AUSTRALIAN LEVERAGE TO GLOBAL CARBON NEUTRALITY

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ABSTRACT

The global ESG compliance push is affecting almost all businesses, and supply-chain emissions are doing the front running. Emission reductions inherent in the renewable energy sector are the perceived as a climate-change savior; however, that sector relies on the minerals industry, which not only supplies it with raw-material inputs but also leads the way in recycling end-of-life materials to maintain sustainability and minimise carbon footprints. Indeed, a vast range of critical minerals is required to maintain the very existence of renewable energy and the battery back-up necessary for storage and grid levelling. The battery industry, an insatiable consumer of minerals, is thus an integral part of the drive towards carbon neutrality and greening of the planet.

Australia occupies a unique position in the supply chain being developed for carbon neutrality, since it is a significant source of many of the resources required – among them nickel, cobalt, manganese, lithium and rare earths. That supply chain starts with exploration and mining to feed the downstream processing and manufacture of the materials being created to electrify the world, including domestic, industrial and transport applications. But that’s not the end of the materials lifecycle; what happens to spent materials at the end of each product's life must also be considered.

Reducing carbon footprints involves more than examining ways of shipping of nickel, cobalt, lithium, iron and phosphorous to battery producers to fashion into storage devices, as indeed it takes more than the mining of rare earths to produce high-performance magnets, or the production of copper to expand power grids. Lifecycle optimisation must also extend into high-technology manufacturing areas.

As the source of a large proportion of the world’s critical minerals, Australia has the greatest potential of any country to reduce carbon footprints by down streaming its mineral products into things like refined metals, magnets, motors, wind turbines, battery chemicals, precursors, anode and cathode active materials, cells and batteries. But if such downstream production is necessary, Australia cannot simply rest on its laurels and keep producing the same minerals it did before (including nickel for the production of ternary cells). Should it not instead backward-integrate from a product with superior lifecycle attributes and mine accordingly to produce that product? As Australia strives to adopt the best available technologies to supply precursors, cathode powders and, ultimately, batteries for renewable energy storage, lithium ferro phosphate (or LFP) is a case in point. For OEMs, advanced materials like LFP can provide previously unrecognised advantages in relation to reducing carbon emissions.

Advanced metallurgical techniques currently being developed by Australian companies as part of ‘urban mining’ – that is, the rebirthing of the critical materials in end-of-life products – provide further environmental benefits.

One could say, then, that Australia has the ultimate leverage in terms of global decarbonisation.

Keywords: ESG, legislation, sustainability, lithium, battery, critical materials, emission reduction, Australia, carbon neutrality.

INTRODUCTION

The global push to carbon neutrality has lit legislative fires around the globe and influenced policy on resource development. The push is impacting all aspects of daily life, none more than the way we generate and use energy. Together transport, electricity and heating account for nearly 50% of greenhouse gas ('GHG') emissions. Displacing coal fired power generation and removing the use of fossil fuels in transport are the most obvious sectors to re-engineer for the benefit of our fragile atmosphere and the dire consequences of accumulating further GHGs.

Today the supply chains that provide the critical materials required to reduce GHG emissions are as fragile as the atmosphere itself and hence most developed nations have a target list of what is referred to as 'critical materials', 'critical materials', 'strategic commodities' or similar. Simply put, these 'critical materials' are those substances that may be subject to supply disruption that impacts on economies, national security or the delivery of advanced technologies.

The Australian federal government published its critical minerals strategy in 2023 citing Australia's wealth of mineral resources, mining and processing expertise and reliability of supply as fundamental factors in development of the nation as a renewable energy superpower. Although the government failed to define what a 'superpower' is, it is probably a fair assumption that it is the sovereign control of a significant part of the renewable energy supply chain. That being the case, it is heavily oriented towards battery materials and the metals required for the e-mobility and power generation. The focus is on Australian control of the renewable energy supply chain.

More recently (May 2024) the Australian federal government handed down its 2024 budget noting that: *"This net zero transformation presents opportunities for Australia's economy, regions, industries, and communities. Achieving Australia's emissions reduction commitments and realising the opportunities that accompany the transition will require significant investment by governments and the private sector."*

Australia is the world's largest producer of lithium, primarily in the form of spodumene concentrates, but downstream processing is also positioning Australia as a supplier of lithium chemicals. Historically Australia has been a major producer of nickel and cobalt and that too has morphed into the supply of battery grade chemicals albeit threatened by expanded production out of Indonesia fuelled by government policy and Chinese investment. Graphite used in battery anodes is also available and advancement towards downstream products, such as spherical graphite is well underway.

The rare earths industry outside China is dominated by Lynas Corporation Ltd with ore sourced from the Mt Weld carbonatite in Western Australia, and downstream processing in Malaysia. Some of the latter capacity is being repatriated to Kalgoorlie. Iluka Resources Ltd is a late entry into the rare earths market with substantial Australian government funding to build downstream refining capacity based on monazite feed from its Western Australian mineral sands operations. The refinery is located on the Western Australian coast at Eneabba where separated rare earth oxides will be produced, not only from Iluka feed stock, but also from concentrates supplied by Northern Minerals Ltd's hydrothermal quartz/xenotime breccias at Browns Range, Western Australia.

The above examples illustrate the potential lead Australia already has in the supply of raw materials or may have in the future. This is clearly acknowledged in Australia's Critical Minerals Strategy 2023-2030[1] and summarised geographically in Figure 1.

