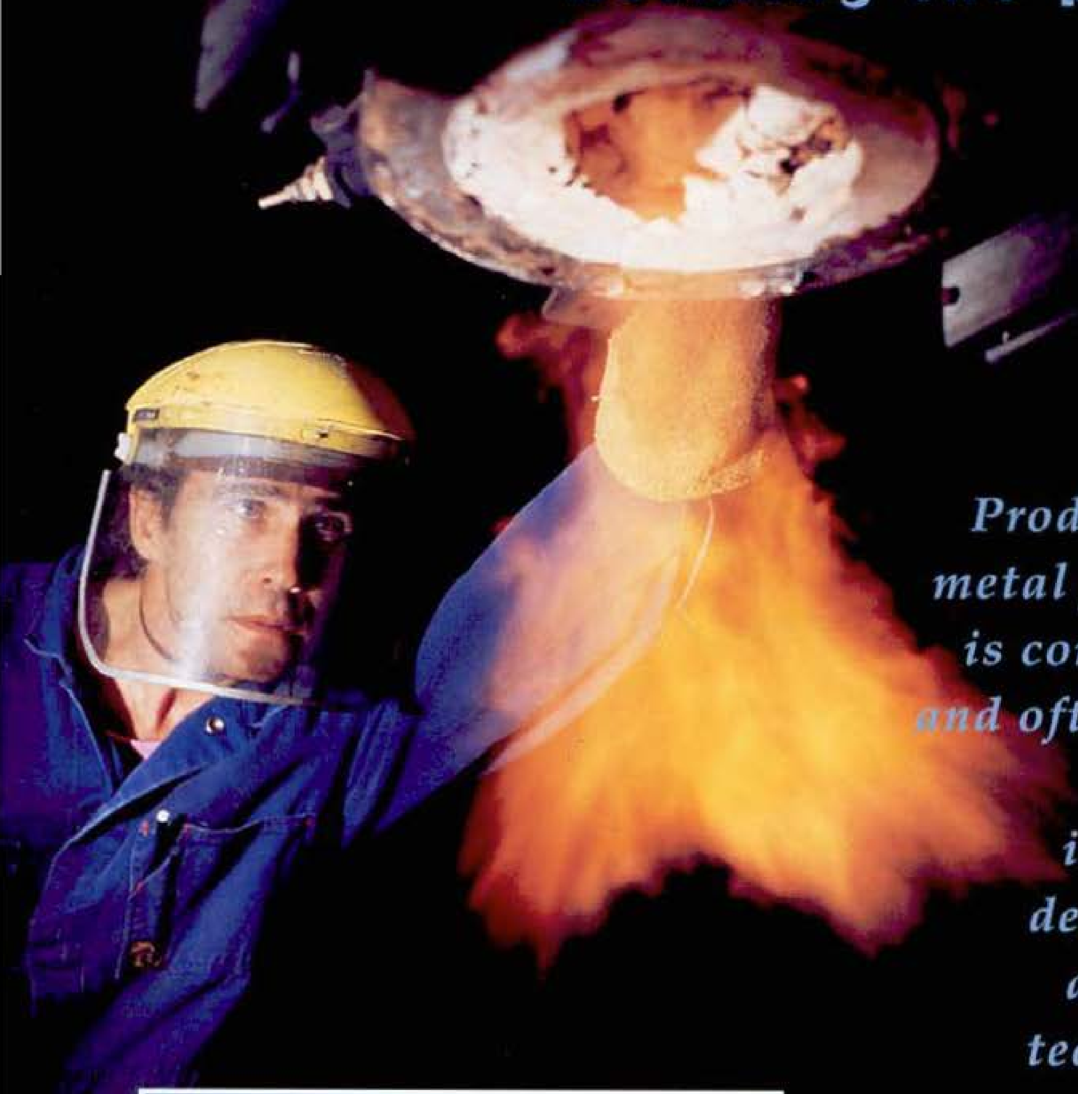
Mineral extraction

Refining the process



Producing refined metal from raw ore is complex, costly and often polluting. Australian industries are developing and adopting new technologies to improve their international competitiveness, as well as protect the environment.

