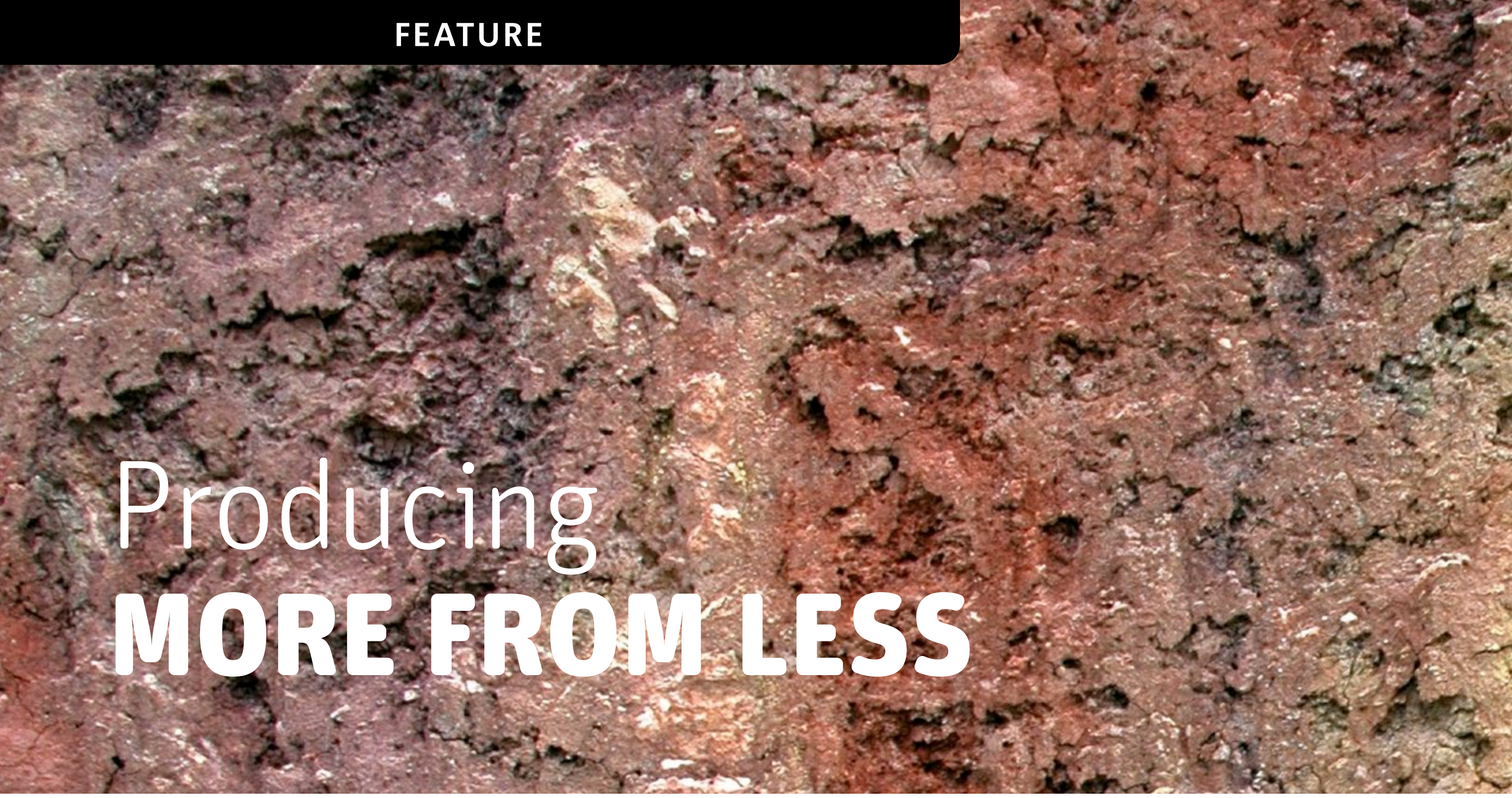


Producing MORE FROM LESS

As more of Australia's accessible and high grade mineral reserves are depleted, CHRIS VERNON reports that our great challenge is to find ways to target and process our lower grade or more complex ores to maintain productivity and value for the nation.

It's an unfortunate fact that the majority of the easy to process, high quality ores in Australia seem to have been discovered and exploited. The following graph shows the trend of declining ore grades in Australia's producing mines, and this is fairly typical internationally.

Australia has an ancient landscape and some exceptionally rich deposits are undoubtedly still to be discovered from under deep land cover or regolith. Such deep ore bodies could be technically and economically challenging to reach and extract.

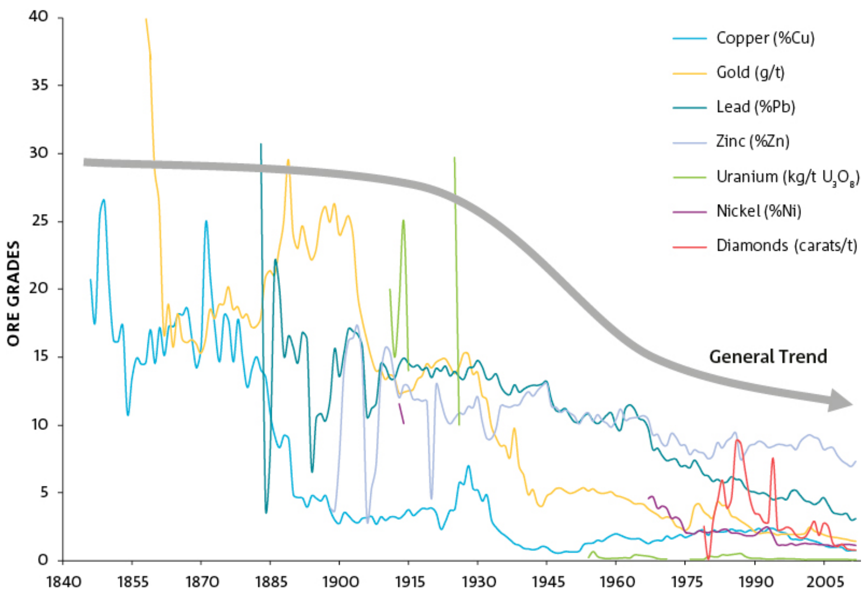
In most situations we are faced with ores that are of declining quality, have difficult mineralogies, and are increasingly expensive to process.

To remain competitive, Australia must obviously produce 'more from less'. This is true not only for existing ore types (where commercial and technical risks are comparatively well known), but especially so for the new lower grade ore types that are becoming necessary to consider.

CSIRO is playing a part in understanding how to improve the efficiency of existing processes, and also uncovering new processing routes for the more difficult ore types that have not yet been successfully exploited.

Activities within CSIRO include advanced geometallurgy techniques to quantify and qualify required processing parameters for an orebody, more efficient drilling and mining, at-face and at-rig instrumentation to rapidly assess ores, and an advanced understanding of processing technologies, from the unit operations of flotation and beneficiation, to value and gangue leach chemistry, impurity removal and separations technology such as solvent extraction and selective crystallization.

Significant efficiencies at the unit operations level can be made through understanding particle interactions, fluid flow phenomena, and how equipment



Source: G. Mudd, Monash University

design impacts on these. CSIRO scientists have developed excellent suites of tools for example to design hardware to increase throughput and efficiency in settling and dewatering, the design of pumps and pipes in order to reduce erosion and make slurry pumping more efficient, and in mixing efficiency.