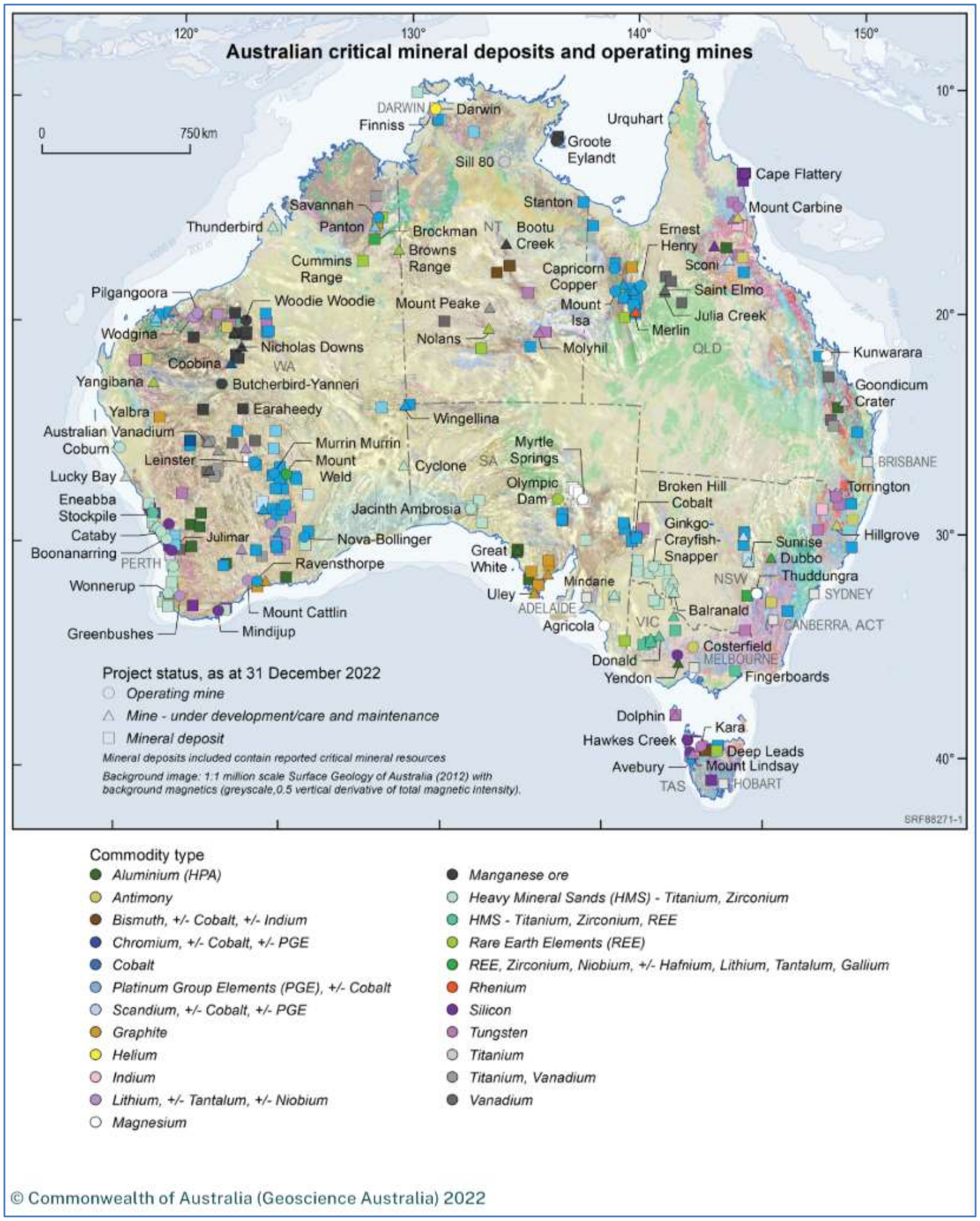


Figure 1 shows Australia's critical mineral endowment.

While it is quite clear that Australia's mineral endowment forms the first link of the critical minerals supply chain, it is far from the control required to become a 'superpower'. Downstream processing has never been a great Australian attribute whereas being the world's quarry has. Things are changing but forefront in planning for the future needs to be gaining a competitive advantage by further the development of new technologies to add to the sustainability of our resources, expanding downstream processing capabilities, and investing in the high-tech applications of the products produced.

While the political powerhouses of the world, the EU and USA in particular, have developed inward looking policies to protect supply chains, the Australian market is too small for such policy drivers to be effective. Australia MUST look outwards and focus on being the preferred and reliable supplier of critical material and value-added products for the global development of carbon reduction technologies.

This paper looks at some of the global drivers and the benefits Australian technologies and products can become an indispensable part of the supply chains necessary for carbon neutrality. This is much more than a technical challenge; it is an opportunity for Australia to use the global drive towards carbon neutrality to expand its economy.

LEGISLATIVE DRIVERS

Global trends

The legislative and policy drivers towards carbon neutrality are many and varied with the most visible the Kyoto Protocol (effective 2005) and the "Paris Agreement". The latter is an internationally binding treaty, effective November 2016 and adopted by 196 parties to hold *"the increase in the global average temperature to well below 2°C above pre-industrial levels*" and pursue efforts "*to limit the temperature increase to 1.5°C above pre-industrial levels*." Backed by the Intergovernmental Panel on Climate Change ('IPCC') analysis of GHG emissions on climate change the parties agreed protocols to reduce emissions on a nation-by-nation basis.

To achieve emission reduction targets it is imperative new technologies are developed and implemented. From a practical point of view this has required the development of targets that affect phase-out of old technologies e.g. internal combustion engines, and the phase-in of alternatives. In the transport sector the alternatives are limited – hydrogen, ammonia and biodiesel are the most advanced zero-carbon fuels but the most advanced propulsion systems are battery powered.

The rate at which legislation is driving ambitions is demonstrated by the introduction of policies in the US and EU as depicted in Figure 2 below.

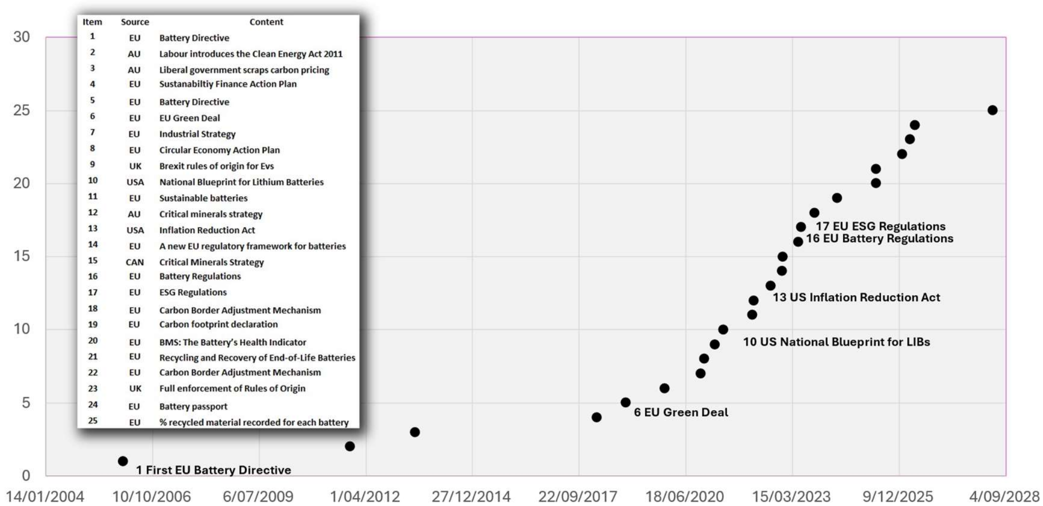


Figure 2. Major policy implementation in the EU and US, commencing with the first EU battery directive in 2005 and extending to sustainability compliance in 2028.