Colin Tregenza

We depend on minerals for our high standard of living: from the steel beams that hold bridges and buildings together, to the copper wiring in fridges and the lead batteries in our cars.

Minerals are also vital to Australia's economic success. The minerals industry comprises 53% ($25 billion) of our commodity exports (including coal, minerals and basic metal products to ingot stage).

It is possible to fossick for gold, silver or copper occurring as discrete, pure elements, but the chances of finding any are slim. The economic reality is that nearly all minerals must be liberated from rock and separated from other elements. For example, iron is found in hematite (iron oxide); lead is found in galena (lead sulfide) and copper is found in chalcopyrite (copper, iron sulfide).

Separating these minerals from the host rock is neither simple nor cheap. The processes required can be divided into three main steps: mining, concentration of valuable minerals, and extraction.

Crushing and grinding the rock into small particles physically liberates the minerals from the host rock and from one another. Mineral particles in coarse-grained lead/zinc ores may be 100 microns across. In complex, fine grained ores, far more grinding may be necessary to liberate mineral particles of less than 10 microns. The mineral is then separated from the waste material to form a concentrate, using processes such as froth flotation or magnetic separation.

The concentrate, however, still contains some unwanted material and the desired metal is most often bound to sulfur or oxygen. Extracting the metal involves chemical solution processing or smelting. In a smelting furnace, lead sulfide or iron oxide, for example, are separated from other minerals and reduced to lead or iron ready for refining.

Each extracting and smelting process adds value to the product, but sometimes this comes at the expense of the environment. For example, because most base metal ores come in the form of sulfides, sulfur dioxide is emitted during smelting. It can then form 'acid rain' (H_2SO_4).

Climatic, geographic and population density factors combine to make this a severe problem in North America and Europe. As a result, sulfur dioxide emission in these countries is strictly controlled. Such restrictions are likely to be introduced to Australia in future, although with its relatively dry climate and sulfur-deficient soils, the problem is of a lower magnitude.

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Other pollutant gases include hydrogen fluoride from aluminium electrolytic processing and hydrocarbons and volatiles from coke-making (used in blast furnaces). Slag – the waste material which is left after smelting – consists of complex mixtures of silica, alumina, calcium and iron oxides and even nasties like arsenic.

Traditionally, these slags have been used in road-making or as landfill. But due to concerns about these materials leaching into watertables, tougher environmental standards are being enforced around the world. Other solid wastes include heavy metals rejected during concentration of the desired mineral and the black mud which remains after washing coal.

Finally, because mineral processing and smelting can be high energy users burning fossil fuels, they contribute significantly to greenhouse gas emissions.

Efficiency and waste

Improved processing methods to help Australia's minerals industry compete in a competitive world market are being developed at CSIRO's Division of Mineral and Process Engineering. Fortunately, many of the new methods being adopted by processors not only cut costs, but also auger well for the environment.

In some cases, mineral processing technology has even helped to meet environmental challenges in other areas. For example, flotation, used in concentrating minerals, has been adapted to treat liquid waste (see 'Foam flotation an efficient waste treatment', *Ecos* 76).

Chief of the division, Dr Rob LaNauze, says the key to developing better mineral processing technologies is to minimise the amount of waste produced. Many of the advances made by the division have enabled the utilisation of by-products formerly treated as waste. Technologies designed to solve specific environmental problems include trapping very fine dusts containing pollutant metals; locking up toxic elements in slag; safe disposal of ferric chloride; and generating electricity from coal waste.