One example of a new technology is the thiosulfate process for gold, developed collaboratively in CSIRO laboratories and now deployed commercially by Barrick Gold (see article page 8).

Thiosulfate is far less toxic than the commonly used cyanide and can be used in more environmentally sensitive areas, requiring less capital-intensive infrastructure. It can also be used on preg-robbing ores, that were previously impossible to treat economically.

Another example is a novel use of solvent extraction to turn weak acid streams into a strong acid stream plus a neutral stream, and yet another that avoids multiple pH changes, consuming lime, and using solvent extraction to directly strip metals from concentrated acid streams.

A process by Direct Nickel (developed for commercial implementation in conjunction with CSIRO) avoids the need for pressure leaching of nickel laterite ores in titanium autoclaves and instead uses stainless steel tanks, thus saving capital cost and energy.

we are playing a part in understanding how to improve the efficiency of existing processes, and also uncovering new processing routes for the more difficult ore types not yet successfully exploited.

Further, the technology consumes an order of magnitude less acid (saving operating costs and resources), and produces commercial grades of magnesia and iron oxide as byproducts, both of which are commercially saleable. This is a good example of resource efficiency – diverting materials that would become a mixed waste stream in a conventional process, to a useful product.

CSIRO is also working on the game-changing technology of *in situ* recovery. This involves drilling into an orebody and leaching valuable metals underground – avoiding the need to dig, and shift overburden. This is a technology particularly suited to deep, stranded orebodies.

Although already practiced in the uranium industry and to some extent in the copper industry, recovery of other metals is generally more difficult. Uranium is recovered from easily permeable sandstone and calcrete-hosted ores at shallow depths, and *in situ* copper, from gravelly deposits. But rich and therefore attractive copper, gold and other mineral deposits generally occur in hard rock, at great depth.

This initiative will potentially make ores that are too deep for conventional mining, and too low in grade to justify the cost of mining, accessible for processing. *In situ* recovery will require new reagents in order to safely extract metals without jeopardising the environment.

Thiosulfate is one example of a novel reagent (cyanide would be impossible to use safely), and in other CSIRO research, acids that occur naturally in nature have been used to extract metals.

In situ recovery isn't just about chemistry, though – a successful implementation will require a holistic approach based on the ore body, rock physics, drilling, pumping and hydrology. The diversity of skills across CSIRO and in our industry partners, will be required to make this development possible.

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Aluminium future out of red mud treatment

Aerial shot of a red mud thickener and the residue area

Vast aluminium global resources that are currently uneconomic to mine could be opened up through a CSIRO-patented process that recovers caustic soda from red mud. TIM THWAITES reports that it may be environmental factors that drive adoption.

Researchers from CSIRO's Mineral Resources Flagship have developed a process that lowers the cost of refining bauxite (aluminium ore) to alumina (aluminium oxide) by treating the waste product generated—red mud—to recover a costly ingredient, caustic soda.

While lowering the costs was the primary intent, a secondary benefit is that it makes the red mud less polluting and easier to handle. Ironically, tougher regulations on the disposal of red mud might well end up driving adoption of the process, according to a principal research scientist in CSIRO's alumina production group, Dr Peter Smith.

"It is a bolt-on process," Dr Smith says. "We just take the residue, and remove the caustic soda. You wouldn't have to change anything upstream in the current refining process at all."

> **It is a bolt-on process. We just take the residue, and remove the caustic soda. You wouldn't have to change anything upstream in the current refining process.**

The process can be applied to some or all of the residue —even independently to reprocess red mud already stored.

The vast majority of the world's bauxite resources includes valuable alumina minerals and alumino-silicate clays which are intimately mixed. Insoluble components of the bauxite are removed by digesting the ore with very hot caustic soda (sodium hydroxide) in what is known as the Bayer process.

Initially the aluminium and the silicate clays dissolve in this solution. Sodium in the caustic soda solution combines with reactive silica to form a disilication product (DSP), which falls out of solution taking sodium with it.

The DSP becomes part of the residue, and the loss of sodium is at significant cost. So, the higher the level of reactive silica in the ore, the more expensive it is to refine. Bauxite with more than about eight per cent reactive silica is generally considered to be uneconomic to process, according to Dr Smith.

Australia has vast reserves of bauxite containing at least that level of silica—at Aurukun, south of Weipa on Cape York Peninsula, for instance, and on the Mitchell Plateau between Kununurra and Derby in the very northwest of Australia.

"Along with the rest of the world, we have cherry-picked the high quality ore, and are rapidly getting to the point where it is running out. But if we could make it economic to process bauxite with up to, say, 12% silica, we would increase our economic reserves significantly."

Between 2008 and 2011, financed by the Australian Government as part of the Asia-Pacific Partnership, CSIRO researchers identified three ways of approaching this problem:

- pre-treating the ore in some way to remove reactive silica
- changing the operating conditions of the Bayer process to minimise the loss of sodium or
- reprocessing the residue from the process to recover the sodium.

The patented process falls into the last category and uses acid dissolution and electrodialysis (salt splitting) to recover the caustic soda.

The residue of the Bayer process is treated with sulphuric acid to neutralise the heavily alkaline mud and scavenge the retained sodium as a sodium sulphate solution. This solution is then subjected to electrodialysis reforming sulphuric acid, which can be recycled, at one electrode and sodium hydroxide, which can be fed back into the Bayer process, at the other electrode.

The treated red mud is left less alkaline and far more tractable for disposal. "We've proven the process, both technically and economically," says Dr Smith.

The project has reached a point where further testing at an refining plant is needed. "You could set something up on a small scale, treating perhaps 10% of the residue."

Working at the the electrodialysis unit in CSIRO's Waterford laboratory

Bauxite mining and refining companies are aware of the work. For example, Rio Tinto, which mines the Weipa deposit on Cape York and owns refineries in Gladstone, central Queensland, has been advising the researchers on the sorts of industrial conditions their process would have to accommodate and how costs and benefits would be viewed. The team has also been approached by interested foreign companies.

"This technology was developed in Australia for Australian bauxite to maximise Australian resources," says Dr Smith. "We would like to see an Australian company take it up."

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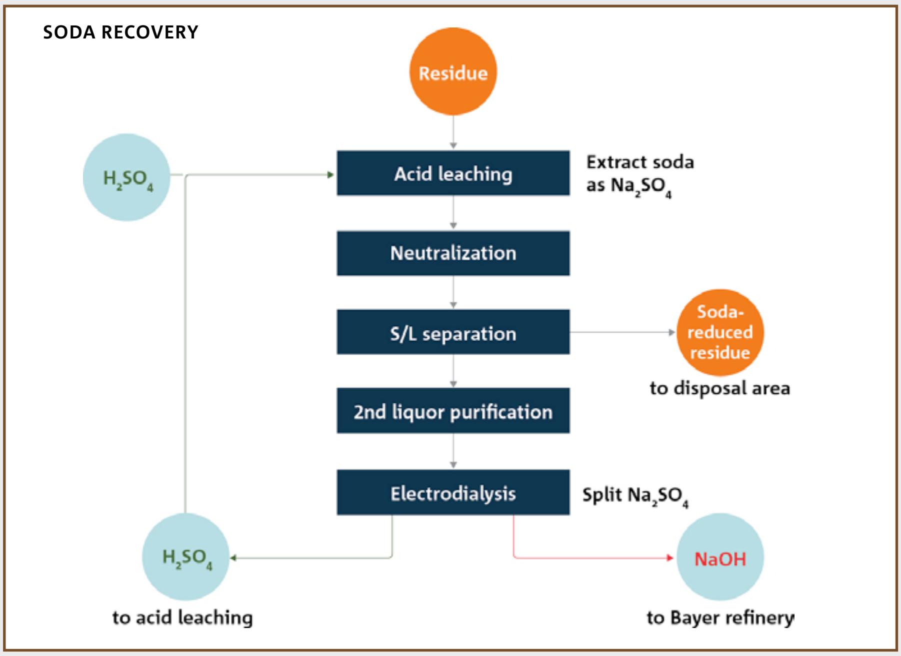

GOLD STRIKE with thiosulpate

Gold produced with a cyanide-free thiosulphate process is adding value to a US gold operation. ROGER NICOLL reports that the process incorporates patented technology developed through a collaboration between Barrick Gold Corporation and CSIRO.