The European Union

To aid sustainability the EU has set targets for battery recycling including collection rates, total material yield and lithium recovery as shown in Figure 3.

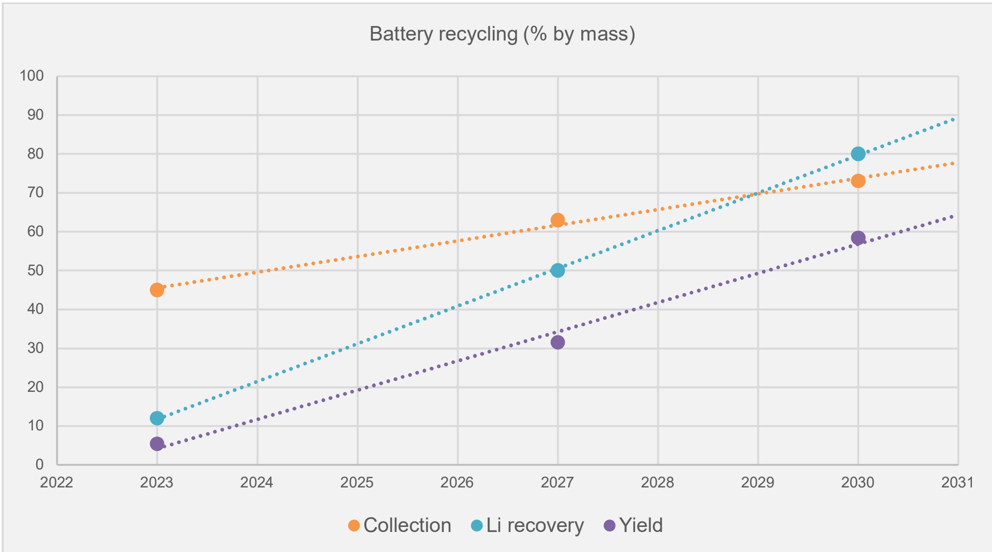


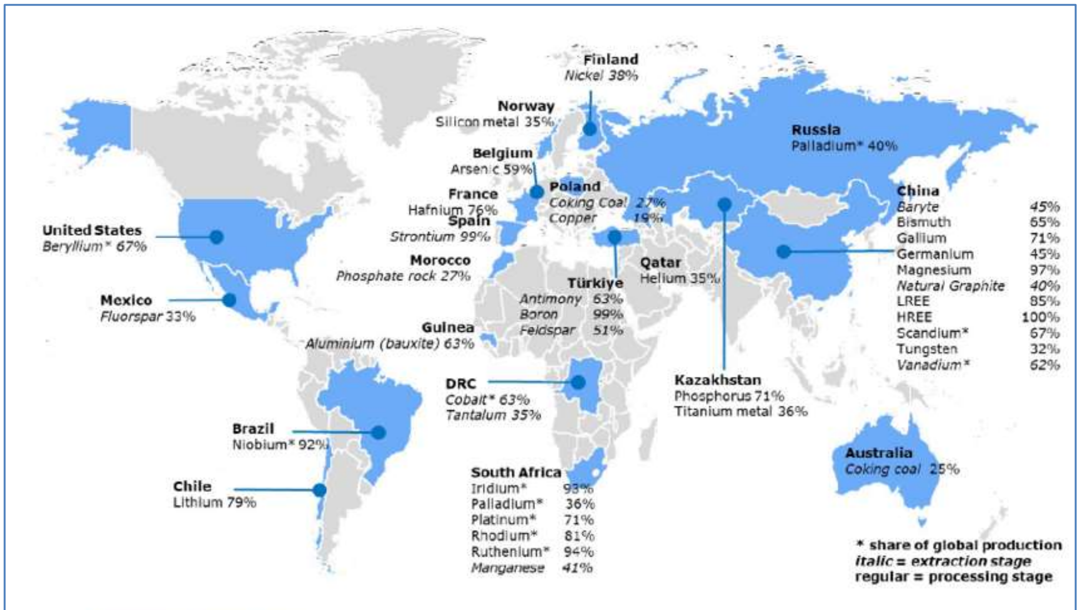
Figure 3. The EU Battery Regulations, May 2023, provide the framework for battery sustainability by setting targets for recycling.

In addition to the sustainability requirements the EU is protecting supply chains by mandating OEMs to have minimum content by mass of batteries, and the EVs in which they are installed domestically sourced. This is further protected by the EU Carbon Border Adjustment Mechanism (CBAM), a tariff protecting European industry from imports free of carbon tax and also the European Critical Raw Materials Act which provides for the following provisions in the critical minerals supply chain by 2030:

- No less than 10% domestic supply input
- At least 40% domestic downstream processing
- At 15% of annual consumption recycled, and
- No more than 65% of each strategic raw material, regardless of the extent of downstream processing, from a single country outside the EU

The European Critical Raw Materials Act clearly shows Europe's supply chain vulnerabilities in decarbonising the economy and some of the opportunities available for Australia. This is clearly illustrated in Figure 4. The European Commission has established a lit of 20 critical minerals. The list is updated periodically and, until recently, didn't include lithium: the reason? There were no cathode producers in the EU and hence it was not considered a vulnerable supply. It is worthy of note that lithium, phosphorus, graphite and cobalt are on the list and nickel is conspicuous by its absence. Turmoil in the nickel industry, and the strong association of Indonesia and China in the production of that metal may result in a change to the list in the future, particularly as EU lithium ion cell production expands and the London Metal Exchange ('LME') applies sanctions to Russian metal production as a consequence of the war in the Ukraine.

In July 2022 the UK government imposed 35% additional duty on imports of Russian nickel, and shortly thereafter the LME suspended Russian nickel brands on warrant in LME-listed UK warehouses.



Source: European Commission, 2023.

Figure 4 shows the source of EU critical raw materials in 2023 demonstrating potential future lack of supply compliance (no more than 65% from one country) for lithium, cobalt, phosphorus, beryllium, niobium, hafnium, bauxite, PGMs, antimony, boron, bismuth, gallium, magnesium, rare earths and scandium.

The EU is looking for reciprocal arrangements with the United States on strategic raw material supply BUT the reality is neither the EU nor the US is capable of securing significant supply within their state boundaries. Supply chain security must include agreements with the nations supplying the raw materials.