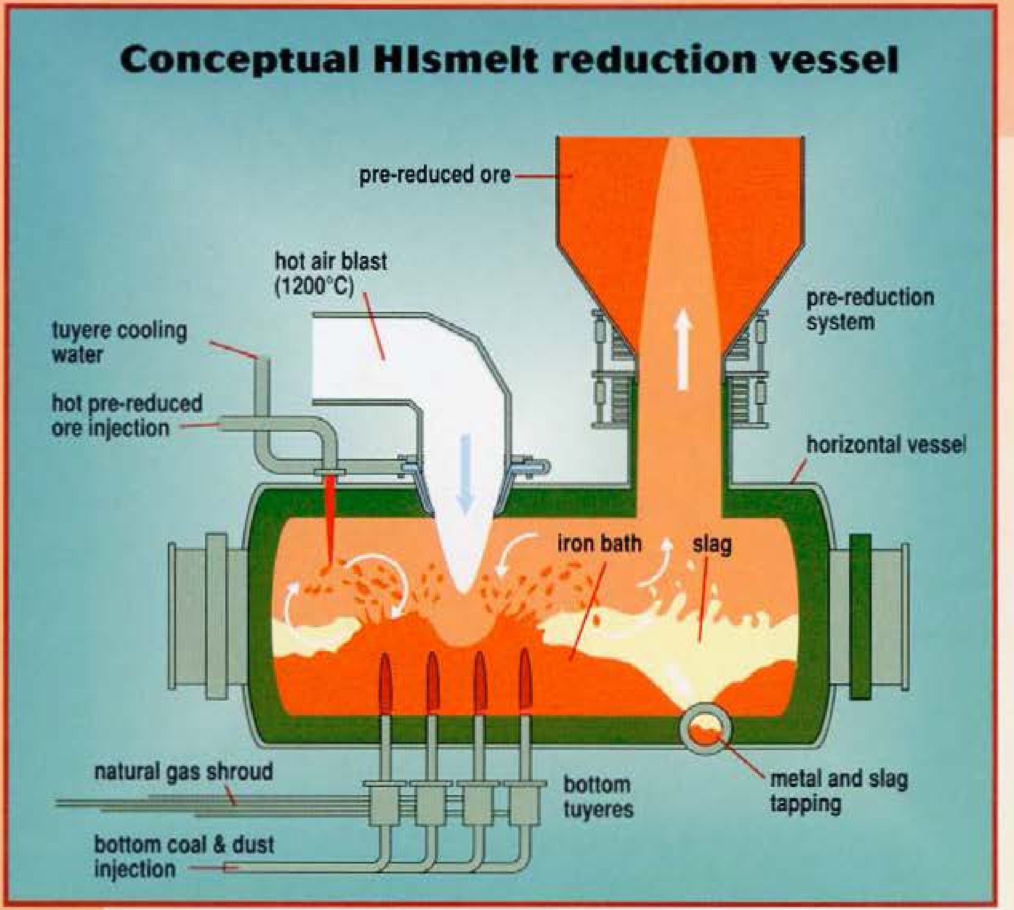
Toxic elements in slag

Toxic elements such as arsenic, which often occurs with nickel, must be separated out during processing. But it's not welcome as a free agent in the environment.

Researchers at the GK Williams Cooperative Research Centre, in conjunction with CSIRO, are experimenting with processes that lock arsenic up in slags in an inert form so it won't leach. (This is similar to the synrock developed to store radioactive waste.)

Initial work has shown that calcium ferrite slags display a much higher

Investing in direct smelting


Conceptual HIsmelt reduction vessel

After 10 years of development, a large-scale direct smelting pilot plant designed to overcome the environmental and economic limitations of conventional blast furnace ironmaking has swung into operation.

The $100 million HIsmelt® Research and Development Facility at Kwinana in Western Australia has been developed to test the HIsmelt Direct Smelting Process, a technology designed to meet the needs of '21st century' ironmakers.

The HIsmelt facility is the product of a joint venture between Australia's CRA Limited and Midrex USA, a world leader in direct reduction technology. Scientists and engineers from CSIRO's Division of Mineral Processing and Engineering have had a long involvement in its development.

For the next 12 months the HIsmelt facility will be evaluated for its conformity to the strict environmental and efficiency standards expected of 'new generation' direct smelting technologies. The eventual aim is to 'scale up' the process to a commercial plant of 0.5 to one million tonnes a year hot metal capacity.