The first gold bar produced with the thiosulphate process was poured in late 2014 at Barrick's Goldstrike plant in Nevada, USA and operations are ramping up to recover gold from four million tonnes of stockpiled ore that was uneconomic to process by traditional methods.

CSIRO's Danielle Hewitt, who worked at the Barrick demonstration plant to develop and prove the Barrick-CSIRO technology, was on hand to see the first gold bar.

"This was a golden moment of more than 20 years in the making, including three years working with Barrick to refine the commercial process," Mrs Hewitt said.

"It's the culmination of years of hard work and a good example of how our partnership culture is manifesting itself on the ground," says Goldstrike General Manager Andy Cole.

"This was a huge initiative, and it would not have succeeded if it weren't for the collaboration, trust and accountability that developed between our project team, CSIRO, the construction group and the Goldstrike operations team."

Thiosulphate has long been seen as a potential alternative to cyanide for liberating gold from ores, but until now it has proved difficult to master. Cyanide is highly toxic and an environmental hazard.

As part of the thiosulphate process at Goldstrike, gold-bearing ore is heated as a thick slurry of ore, air, water and limestone in large pressure chambers or autoclaves and then pumped into the new 'resin-in-leach' circuit that takes place inside large stainless steel tanks.

Within the tanks, the slurry interacts with thiosulfate and a fine, bead-like material called resin that collects the gold.

At full capacity, 13,400 tons of ore can be processed daily, with leaching taking place simultaneously in two sets of seven tanks.

The thiosulphate process will enable Barrick to contribute an average of 350 to 450 thousand ounces of gold each year to their operation, allowing the large plant to keep operating, preserving jobs and bringing much needed income to the State.

"Replacing cyanide with the non-toxic thiosulphate stands to reduce environmental risks and open other opportunities in countries where gold cyanidation is banned," says CSIRO Team Leader for Gold Processing, Dr Paul Breuer.

"Thiosulphate processes may also be viable for low-grade deposits or deep ore bodies, where *in situ* recovery would be safer for workers and the environment," Dr Breuer said.

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The Barrick plant including giant stainless steel tanks to run the cyanide-free process

Yeonuk Choi, Danielle Hewitt and John Langhans with the first gold bar produced with the cyanide-free process

New technologies can drive down C1 cost and make an operation viable

The challenge with complex ore bodies is typically an economic one but new technologies and approaches can transform C1 costs and make all the difference, writes PAUL DOWD.

Primary production cost or C1 cost is what focuses just about everyone in our industry, with an even greater focus when commodity prices are low. To remain robust and competitive we need projects that are in that lowest 20 percentile of C1 cost.

Basic economics is the reason why virtually all the deposits close to the surface, with high grade, and large tonnages have been mined out decades, if not longer, ago.

For the complex and challenging ore bodies that remain, cost is always a key concern because these resources are often deep, lower in grade and have complexities of included minerals that may be deleterious or difficult to extract. In some cases the minerals present are valuable and can be marketed.

The C1 cost balanced against the output products is what makes an operation viable or not. If secondary minerals can be extracted and sold this adds to the output value that offsets (C1) costs whereas minerals that incur a penalty in the extraction, separation or processing, do the opposite.

In the current industry climate, it takes a lot of effort, equipment, technology and experience to determine how minerals can be won at an economic price.

On the output side – grade, recovery and throughput are vital to the economics and, in particular, recovery presents one of the best opportunities.

In some cases recovery is the low hanging fruit when compared to investing the same amount of capital in an initiative to try to reduce costs.

Take the example of a gold operation in which there is an opportunity to:

- employ either a technology or initiative costing $A1million that increases recovery by 1%, or
- employing that same capital into initiatives that save 5% of operating costs, (opex).

At, say 500 t throughput per hour, a head grade of 3g/t and a price of $US1150 the 'payback' for the recovery improvement is measured in days, whereas the opex option is more than a month. The total value per hour for the recovery option is more than 5 times that of the opex option.

This is not to suggest that initiatives to lower opex are not appropriate and important. This simplified case merely illustrates the need to consider direct and indirect initiatives to lower C1 unit costs and therefore increase margins.

One of the greatest impediments to recovering or liberating minerals can be the amount of energy required to reduce the particle size to allow that liberation.

In the past we have simply added more energy and used brute force to hammer the ore until everything is broken down to a particular size. Energy is an ogre for the industry and can quickly send the cost equation out of balance.

In our current environment we need finessed approaches and there are some exciting ones on the horizon like the high tonnage ore sorter being developed by CSIRO.

The beauty of this sophisticated technology is it uses a number of different spectra to sort the payable material from the large quantities of barren or gangue material. By diverting the gangue before it gets to the ore crusher, large amounts of energy are saved that would have been expended on essentially waste material.

> **"In the current industry climate, it takes a lot of effort, equipment, technology and experience to determine how minerals can be won at an economic price.**

> **"It is a great example of a smart technology that could transform the industry's cost equation and indeed its energy use and environmental performance.**

While ore sorting has been around since the early 1970s, achieving success with large rock sizes and high throughput rates has been problematic before now.

It is a great example of a smart technology that could transform the industry's cost equation and indeed its energy use and environmental performance.

Of course there are technology challenges and opportunities for the downstream extraction and processing in areas such as chemical and bioleaching. But if we can make these big gains in the upstream, such as through the smart ore sorting, then it will greatly improve the effectiveness of the chemical and physical processes downstream.

These are the sort of initiatives that we need to be able to operate at the lower end of C1 costs and continue to be viable in difficult times. Indeed, these are examples of innovations that could make previously uneconomic ore bodies worth mining. ●

Paul is Non-Executive Director, Oz Minerals and Chair of CSIRO's Mineral Resources Flagship Advisory Committee

SETTING SIGHTS ON ‘invisible’ mining

A new and largely untapped frontier that could change the economics of mining and improve environmental performance is the focus of a coordinated campaign spearheaded by CSIRO. TONY HESELEV reports

***In-situ* mining at the Beverley uranium field**

Australia has long been a world leader in the resources and energy sector.

In-situ recovery or ISR, particularly from hard rock ore bodies, is a technology that involves drilling, rock fracturing and leaching of value metals away from gangue while the rock remains in place. It has the potential to be a game changer for deep and sub-economic deposits, and provide an alternative to open cut and underground mining.