United States of America

The United States of America ('US') has implemented the Inflation Reduction Act ('IRA') which, although a very broad piece of legislation, provides for supply chain protection to the battery industry by way of subsidies, loans, grants and tax incentives. It is an adjunct to the US National Battery Blueprint which provides for:

1. secure access to raw and refined materials for commercial and defence applications,
2. support a processing industry to meet domestic battery demand,
3. stimulate the domestic production of active materials, cells and battery packs,
4. develop end-of-life recycling for critical materials, and
5. advance battery technology through R&D, STEM education and workforce training.

The IRA focuses strongly on internal supply and domestic production but treats nations with free trade agreements as complying with the Act with the ability to supply commodities without end-users of those commodities losing the benefits that may otherwise accrue through domestic supply. The IRA requires that EV manufacturers source 40% of critical battery minerals domestically or with free trade partners by 2024 increasing to 80% in 2026. This strongly favours the use of Australian sourced lithium and other battery metals.

The IRA defines Foreign Entities of Concern ('FEOC') which can be sovereign states or companies with more than 25% Chinese equity. FEOC includes China, Russia, North Korea, and Iran. While the defined states seem to be remote for Australian commerce, much of Australia's mining and mineral processing industry has a considerable proportion of Chinese equity. Australian public companies need to manage their share registers to avoid becoming FEOC or quarantine product by the judicious use of joint ventures.

Most of the provisions of the IRA will become effective in the near future with full implementation by 2025. This has prompted an appeal by China to the World Trade organisation on restrictive trade practices prejudicing the Chinese economy. In April 2024, as a consequence of pressure from OEMs, the US Biden administration extended IRA compliance time frame for graphite, 90% of which is sourced in China, a further two years, to 2027.

Adding to the above complexities, the European Commission is currently investigating whether Chinese manufacturers benefit from unfair state subsidies. This brings to the fore China's similar allegations with respect to the Australian wine industry which China countered by applying up to 200% tariff on Australian wine with decimating effect! We are in a three-way trade war (EU, US and China) with collateral damage in Australia and other jurisdictions.

The US has only 20 free trade agreements in place, such agreements being critical for foreign supply to comply with the IRA. Significantly few of the counterparties are potential suppliers of critical raw materials to the US or are involved in the supply of materials to the green energy sector. The exceptions are:

- Australia
- Canada
- Chile
- South Korea
- Mexico
- Morocco

that collectively have supply capability of lithium, nickel, cobalt, graphite, rare earths and phosphorus. South Korea has the ability to provide a range of value added products to service the US battery industry.

Notably the IRA imposes penalties on product imported from China, currently the biggest supplier to the US battery industry. The US government has had the relationship between General Motors ('GM') and China's CATL (the world's largest battery manufacturer) under the microscope, seeking documents about the CATL partnership and its plan to build a $3.5 billion battery manufacturing plant in Michigan using Chinese technology. It would appear GM was reluctant to supply the requested documents and have put construction into hibernation.

2023/24 has seen a slowing in EV demand in the US and a continued dominance of Chinese supply while the US domestic industry builds capacity. It also appears the contractual/corporate relationships between US OEMs and the Chinese battery superpowers are changing to accommodate the advantages available through the IRA. Regardless of corporate strategies dealing with Australia, having a free trade agreement in place with the US provide a path of least resistance for the supply of raw or processed materials.

Australia

The federal budget 2024

On Tuesday 14 May 2024, the Australian Treasurer handed down the 2024 budget on behalf of the federal Labour government. The budget is part of the mechanism for implementing policy and acknowledged that critical minerals are a key input to many clean energy technologies.

The budget paper s went on to say:
"Scaling the supply of critical minerals will be essential to support the global transition to net zero by 2050. Australia can improve the resilience of supply chains and add more value to our resources by processing and refining critical minerals.

"Critical minerals are a key input to many clean energy technologies. Scaling the supply of critical minerals will be essential to support the global transition to net zero by 2050. By adding more value to our resources by processing and refining critical minerals, Australia can improve the resilience of global supply chains. This Budget establishes a Critical Minerals Production Tax Incentive for eligible processing and refining costs from 2027–28 to 2039–40 to incentivise investment in refining and

processing of the 31 critical minerals currently identified on the Government's Critical Minerals List, at an estimated cost of $7.0 billion over the decade.

"The Government is also partnering with states and territories to complete pre-feasibility studies for critical minerals common-use infrastructure through the Critical Minerals National Productivity Initiative, and supporting up to $1.2 billion in priority critical minerals projects through the Critical Minerals Facility and Northern Australia Infrastructure Facility. This includes the Alpha HPA alumina project in Queensland and Arafura Rare Earth's Nolans Rare Earth project in the Northern Territory.

"The Government is investing $556.1 million over ten years to progressively map Australia's potential for critical minerals, alternative energy, groundwater and other resources, providing scientific information to guide future investment."

The budget provides for a 10% tax rebate on eligible production expenditure or an equivalent refund if there is no taxable revenue. The estimated cost is a total of A$17.6B up to 2041. It all seems like a positive move, but the program will not commence until 2027 and runs the political risk of being overturned with an intervening change of government. This budget decision, rather than being positive, may be sufficient to force the closure of further ailing Australian nickel operations which are an integral part of the battery material supply chain. Clearly such an outcome was not contemplated by the Resources Minister Madeleine King who commented the budget was:
"……..the most significant resources budget that any government has ever released."

In the traditional budget reply speech was delivered by the leader of the federal opposition on 16 May 2024. The speech turned Australian critical minerals policy into a political football by pledging the removal of the A$13.6B in tax incentives to the critical minerals and renewable hydrogen sectors if gaining power at the next election that must be held before 27 September 2025.

The Australian Critical Minerals Facility

Export finance Australia manages the A$2B Critical Minerals Facility. The facility was established in 2021 and so far A$1.5B has been committed to Iluka Resources, Renascor Resources and EcoGraf (see **THE INNOVATORS** below).

RENEWABLE ENERGY STORAGE

Hydroelectricity is likely to remain the world's largest energy storage mechanism for many years to come and "pumped hydro" a practical means of optimising capacity utlisation. Grid-scale power storage in batteries is flourishing in areas where there is plenty of wind and/or plenty of sunshine making Australia a prime candidate for large-scale battery storage. At a smaller scale Australia could be considered the Mecca of roof-top solar. More than one in four houses have solar generating power capacity and per capita installations far exceed those of other jurisdictions considered to be leaders in green energy, including Japan, California and Germany. Conventional lithium ion batteries, including lithium ferro phosphate ('LFP') and ternary batteries such as nickel cobalt manganese ('NCM') dominate current installations storage and backup for roof-top solar power generation.