But first, HIsmelt must prove able to demonstrate the potential for lower cost operation than its predecessors. Present blast furnace ironmaking technology has a number of limitations. These include: dependence on large scale for economics; the requirement for agglomerated or lump feed materials; reliance on a major proportion of fuel as coke; the ability to process a limited range of iron ores; a lack of operational and product flexibility; and adverse environmental impacts.

The HIsmelt Direct Smelting Process, on the other hand, can produce hot metal suitable for making quality steel from a wide range of iron ore fines (with minimum feed preparation) and can efficiently use a variety of coals. Unlike blast furnaces, it depends on high intensity, rather than large scale, for economic efficiency. Also, the technology will meet the future emission control standards.

A bath of energy

In the HIsmelt Direct Smelting Process, combustion reactions and heat transfer occur in the gaseous region above an intensely-stirred molten iron bath. In the bath, volatile components in coal are cracked to carbon and hydrogen. Iron ore is reduced by the dissolved carbon, liberating carbon monoxide gas. These bath reactions are all endothermic.

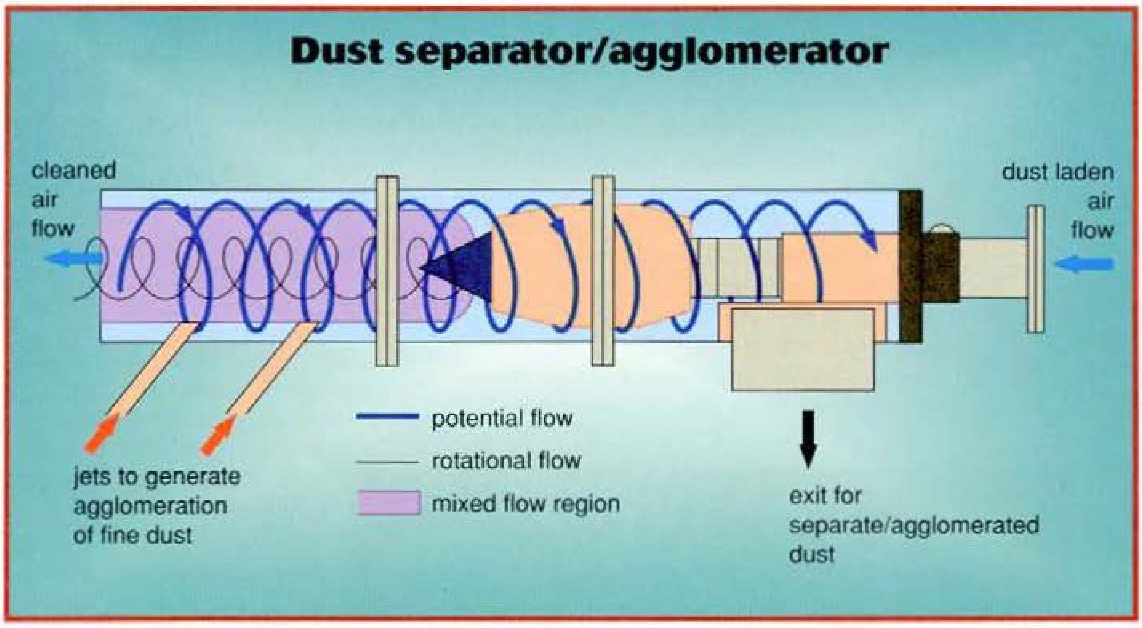
The large quantities of chemical and thermal energy in the gas leaving the bath are used to improve the heat balance of the process. This is achieved through high levels of post combustion of the liberated carbon monoxide and hydrogen combined with high levels of heat transfer efficiency. It's these two factors which make the process viable.

The chemical energy in the carbon monoxide and hydrogen is recovered by injecting preheated air and burning the gases to carbon dioxide and water vapour. Conditions are arranged so that the heat from these exothermic reactions is transferred to the iron bath, so maintaining a steady temperature for the smelting process. To transfer the heat (via radiation, convection and transfer to droplets thrown up from the bath), a high velocity jet of hot air (1200°C) is blown into the upper space of the vessel.