Once proven, the technology will provide access to metals via ore deposits previously considered uneconomic or stranded – because of their low grade, small size, depth or location. This could turn assets that companies currently consider ‘unminable’ into profitable projects for the future.

ISR is already used widely in the uranium industry, and is being evaluated at gold and copper operations in Australia and the US.

It has the potential to halve the costs of conventional mining by avoiding the need to bring rock to the surface, and then crush and mill this rock before subsequent processing.

This results in significantly reduced energy costs and greenhouse gas emissions. And by not having to dig up topsoil and other ground, ISR prevents waste stockpiles and holes in the ground at the end of the process.

The metal extraction involves pumping solution through the fractured rock and back to the surface and requires a relatively small amount of infrastructure at the surface.

ISR is not without its challenges and an appropriate ISR target must have suitable geology and hydrology along with other environmental safeguards. The challenges of rock fracturing and mineral extraction will also result in lower production recovery rates than using conventional mining and surface leaching methods.

These economic and environmental factors were among many discussed at the Cutting Edge Science Symposium on ISR at the Australian Minerals Research Centre in Perth in late 2014.

CSIRO brought together 77 key local and overseas participants and potential ISR partners from the mining and petroleum industries, universities and other research houses, industry service providers and regulatory bodies.

It was the first ISR symposium convened by CSIRO, and was unique in that it examined the potential of ISR to be an alternative recovery approach to those currently used for any metal or element (compared with other ISR conferences that have focused on uranium).

Participants examined the knowledge and capabilities that can be applied or adapted to *in-situ* extraction of various commodities, including geology; hydrology; hydrometallurgy; regulatory, environmental and social impacts; and techno-economics.

The symposium was the first step towards identifying the main challenges and knowledge gaps that need further work, with the aim of developing a road map to meeting those challenges.

Dr Paul Breuer, the Team Leader of Gold Processing in CSIRO's Mineral Resources Flagship, identified the key technical challenges for ISR in hard rock deposits as:

- measuring the porosity and permeability of rock types and how to maximise permeation
- creating direct access pathways to the desired mineral/element
- demonstrating and gaining acceptance that ISR is an economically sustainable technology with reduced environmental risks.

"The fracturing needed is a challenge particularly in hard rock orebodies at depth where there isn't permeability to start with, and where you can't pump the solution past the minerals you're trying to recover," Dr Breuer said.

"We need to understand how to create these pathways to the desired mineral. There's a lot known about technologies used in blasting every day, for example hydrofracturing used for block caving in coalmines, but these haven't been applied to ISR applications."

The difficulty in obtaining an accurate evaluation of whether a deposit is suitable for *in-situ* recovery, from the limited exploration and resource drilling material, is also an issue.

Researchers are aiming to increase confidence in ISR by establishing an evaluation template. More accurate indications of the project economics from laboratory analysis rather than field trials would reduce the timeframe and cost of evaluations.

Working at the wellhead of an *in-situ* mining operation. *Source:* Heathgate Resources

Deep open pit mine – *in-situ* mining can be an alternative to open pit mining for some operations

Dr Dave Robinson, the Group Leader of Base and Precious Metals in the same Flagship, said a lot of great technology has been independently developed for drilling and fracturing.

"Now it's time to pull all this work together and see what's left to solve so that we can turn this into a technology that benefits the industry and the environment," he said.

To make a deposit amenable to ISR, all aspects had to be considered collectively.

"CSIRO and our partners are well positioned with capabilities and networks to coordinate a path forward for the development of ISR," Dr Robinson said.

"Our long-term goal is to develop ISR as an alternative technology for extracting lower grade resources not economically accessible using conventional methods.

"Changing the economic paradigm of orebodies will stimulate the industry. At the same time we can examine the environmental and social implications of the technology and work with the community and legislators to develop responsible ways forward."

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It has the potential to halve the costs of conventional mining by avoiding the need to bring rock to the surface for crushing, milling and processing ...

The bugs that boost leaching

Naturally occurring 'bugs' such as bacteria and archaea may hold the key to a technology that can turn low grade deposits into economic projects. TONY HESELEV reports

Bacteria, those microscopic organisms, are among the unlikely heroes for researchers and mining companies working to establish economic methods to access difficult to extract or low value ores.

Biohydrometallurgy (or biomining) uses certain microorganisms to recover precious and base metals from mineral ores, concentrates and waste materials, by helping to process target minerals or elements.

Natural microorganisms catalyse chemical reactions, which lead to the dissolution of metals from minerals. This process has been used in commercial operations to extract copper, nickel, cobalt, vanadium, zinc and uranium from complex ores.

Copper has been the most common base metal extracted with bioleaching and according to some estimates, bioleached copper represents up to 15% of the world's copper production.

Bio-oxidation has also been used to treat sulphide containing gold ores before leaching of the gold using chemical reagents. This has environmental advantages of reducing the consumption of hazardous chemical leaching reagents such as cyanide.

Bio-oxidation can also produce more stable waste products, which reduces the risk to the environment as a result of the mining process.

Biohydrometallurgy has the potential to transform uneconomic reserves into viable ventures due to the low cost of allowing microorganisms to do the work. It can be attractive for low grade ores that are too expensive to mine using conventional processes or that contain impurities that foul conventional processing equipment.

The most common method of biohydrometallurgy in Australia is the oxidation of refractory gold minerals in tanks.

Another method – known as heap bioleaching – involves constructing a small hill and using microorganisms to extract the target metals.

The heap is aerated from the bottom to keep the bugs alive, and acid containing the bugs trickles from the top, percolating through the air spaces, and the target material is extracted in leachate.

The listed Australian-based nickel sulphide explorer and producer, Western Areas, took over the BioHeap® business developed by Pacific Ore (Australia) Pty Ltd in 2009.

BioHeap® is an internationally patented bacterial leaching technology that uses proprietary microbial cultures to leach or 'liberate' valuable metals from sulphide ores, and provides amenability, column and pilot testing services for other miners.

The company says that nickel, copper, cobalt, zinc and refractory gold ores are all suited to BioHeap® processing.

The bugs, which come from land and sea, are grown and maintained in a 'soup' mixture at the company's Perth laboratory.

Craig Fitzmaurice, Group Metallurgy Manager of Western Areas, said: "BioHeap® uses a range of microorganisms that were originally sourced from nature but have been adapted over time using proprietary methods."

"The BioHeap® process has been shown to operate at temperatures ranging from 15°C to 95°C. The mixed BioHeap® cultures contain a range of microbes that together can span this wide temperature range."

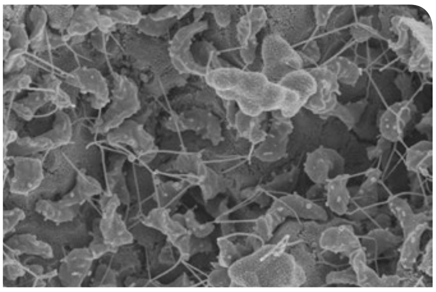
Biomining could also be used in conjunction with *in-situ* leaching. For example, biological recovery agents could be generated in bioreactors placed on top of or near the target deposit to prepare the required solutions for *in-situ* recovery.

CSIRO researchers look for microorganisms that can tolerate a range of conditions (including heat, elevated concentrations of chloride, sulphate and metals) in leaching processes. The researchers have found bioleaching microbes in mine sites and acid sulphate soils in the West Australian wheatbelt.