There are other battery storage candidates including sodium ion and various types of 'flow batteries'. The latter include zinc bromine (patented in 1879) and the vanadium flow battery, patented by the University of New South Wales in 1986. The latter leads the way in flow battery commercialisation with the largest example being installed in Chinese city of Dalian. It has a capacity of 400 MWh and output of 100 MW enough supply up to 200,000 residents each day.

Australia's first commercial installation of a vanadium flow battery was completed in South Australia in mid-2023. It is a modest installation taking power from nearby photovoltaic panels and storing up to 8MWh.

The choice of battery for renewable energy storage must consider many factors including lifecycle cost, footprint and recyclability. Indeed the latter will be a major driver in future markets where material supply and sustainability will be paramount. The vanadium flow battery has great longevity and is close to 100% recyclable. It operates well at high temperatures. The most competitive lithium ion counterpart, and the fastest growing sector of the battery industry is LFP. This chemistry is ideally suited to stationary energy storage and is significantly cheaper than ternary counterparts. LFP now accounts for over 50% of the lithium ion battery market.

So it is that LFP looks like a great candidate however the ability to recycle the active materials, on a commercial basis, is proving to be a challenge and while the challenge remains unresolved, vanadium flow batteries may well be the most sustainable choice for stationary energy storage applications for large-scale stationary storage applications.

LFP recycling solutions may be an area where Australian expertise can provide a leading edge for the LFP market on a global basis.

ELECTRIC VEHICLE SUPPLY PROJECTIONS

China currently commands about 45% of the global EV market with about 10 million sales forecast for 2024. Worldwide sales of EVs rose by 14% in 2022, compared with the previous year and were up a further 18% in 2023. Markets have sensitivity to subsidies, tariffs, and purchase price and with recent lithium price peaks, OEMs were searching for ways to reduce the cost of their vehicles, passing on those savings to consumers to maintain demand. Not only did the high price of lithium affect demand, it accelerated development of high-energy density LFP technologies to cut costs. Not only does LFP use less lithium per unit of energy stored, but the other elements in the cathode active material, iron and phosphorus are cheap in comparison with the nickel and cobalt used in ternary cells.

China introduced the first tax exemptions for EVs 10 years ago, has announced several extensions since and recently extended the tax breaks to 2027. Presently each vehicle, be it EV, plugin hybrid or hydrogen fuel cell, commands a sales tax exemption of up to 30,000 yuan (about US$4,175) sliding back to zero in 2027. The imminent threat of removing tax exemptions has previously slowed EV demand in China, the world's largest EV market, with subsequent demand driven impacts on the price of battery commodities. The biggest impact was on lithium chemical prices which tumbled from late 2022 in parallel with cobalt. Potentially this rings warning bells for 2027 when Chinese EV subsidies are once again planned for removal.

Goldman Sachs suggest the global EV market will expand to 73 million unit per annum, up from a mere 2 million in 2020. They predict a change in demographics over that time with the EU eclipsing China in terms of proportion of the vehicle market dominated by EVs (Figure 5).

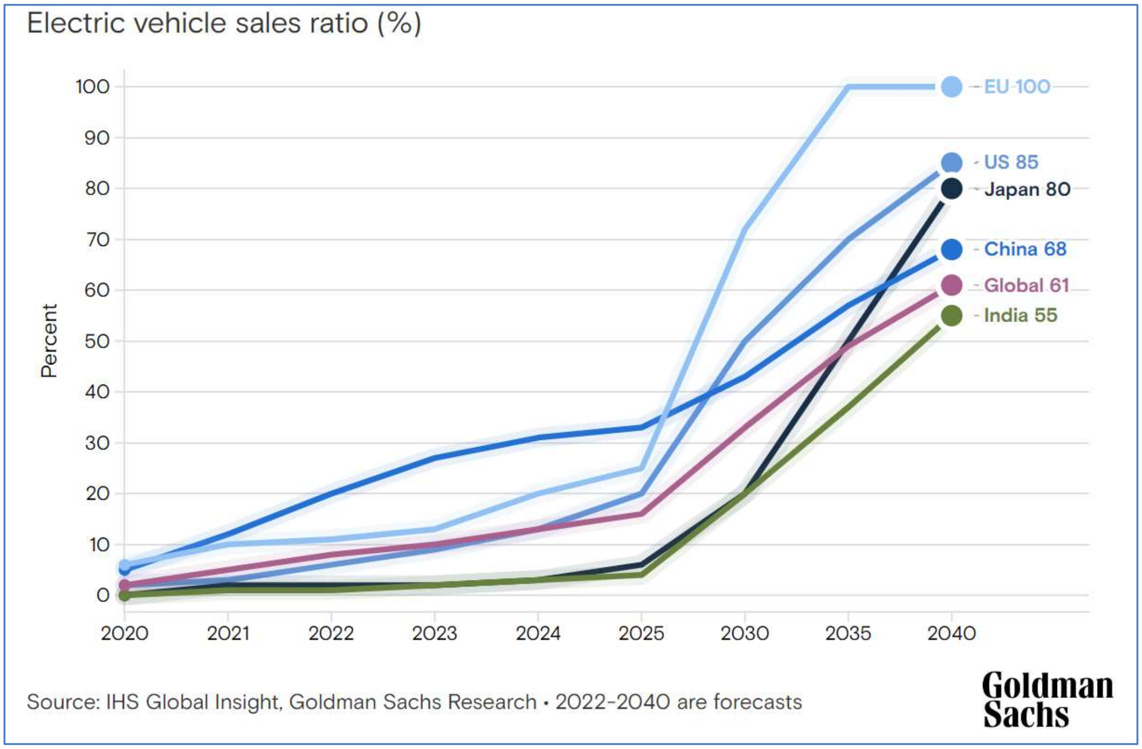


Figure 5. EV sales expressed as a percentage of total vehicle sales.