Iron can be produced more economically and in smaller quantities, tailored to market demands. With HIsmelt direct smelting, iron production becomes feasible at quantities of only 500 000 tonnes of iron, compared with the two to three million tonnes required for economies of scale in the conventional blast furnace route.

The environment will benefit in various ways. Less fuel is required to produce the same amount of iron. The process will also tolerate a greater range of coal types than conventional smelting and does not require iron ore particles to be sintered or pelletised before entering the furnace. Perhaps the greatest environmental benefit will result from the elimination of the coking process. Coke is unnecessary in the new process because coal particles are directly injected into the bath.

CSIRO's contribution to the project has involved laboratory testing the process fundamentals (in particular examining the way in which coals and iron ore react with the melt) and assisting development of the pre-reduction component of the process in which fine iron ore is partially reduced before entering the smelting vessel. The scientists have also used mathematical and physical modelling to examine flows of gases, solids and melts, an aspect critical to obtaining optimum process performance.



Dust separator/agglomerator

Dr John Hall and his team have developed an efficient method of trapping very fine dust, a by-product of the smelting process. Once it has been separated, the dust can be agglomerated with additives, ready for hardening into an unleachable product.

capacity for arsenic than the conventional iron silicate slags used in the non-ferrous industry.

Whiter than white

The same research partners are seeking a 'cleaner' method of processing minerals with chlorine.

At present, chlorine processing is mainly used in the production of titanium oxide, the pigment responsible for the white colouring in tiles, paints and plastic. The process could be used more widely in metal extraction and refining if ferric chloride, one of the less manageable by-products, could be eliminated or disposed of safely.

A Fluidised Bed Reactor system to dechlorinate iron chloride has been developed. It produces a benign form of ferric oxide safe to use as landfill, and chlorine gas, which can be recycled for use earlier in the process. A small pilot plant is being constructed.

Trapping very fine dust

An often troublesome by-product of the smelting process is the very fine dust (which can contain pollutant metals) emitted along with flue gases. Filters for trapping this dust tend to clog up, blocking the exhaust gas flue.

A horizontal tube which is simple and cost-effective is the key feature of a dust separation concept by Dr John Hall and his team at the Division of Mineral and Process Engineering in Melbourne.

The separator has no filters. Instead, very fine particles, down to one micron and below, are extracted using cyclonic air flows. The dust can also be agglomerated with additives: the particles are then large enough to flow freely (when they're very fine they are unmanageable). Ideally, the dust – with its pollutant metals – would then be hardened into an unleachable product.

Electricity from coal waste

The fine tailings of coal washery waste (the shale and dirt washed from coal) form a black mud which can't be revegetated. A conventional incinerator cannot burn this coal waste. But a fluidised-bed combustor can. The combustor, developed at CSIRO in the 1970s, is now a proven technology for all sorts of waste disposal including slurries containing 60% water.

Upward jets of air suspend a burning bed of fuel, ash and sand, encouraging efficient burning. The sand acts as a reservoir of heat. The volume of waste material is reduced by up to 80% and the resultant ash can be safely put back in the mine. (In Europe it is used in the manufacture of tiles and ceramics.)

Once started, the combustion process is self sustaining. In fact, electricity can be generated. At present about 30% of the coal that is washed is discarded as waste. Through fluidised bed combustion much of this energy could be recovered. LaNauze says processors could be using this coal 'waste' to generate power. This could then be sold to a state electricity grid.

With the drive to use public funds more effectively and concern over

More complex than the average vacuum. Cyclonic air flows, rather than filters, are used to trap very fine dust particles which can contain pollutant metals.

increasing stockpiles of coal washery waste, the climate may well be right for private generation of power, LaNauze says. In the United States, legislation has been introduced to encourage such schemes, which are operating successfully.