These salt-tolerant microorganisms have been used to develop bioleaching cultures that could be used for biomining operations where fresh water is scarce or where the leach liquors are salty.

Heap bioleaching of copper

Biooxidation of refractory gold ores in bioreactors



Bioleaching bacteria on chalcopyrite ore

CSIRO has collaborated with several mining companies in Australia and overseas in base metal and precious metal spheres for developing and optimising biohydrometallurgical processes.

Dr Anna Kaksonen, who is Research Team Leader of Bioprocess Technologies and Environmental Engineering at CSIRO, lists examples of potential new uses of biomining as:

- bioleaching of oxide ores
- bioleaching of rare earth elements from low grade ores
- biological recovery of metals from waste materials and
- separation of minerals through bioflotation.

In the latter case, microorganisms or their extracellular material can change the surface chemistry of the minerals, enabling their selective separation.

Microbes may also be able to remove unwanted or penalty elements from ore. For example, microorganisms can be used for removing phosphorus from iron ore.

Dr Kaksonen's team has also developed bioprocesses that can remove contaminants from hydrometallurgical solutions and effluents.

Biohydrometallurgy has already been applied to a range of sulphide minerals and refractory gold ores containing pyrite, pyrrhotite and arsenopyrite, according to Dr Kaksonen. It could also be used for recovering metals from waste materials such as slags from smelters, converter sludges and electronic waste.

"Biohydrometallurgy has already been conducted in heaps/dumps and reactors at commercial scale," she said.

"Future developments could lead to its large scale application in vats and in situ-type environments."

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CSIRO's Christina Morris working with bioleaching microorganisms in the lab

The **rare earth** CHALLENGE

While not especially rare and not really earths, there is no doubting the difficulties in mining and processing the rare earth group of metals, or their importance to the global economy. TIM TREADGOLD reports

Without the 15 elements which make up the immediate rare earth family, plus two close relations, a number of new and critically important technologies could not work.

From flat-screen computers and smartphones, to wind turbines, lasers, microwaves and high-strength magnets, chances are that one or more rare earths have been used in their production.

While the uses continue to grow for rare earths such as lanthanum, neodymium and samarium, along with their 'cousins', yttrium and scandium, the underlying business of finding, extracting and refining them has changed little over decades.

There are a number of reasons why development of new methods has been slow including the fact that rare earths are often found in complex geological settings with multiple ore types and industry has generally required only small amounts of each element.

Adding to those issues are the challenges of erratic price movements affecting investment decisions and the dominant role of one country in the rare earth business. China accounts for more than 90% of global rare earth production and at one stage accounted for 97% of production.

It is China's dominance which helps keep rare earths at the top of the 'risk list' compiled by the British Geological Survey which assesses the importance of minerals needed 'to maintain our economy and lifestyles', and China's dominance which has inhibited the entry of rival producers and the development of new technologies to process rare earths.

"It is a complex industry which can be especially difficult for new entrants," said CSIRO's Chris Vernon, who has spent a number of years studying the rare earths industry.

"A starting point in understanding the complexity is that while most of the rare earth elements are reasonably abundant in the earth's crust they do not occur in easily mineable concentrations."

Cerium, one of the 'lighter' rare earths, is the 25th most abundant element which means it is as common as copper, but it is not often found in distinct economic deposits.

That means the first step for a company trying to enter the rare earths industry is to thoroughly understand the composition of a discovery, especially the breakdown between heavy and light earths.

As a general rule heavy rare earths, those with a higher atomic number, attract a higher price than light rare earths - those with a lower atomic number. This is partially due to comparative rarity, but also because the heavier rare earths are becoming essential to modern living, used in LEDs, lasers and powerful magnets.

But, even when an orebody's composition is well understood it is difficult to establish a clear pricing structure because of the control on the market exerted by Chinese producers and variable levels of supply and demand.

Marketing is very much the job of the mining company involved. Where CSIRO is playing an important role is in helping to understand orebodies and helping to design process routes.

Table 1: Rare earths and their uses

Name	Symbol	Atomic Weight	Used in
Lanthanum	La	138.91	Cracking catalysts in petroleum refining. Lasers. Green phosphors.
Cerium	Ce	140.12	Glass polishing, catalysis, component in phosphors.
Praesodymium	Pr	140.91	Pigment (yellow), optical properties in fibre.
Neodymium	Nd	144.24	Permanent magnets, lasers, filters in welding goggles.
Samarium	Sm	150.36	Permanent magnets, lasers, optical and microwave devices.
Europium	Eu	151.96	Phosphors.
Gadolinium	Gd	157.25	Phosphors and scintillation agents. Contrast agent in medical X-rays.
Terbium	Tb	158.93	Phosphors, lasers and magneto-optic recording systems.
Dysprosium	Dy	162.50	Additive to Nd magnets to improve temperature properties.
Holmium	Ho	164.93	Strong magnetic and microwave properties – niche scientific uses.
Erbium	Er	167.26	Phosphors, fibre-optics, lasers.
Thulium	Tm	168.93	Lasers, portable X-ray generators, magnetic and microwave uses.
Ytterbium	Yb	173.04	Silicon photocells and strain gauges.
Lutetium	Lu	174.91	X-ray phosphors and X-ray detectors.
Yttrium	Y	88.91	Phosphors and microwave generators.

... our rare OPPORTUNITY

"Finding better and less energy intensive ways to extract rare earths from an ore body is high on CSIRO's research agenda.

Liberating rare earths is typically not easy because of the way the elements are tightly locked into complex orebodies.

"Part of our work has been focused on the conventional rare earth process routes and part is on finding new and better ways to extract the elements," Dr Vernon said.

The currently preferred treatment method is quite extreme in the way it uses acid, heat, and pressure. It is not only expensive but can cause environmental issues.

"We have made good progress in understanding different ores and in changing the conditions for dissolution, including the identification of ways to use much less heat and acid," Dr Vernon said.

"Instead of assuming that everything has to be done under the most extreme conditions we look to understand the processing properties of each particular ore and tune the cracking and leaching conditions."

One possible way of doing that is to alter the crystal structure of the mineral of interest, a step that can be taken by fine-grinding or by heat.

"We're looking at ways that use less energy, particularly at hydro-thermal processes which attack the crystal lattice of the mineral.

"You can use a catalyst by putting in certain anions or cations which will promote that process," Dr Vernon said.

In the traditional route preferred in China, the solvent extraction stage, can require the mineral-rich solution to be passed through 100 stages.

"We're developing capabilities in synergistic solvent extraction (combining two commercially available extracts) which achieves better separations by tuning the process," Dr Vernon said.

"It becomes a significant cost saver because fewer stages of separation are required. It's a way of vastly reducing the number of solvent extraction stages needed."

While every ore is different and a range of trials with different inputs have been used to date, a 50% reduction in energy use is "in the ball park" of what is achievable, according to Dr Vernon.

Differences in the composition of orebodies is just a starting point for companies working in the rare earths industry. Further down the processing path, the next challenge is to separate the different elements, because they share a high degree of similarity, but great differences in demand and price.

The interest in the rare earths industry remains high despite its difficulties and a crowded field of potential starters.