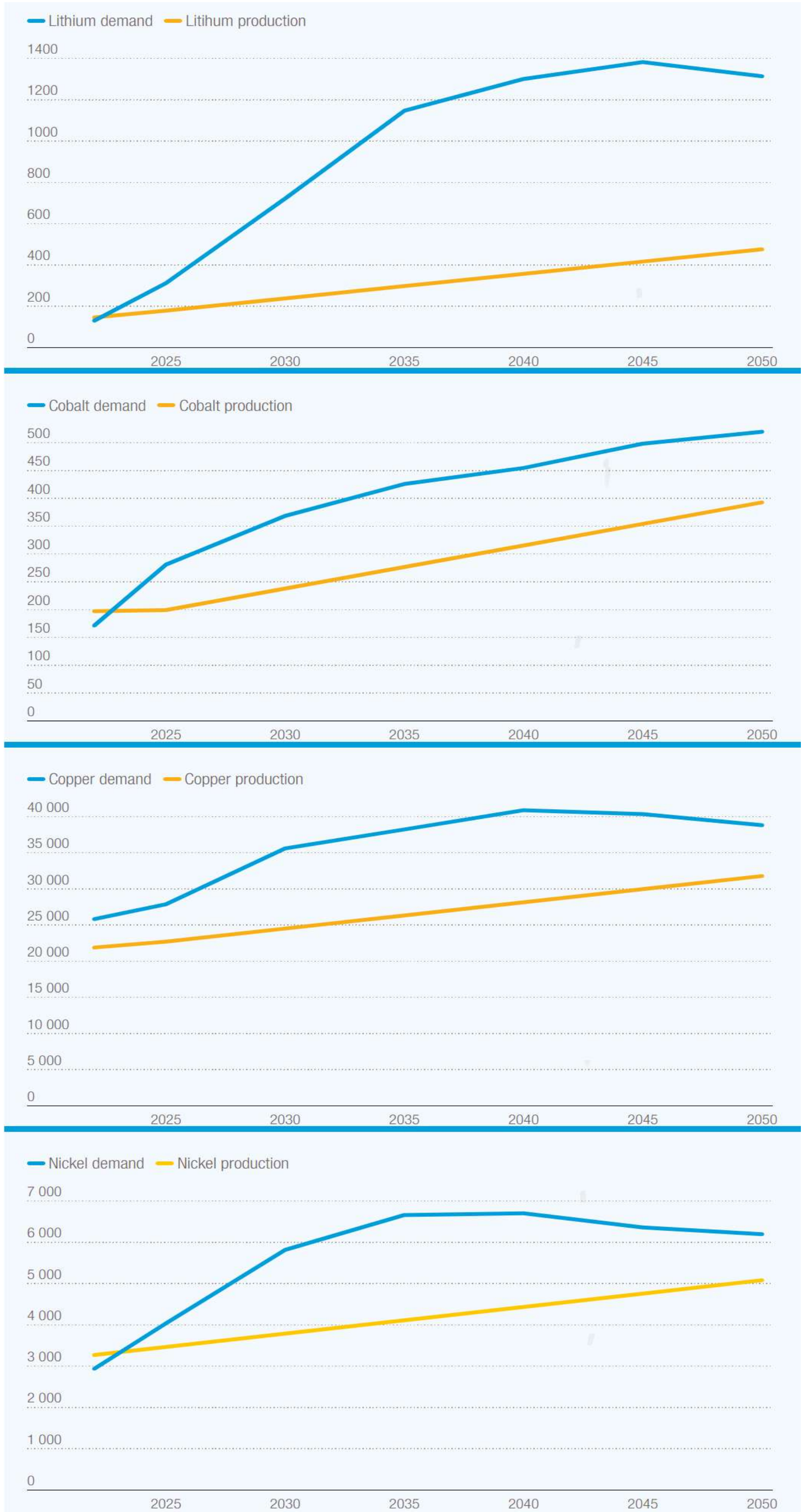
QUANTUM OF CRITICAL MINERALS REQUIRED

Defining critical mineral demand on a global basis is a daunting task as the materials defined as critical vary from jurisdiction to jurisdiction. Suffice to say the largest tonnage commodities involved in the energy transition are a little easier to quantify as has been done by United Nations Trade and Development ('UNCTAD') (Figure 6). While this represents only a small proportion of the critical minerals by number, it does constitute the bulk of the critical metals required to produce cathode active mmaterials for lithium ion batteries. The projections demonstrate a common consensus and that is critical minerals will be in short supply as we strive towards zero carbon. Many projections predict much greater supply gaps, but none predict oversupply in the medium to long-term.

Australia is a significant producer of battery metals; indeed it is the largest producer of lithium and the eighth largest producer of copper, and home to the world's second largest copper producing company, BHP. Groote Eylandt, operated by South 32, produces 12% of the world's manganese ore.

Australia is the fourth largest producer of cobalt, behind the Democratic Republic of Congo ('DRC'), Russia and Indonesia. Globally 98% of cobalt is produced as a byproduct, mainly from nickel and copper production. Australia is no exception having Glencore's Murrin Murrin lateritic nickel operation as the largest cobalt producer in the country. Changing dynamics in the nickel market have seen the rapid rise of Indonesian production of both nickel and cobalt. Nickel production in Indonesia has risen 10 fold since 2015 making it the world's largest producer at around 1.8Mt in 2023[5]. The stratospheric rise in production resulted from the banning of nickel ore exports and subsequent Chinese investment in Indonesia's domestic nickel production.

Consumer pressure and voluntary constraints on the use of cobalt originating from the DRC have not only affected market dynamics but have also influenced the chemistry of choice in lithium ion batteries resulting in the reduction of cobalt and increase on nickel in ternary cells of the NCM (lithium nickel cobalt manganese) cells, and a shift towards lithium ferro phosphate ('LFP') cells.



Source: UNCTAD based on data from IEA and USGS

Figure 6. World mine production and demand for lithium, cobalt, nickel and copper in metric tons.

Being a prolific producer of battery metals, Australia is well positioned to engineer a more beneficial position in the supply chain by developing the expertise to produce value added products from these metals rather than exporting ore or concentrates.

CAN WE BRIDGE THE SUPPLY GAPS?

Supply and demand impact on battery materials are not synchronous due to varied provenance of materials, legislative constraints, consumer pressure and changing battery chemistries. It is imperative to evaluate the impacts of future changes and maximise the benefits Australia can reap by filling the gaps, not only at a natural resource level, but also by short circuiting some of the supply chain by downsteam value adding, and the application of advanced technologies to improve sustainability from mining though to battery production, and beyond into recycling. Some of the trends evident are presented below and these must be considered as we plan for maximising Australia's leverage to global carbon neutrality. Opportunities abound but pre-empting supply chain changes will amplify the benefits.