The technologies described above were developed to solve specific environmental problems, yet often yielded opportunities for increased efficiency. Other advances are efficiency-driven, yet lead to environmental gains. Following are some examples.

Sirosmelt and HIsmelt®

After many years of research and development, Sirosmelt is now firmly established in the commercial market. It is a type of bath smelting, like HIsmelt (see story, page 26), for non-ferrous metals involving an intense submerged combustion process.

As in HIsmelt, there is no need for a sintering stage and, compared with conventional blast or reverberatory furnace smelting, Sirosmelt is far more efficient, providing significant energy savings.

Isasmelt, an adaptation of Sirosmelt in use at Mt Isa Mines (MIM) compares favourably with the best in the world, according to the company's manager, marketing of technology, Bob Greenelsh. Greenelsh says the process is almost energy neutral: the energy generated from waste heat recovery drives the oxygen enrichment plant and almost no new fuel (coal) is required once the process is under way.

Slag is poured from a 50 kilogram Sirosmelt pilot plant. Sirosmelt is now firmly established in the commercial market.

Aluminium production

At present, electrolytic reduction is used to produce aluminium. In an electrolyte of aluminium fluoride, an electric current breaks down alumina (aluminium oxide) into aluminium metal and oxygen. This process, however, uses a great deal of energy and hydrogen fluoride gas can be given off.

A team led by Dr Raj Rajakumar is investigating an alternative carbothermic process. They have a number of problems to consider.

Very high temperatures are required to reduce aluminium oxide with carbon because it is stable compared with, for example, iron oxide. Aluminium and carbon monoxide gas (which can be burnt to carbon dioxide, giving power) are produced. Unfortunately, various nasties (carbides and oxycarbides) are also produced. As knowledge of the thermodynamics and kinetics of the process increases, researchers hope to gain more control over the reactions.

Although the whole research and development process may take many years, the potential advantages provide a great incentive: savings in energy; increased efficiency and control; the elimination of various environmental problems such as hydrogen fluoride in the waste gas; and the safe disposal of spent electrolytic pot liners.

In the meantime, improvements to the current electrolytic process continue to be made. Researchers are experimenting with inert anodes which will not be consumed while collecting the aluminium. This results in increased efficiency because the distance between cathode and anode will not vary once set at the most efficient distance.

The Australian Aluminium Development Council is partially funding field trials of a hydrogen fluoride laser monitoring system. It measures concentrations of the gas both in and around aluminium smelters and will alert plant operators when one of the many electrolytic cells goes 'off spec'.

Modelling and measurement

Mineral processing and smelting processes cannot simply follow fixed recipes because the ingredients often vary in quality, size or amount. Improved measuring technology is constantly being sought.

The Coalscan gauge, developed by the Division of Minerals and Process Engineering, monitors the levels of mineral matter, ash, moisture and coal during various stages of processing. Using this information, feedback systems can adjust processing conditions to control the quality of the coal and the levels of potential pollutants, and to maximise output.

Processors using Coalscan have increased coal recovery by 3-4%. Energy savings result because less coal needs to be mined for the same output. More than 200 Coalscan gauges have been sold worldwide by the manufacturer Mineral Control Instrumentation Ltd.

The division has also developed a monitoring tool, QEM*SEM, that provides off-line, particle by particle mineralogical analysis.

Designing cost and energy-efficient plants requires accurate information about mineral distribution at various points during processing. QEM*SEM, developed at CSIRO, provides off-line, particle by particle mineralogical analysis.

As the more attractive, coarse-grained ores are mined out, measurement of the more complex, fine grained ores will be critical in determining their viability for processing.

Greater control

The move to smaller, more compact and efficient processes together with sophisticated measuring instruments means more control over mineral processing and smelting, and, therefore, over production of wastes. Greater efficiency also means fewer wastes are produced and with energy savings less fuel is used and therefore less greenhouse gases produced.

An efficient, competitive mineral processing and smelting industry is vital for Australia's economic wellbeing; so it is fortunate that the drive to efficiency and to improve waste production and disposal are often complementary.