As companies in the rare earth business, and CSIRO, develop their understanding of processing rare earth ores, Australia could become a world-class supplier of rare earth elements. ●

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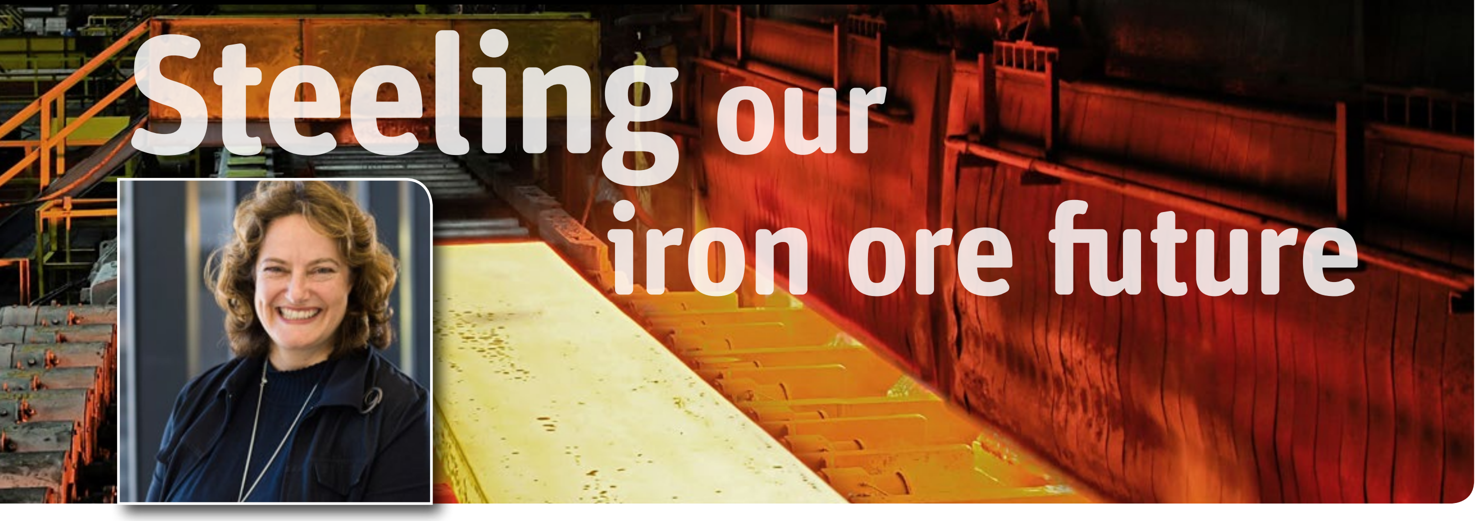

Steeling our iron ore future

Research and innovation is unearthing new tools and approaches for tackling current challenges and boosting viability and productivity, at a time when the plunging iron ore price is casting a shadow over the future of the industry. ANNA LITTLEBOY reports

Australian iron ore producers are facing very challenging times and tough decisions in the wake of four years of declining iron ore prices and the recent plunge below US $50 a ton.

The profits and expansion possible during the mining boom that saw iron ore price rise over six years to $1.80 per ton in 2011 are clearly not possible in the current market.

Working to increase outputs is one way to increase returns. However this puts pressure on margins and on the long-term sustainability of the industry.

The current iron ore predicament begs questions such as: 'is this the best time to sell large quantities of ore?' or 'should more be processed into niche or value-added steel products?' or 'should more be left in the ground to sell when the price is high?'.

Science, and a smarter approach to mineral resource development and innovation across the value chain can make an industry viable and sustainable where it otherwise is not. Survival in the current market almost demands such an approach.

Collectively, our aim is to gain the most value from our mineral reserves for our industry and nation, at least cost and environmental impact, for as long as we can.

Science and innovation can contribute to cost minimisation, to value adding opportunities and integrated approaches that assist smart decision making – and CSIRO and collaborators cover that entire spectrum.

Across the value chain from iron ore to steel we have some exciting work happening and breakthroughs being made, for example our:

Optical image analysis systems (including latest MINERAL4 software package) enables us to more readily characterise and evaluate ore resources – this allows for efficient targeting of ores and has great potential to save time, energy use and costs

Strategies for predicting beneficiation and downstream processing performance – includes work relevant to the range of lower grade iron ore resources now utilised, ways to reduce water usage, optimise sinter, pellets and lump for blast furnace performance - all vital for the successful marketing and acceptance of Australian ores

Impurity removal techniques for taking out alumina, silica and phosphorus from lower grade ores via processes such as heat treatment and leaching, reverse flotation and microbe induced flotation. This is also crucial for the reputation of Australian ores in the marketplace.

Green steel – is also a visionary integrated process that CSIRO and industry partners BlueScope Steel and Arrium took on to lower the greenhouse gas emissions of our steelmaking and rekindle the industry. The two main components of this work are:

Dry slag granulation – iron blast furnace technology that is now being commercially scaled-up in China (see article page 17) will produce a cement product out of waste slag while saving heat energy and making enormous reductions in water use and greenhouse emissions.

Renewable charcoal instead of coal and coke – CSIRO and partners found that a third to a half of coal and coke used for steelmaking could be replaced with designer biochar – a charcoal produced through pyrolysis of plant matter and trees from plantations or waste streams from agriculture, forestry or wood processing. This has the potential to vastly reduce greenhouse gas emissions from the Australian steel industry, provide a renewable and sustainable source of blast furnace fuel and allow Australian steel to differentiate itself in the marketplace through its 'carbon-light' credentials.

Added to the above, some powerful technology and tools are available to support decision-making, process optimisation and environmental monitoring and social innovation.

In spite of the downturn in iron ore price, there is much going on to support a viable, and productive industry into the future.

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Global vision for 'green steel'

The vision for a cleaner, greener and more productive steel industry, moved a step closer with the recent signing of an agreement with a company in China to scale-up CSIRO's dry slag granulation (DSG) technology.

Ten years in the making, DSG is smart Australian technology that harvests blast furnace waste and converts it into a granulated product to make cement - saving water, heat energy and greenhouse gas emissions in the process.

An agreement, signed in March 2015 by CSIRO and the Beijing MCC Equipment Research & Design Corporation, paves the way for the industrial scale demonstration and introduction of the DSG technology.

CSIRO Director of the Mineral Resources Flagship, Jonathan Law, hailed the agreement as a landmark for Australia-China research collaboration and planet-friendly steel production.

"Our collaboration is an exciting step towards the uptake of an innovation with real prospects of transforming the productivity and environmental performance of global iron smelting," Mr Law said.

"If all steel production on the planet used dry slag granulation each year it could save the equivalent of 14% of Australia's energy use, 10% of the nation's greenhouse gas emissions, and enough water to meet a quarter of Melbourne's residential water need."

The DSG technology that is fitted to blast furnaces includes:

- a spinning disc and surrounding granulation chamber that separates molten slag into droplets under centrifugal forces,
- use of air to quench and solidify the droplets,
- extraction of a granulated slag product
- system to extract heated air.

To overcome the challenges of converting molten slag at 1400°C to uniform dry slag without the use of water, research group leader, Dr Mark Cooksey said the CSIRO team had to fine-tune the shape of the spinning disc and the surrounding chamber with a unique system for blowing in cool air, collecting granulated slag at the rim and piping out air at 600°C.

"The 'glassy' product is ideal for cement manufacture, and has significantly lower associated greenhouse gas emissions than cement produced by conventional methods," Dr Cooksey said.