Nickel

Using nickel as an example and by analysing the effects of a rapid increase in supply from Indonesia supported by Chinese capital, we can see that there has been severe impact on the nickel price. Nickel prices have remained relatively low since Indonesia introduced its nickel ore export bans bans about 10 years ago[2] and subsequently ramped up domestic nickel production.

With nickel production currently coming offline in Australia due to competitive pressures, it would seem logical that supply gaps be filled by further expanding production from Indonesia. But the Indonesian industry, dominated by the high-pressure acid leaching ('HPAL') of laterites and the smelting of laterites to produce nickel pig iron ('NPI') has a very high carbon footprint and produces considerable environmental pollution. HPAL plants have about twice the carbon footprint of nickel produced from sulphides and the NPI plants, being fuelled by coal, about six times the carbon footprint[3]. There is enormous pressure from consumers, OEMs, the World Trade Organisation and governments for Indonesia to clean up its nickel industry and remove trade restrictions. Indeed 2021 saw the EU lobby the WTO to establish a panel to seek the elimination of unlawful export restrictions imposed by Indonesia. Deforestation, carbon emissions, tailings disposal, coal ash disposal continue to plague the Indonesian nickel industry.

So it is that the world's largest nickel producer may be itself a supply chain vulnerability exacerbating the projected gap between future supply and demand. Further supply concerns have arisen in May 2024 with Philippine trade officials announcing the intention to expand from the current two refineries by adding a further three HPAL plants. Potential investment from China, Australia, America, Japan, and Korea have been cited as the source of capital. Other news reports suggest the US is negotiating directly with the Philippines government to prevent Chinese dominance. It is thought that these negotiations include a trilateral arrangement by which the Philippines would supply ore, the US would provide financing, and a third country such as Japan, South Korea or Australia would provide processing expertise.[9]

Lithium

Softening of EV demand in 2023 has been widely credited for the reduction of record 2022 inventory levels held by lithium chemical companies and battery producers. Destocking reduced demand with a subsequent catastrophic fall in price of both chemicals and concentrates (Figure 7). Lower government incentives and inadequate charging infrastructure are expected to curtail EV sales in 2024. According to Wood Mackenzie, the rise of lithium iron phosphate (LFP) cathode chemistries, which require lower lithium content, is outpacing the growth of high-nickel cathode chemistries. This trend exerts further downward pressure on the rate of lithium demand growth, but also provides an opportunity for Australian companies involved in the development of LFP cathode active materials.

Lithium carbonate prices plummeted from spot highs around US$90,000/t to current levels (May 2024) of around US$15,000. Reduced demand has resulted in major producers curtailing production, but demand is likely to rise as restocking becomes a necessity and improved charging infrastructure boosts consumer confidence.

Financial analysts have differing opinions with respect to timing on lithium's future rise from over supply into deficit, but most agree that deficit will occur, bolstering commodity prices and creating great opportunities to utlise latent capacity and expand operations. That aside, the Australian lithium industry needs to critically evaluate its own performance and strive to optimise the use of its resources. All of the Australian lithium industry is based on the recovery of spodumene from pegmatites and it is that recovery which is preventing the optimal utilisation of resources. At best spodumene concentrate producers achieve a yield of around 75% with some being far below that level.

If the recovery dilemma can be resolved, perhaps the pending supply gap can be filled from Australian spodumene production without even expanding planned mine output i.e. simply recover more lithium units from the materials mined. Australia has a great opportunity to develop the technologies to improve yield, reduce operating cost, reduce carbon footprint and extend resource life.