"DSG also saves water when compared with alternative wet granulation processes and avoids potential underground water pollution.

"The bonus is that the heated air extracted from the DSG process can be used onsite for drying, preheating or steam generation."

In entering the collaboration with MCCE, CSIRO has recognised the R&D reputation of the Beijing-based company and its ability to scale-up the technology and introduce it into China - where 60 per cent of the world's 300 million tonnes of iron blast furnace slag is produced each year.

Under the agreement MCCE is to scale-up and demonstrate the technology at industrial scale and, upon success, commercialise it in China and then potentially worldwide.

The agreement is the culmination of more than a decade of DSG technology development by CSIRO and industry partners including Arrium and BlueScope.

This work covered initial design and proof of concept stages through to the construction and operation of prototype DSG pilot plants at small, intermediate and large scales.

"DSG is just one of the CSIRO innovations in sustainable steel production and one of many solutions we have found for national and global challenges in the minerals industry," Mr Law said.

"We're exporting green technology to complement our raw material exports, which I think is a really good story for Australia and our role as a global citizen."

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Seafloor
– the new frontier

The mineral riches of the world's ocean floor are on the verge of being tapped following advances in technology, growing demand for resources and legal frameworks that make exploration and mining possible. ROGER NICOLL reports

Sampling drill cores extracted from the seafloor

Seafloor ores have long been seen as the next frontier for resource exploration and extraction. Technical and logistical challenges of working in remote, deep sea locations, along with concerns for the ocean environment, have been key barriers in the past.

Depressed world metal prices and the availability of resources from land operations in the developing world, have also delayed the desire to pursue this opportunity. However, as land resources are depleted, attention has shifted back to the massive seafloor sulphide deposits that are rich in copper, gold, silver and zinc.

Canadian company, Nautilus Minerals was the first company to explore the ocean floor for polymetallic seafloor massive sulphides and to be granted a lease and environmental permit to mine such deposits.

Nautilus are gearing up to mine at a site known as Solwara 1, at 1600 metres depth in the territorial waters of the Bismarck Sea off Papua New Guinea.

"Given that 70% of the planet is covered by water and that significant high-grade mineral resources have been identified on the ocean floor it makes sense for the mining industry to move offshore in much the same way the oil and gas industry did 50 years ago," said Mike Johnston, CEO of Nautilus Minerals.

"Solwara 1 has a copper grade that is more than ten times higher than the average copper grades we find on land," Mr Johnston said. "The deposit is about seven per cent copper but is also comes with gold of six grams per tonne on average and up to 20 grams per tonne in some areas."

To overcome the technical and environmental challenges of operating safely and effectively at sea and on the seafloor, Nautilus along with partners, Soil Machine Dynamics and GE Oil & Gas have designed the key 'seafloor production tools' (see Figure 1) and the 'riser and lifting system, namely:

- the auxiliary cutter to pioneer and prepare the rugged sea bed
- the bulk cutter to excavate material once the auxiliary cutter has set up the site
- the machine to collect and draw the mined material, as part of a seawater slurry, through a flexible pipe to the subsea pump, and on to the production support vessel via the riser and lifting system.

"We are delighted that factory acceptance testing of the seafloor production tools has been completed and are excited with the next stage of commissioning and wet testing of the seafloor machines to begin soon," Mr Johnston said.

Powerful hydraulic cranes will be used to lift the cutting machines out over the vessel and carefully deploy and lower them into the ocean.

The riser and lifting system will be a 'closed system' that, according to Nautilus, will:

- receive the slurry from the collection machine
- use a subsea lift pump to push it through the 12-inch risers to the production vessel
- separate ore and water onboard the vessel
- pump clean and filtered water back down the two 8-inch riser pipes to drive the main pump.

Massive seafloor sulphide deposits like this are rich in copper, gold, silver and zinc

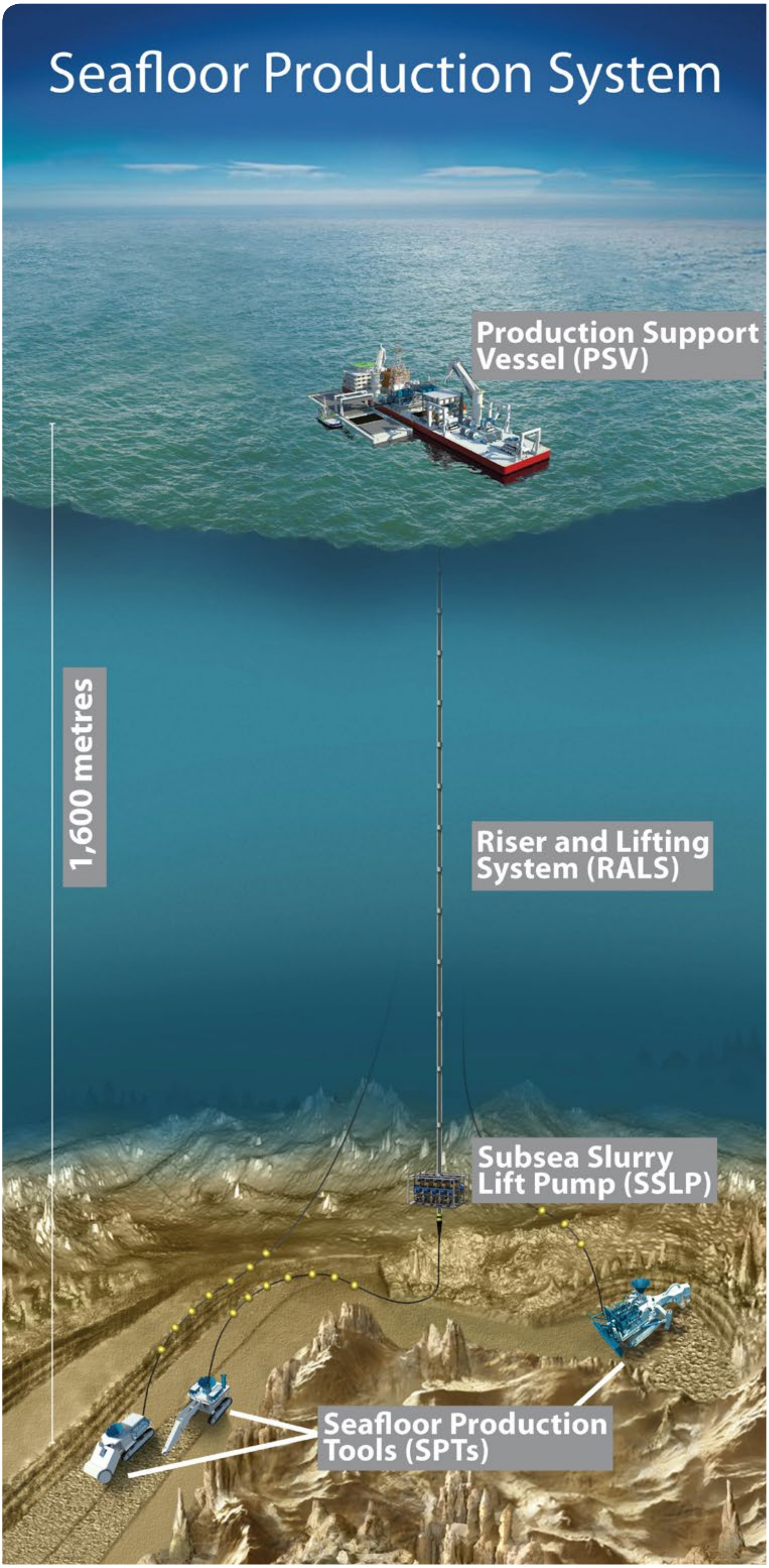
... it makes sense for the mining industry to move offshore in much the same way the oil and gas industry did 50 years ago.

In addition to its seafloor mining agreement with PNG, Nautilus holds more than 100 active prospecting licenses in Tonga, Fiji, the Solomon Islands and Vanuatu. It is one of a growing number of entities looking to develop seafloor mining resources through agreements administered through the International Seabed Authority (ISA) established by the United Nations for managing development of the open ocean for the benefit of all mankind.

“As part of our joint venture Agreement for Solwara 1, PNG has an initial 15% interest in the Project and a significant long term interest that will ensure the ongoing economic benefits for the State and the Province of New Ireland,” Mr Johnston said.

In November, 2014 Nautilus entered into an agreement to charter a vessel with Marine Assets Corporation (MAC) which will own the vessel and provide marine management. Subsequently MAC entered into a contract with Fujian Mawei Shipbuilding to design and construct the vessel in accordance with Nautilus’ specifications.

“We are excited to achieve this significant milestone and look forward to the building of the production vessel for delivery in late 2017 and to make seafloor mining a reality,” Mr Johnston added.



up next in resourceful ...

In Issue 8 of **resourceful**, we will look at our resource reserves and security, the latest technologies and innovation to extend life in use, recycle and recover wealth from waste and to advance a circular economy.

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THE CONVERSATION

The smell of rain: how CSIRO invented a new word

The word 'petrichor' was invented by CSIRO scientists Isabel (Joy) Bear and Richard Thomas to describe the distinct odour of rain in the air. Derived from the Greek 'petra', meaning stone, and 'ichor', meaning the ethereal blood of the gods, the name was given to the oil released from the earth into the air before rain begins to fall.

Originally published in Nature in 1964, Bear and Thomas found the aroma itself comes about when increased humidity – a pre-cursor to rain – fills the pores of stones (rocks, soil, etc) with tiny amounts of water and is enough to flush the oil from the stone and release petrichor into the air. This is further accelerated when actual rain arrives and makes contact with the earth, spreading the scent into the wind.

https://theconversation.com/the-smell-of-rain-how-csiro-invented-a-new-word-39231

Sea level is rising fast – and it seems to be speeding up

Many observations have shown that sea level rose steadily over the 20th century, and faster than previous centuries, according to **Christopher Watson**, University of Tasmania *et al*. Satellite and coastal observations have shown seas have risen faster over the past two decades than they did for the bulk of the 20th century.

Sea level varies from year to year, as water is exchanged between the land and oceans (for example during the Australian floods associated with the 2010-11 and 2011-12 La Niña events), and as a result the observed increase in the rate of rise over the short satellite record is not yet statistically significant.

Understanding of sea-level change is incomplete, particularly when it comes to forecasting contributions from the ice sheets. Currently, observed sea-level rise is consistent with the most recent IPCC projections.

https://theconversation.com/sea-level-is-rising-fast-and-it-seems-to-be-speeding-up-39253

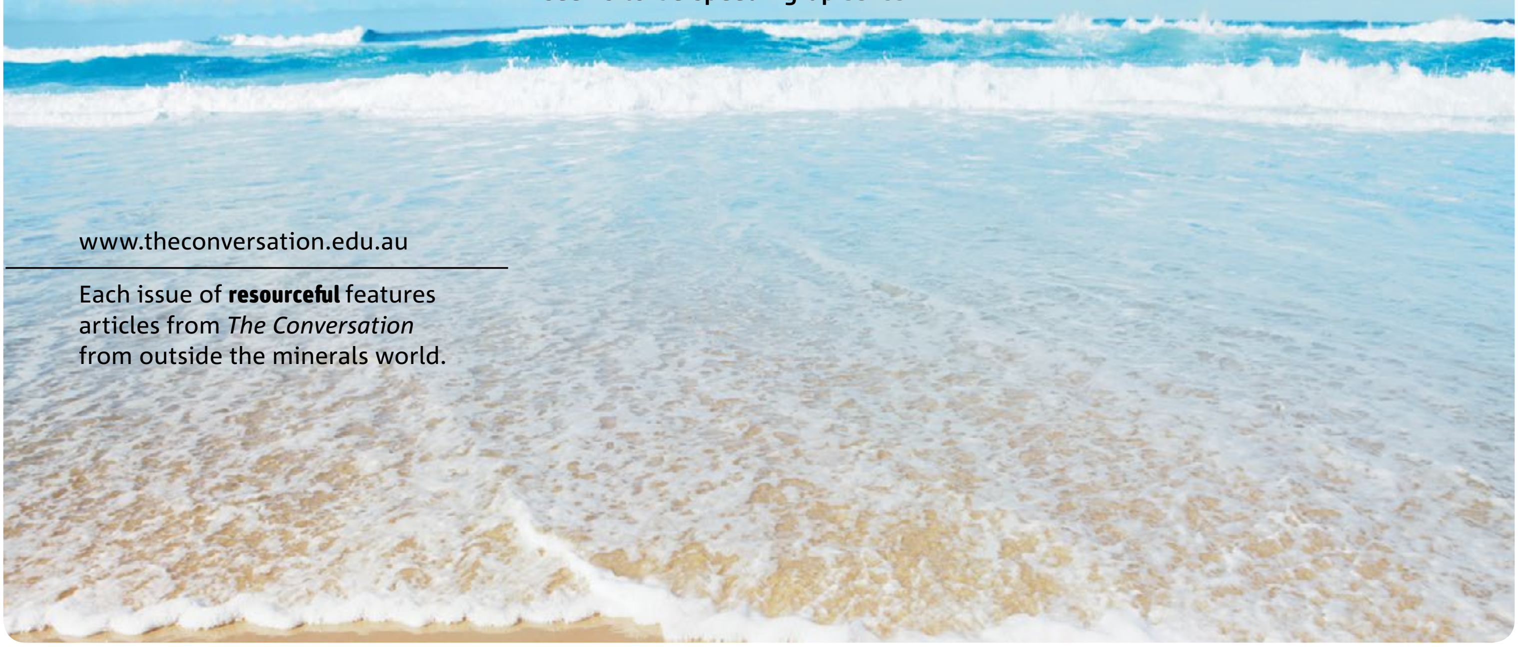
Big Data and keeping things private

Massive volumes of data about us are collected from censuses and surveys, computers and mobile devices, as well as scanning machines and sensors of many kinds writes CSIRO's **Christine O'Keefe**. But this data can also reveal personal and sensitive information about us, raising some serious privacy concerns.

Traditionally, the data custodians responsible for granting access to data sets have sought to protect people's confidentiality by only providing access to approved researchers. They also restricted the detail of the data released, such as replacing age or date of birth by month or year of birth.

The rapid technological advances in our society are creating more and more data archives of many different types. It's vital that we assess the ethical and privacy risks from secondary use of this data to reap the potential benefits from access to the information.

https://theconversation.com/big-data-is-useful-but-we-need-to-protect-your-privacy-too-40971



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Each issue of **resourceful** features articles from *The Conversation* from outside the minerals world.