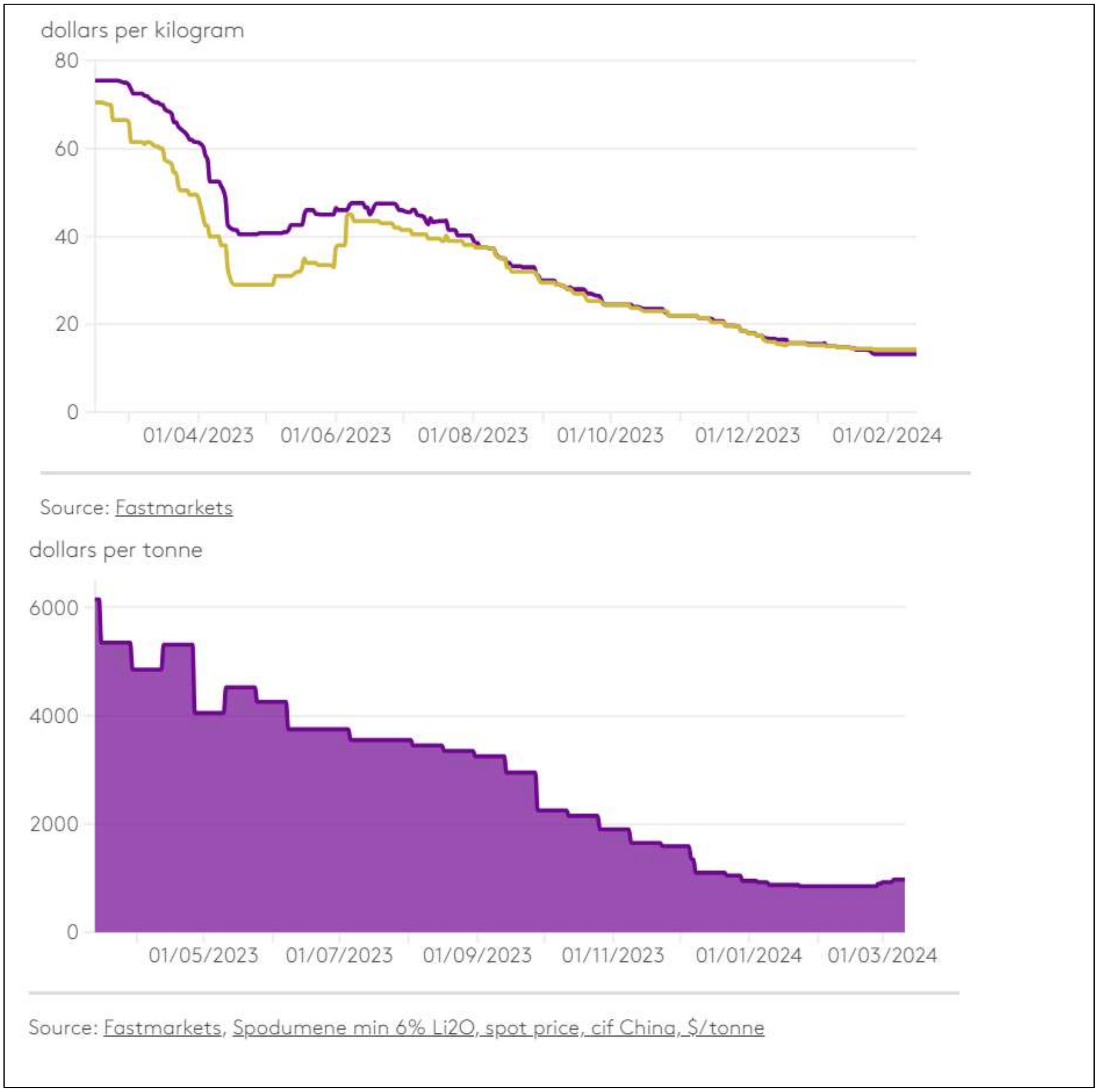


Figure 7. Recent pressure on lithium prices

Cobalt

Cobalt is a byproduct metal with 60% of global production emanating from copper mining, and 38% form nickel. Only 2% is primary production from Marocco and Canada. The forecast supply gap is exacerbated by the lack of primary production resulting in output being tied to copper and nickel production i.e. there is little flexibility in controlling output to meet demand.

Recent publicity relating to human rights abuse and child labour employed in operations in the DRC evoked outcry around the globe particularly with products such as mobile phones[7]. Consumer pressure has led to companies such as Tesla increasing the nickel content of their batteries at the expense of cobalt or even going to cobalt free batteries such as LFP, LMFP (lithium manganese ferro phosphate) albeit the latter examples are probably driven more by cost and safety than ethical concerns. Be that as it may, the cobalt supply gap is likely to be with us for some time as the rate of demand (Figure 8) increase is predicted to rise in the short-term reducing to a constant rate from about 2030 (Figure 6).

As the rate of increased demand in copper and nickel reduce, the ability to supply the required amounts of cobalt my be jeopardised unless more primary, as opposed to byproduct, cobalt production is brought on stream. Potentially production of primary cobalt is one solution that could benefit Australia.

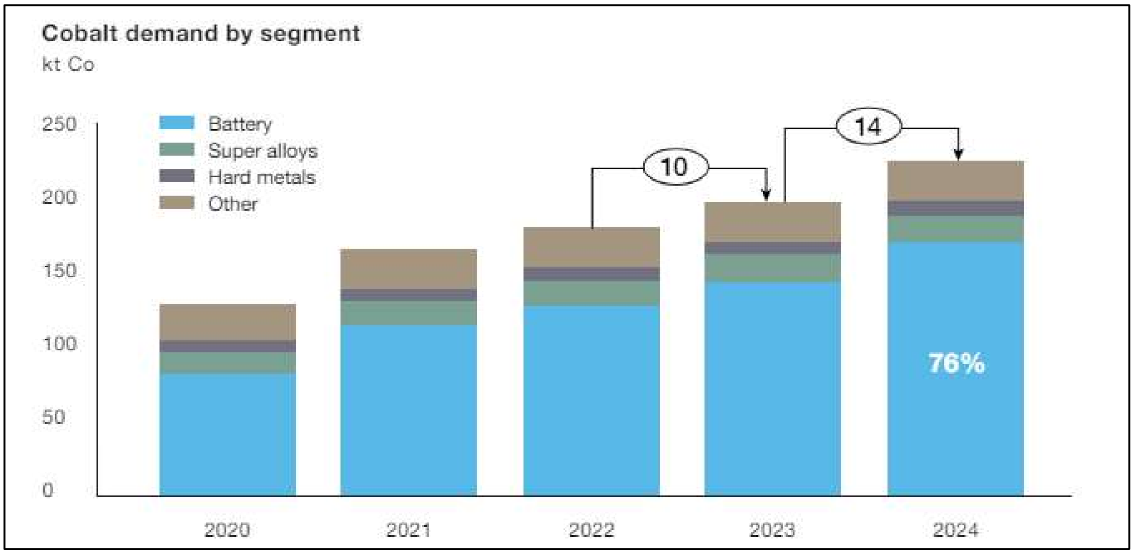


Figure 9 shows the increasing rate of demand for cobalt rising from 10% in 2023 to 14% in 2024 (source – the Cobalt Institute)

Copper

Copper has much more diverse applications than other battery materials with 60% consumed in the production of electrical wire and cables, and 20% in roofing and plumbing. In 2020 about 24%was consumed in clean energy technologies. That is anticipated to grow to 45% by 2040.

The diverse use of copper results in much more complex demand dynamics than the critical metals having clean energy technologies as the bulk of their market. Regardless, the move away from fossil fuels, particularly in the transport sector will require substantial upgrades to power grids. The fossil fuel energy displaced by renewables will require copper cabling to deliver to the consumer and it is unlikely existing grid infrastructure will have the necessary capacity.

Western Australia has more than half of its electrical power delivered outside the state-controlled grid. Most of this exists in microgrids, unfortunately many of which serviced by diesel generators, on remote mine sites. Regardless, the miners are leading the energy transition with some of the world's largest non-government renewable energy project currently being installed. Australian expertise in the establishment and utilisation of microgrids is a potential export opportunity.

Graphite

Graphite is the most commonly used active material in lithium ion anodes. It is probably not the best material but in terms of a trade-off of cost v performance it is very hard to beat. It can be natural or synthetic, comes in a wide range of product forms and quality but for battery applications natural graphite is superior. It does require significant downstream processing, often with very significant production losses.

China produces about 2/3 of the world's natural graphite and dominates the global market in downstream graphite products. It is a constrained supply chain now subject to Chinese export controls imposed in October 2023 to preserve graphite for the Chinese domestic market. This creates a great opportunity for other graphite producing jurisdictions, including Australia, where a number of projects are preparing for production, some vertically integrated with downstream processing.

RECYCLING – THE SUPPLY GAP DISABLER?

Society needs to shed its single-use mentality and focus on sustainability and optimising the utilisation of non-renewable resources. We live in a world of prolific waste and poor resource utilisation. There are of course exceptions, the lead-acid battery industry being one example. Lead-acid batteries have been at our service since 1859 and have become the principal means of electrical storage but will be overtaken by lithium ion batteries. Recycling of lead acid batteries commenced in 1920 and today 95% of lead acid batteries are recycled on a global basis. This has been a great success story.

Lithium ion batteries pose far greater recycling challenges than their lead-acid counterparts. Lead acid battery recycling requires little more than breaking, separation, sulphur removal, smelting and refining. The components are few, and the chemistry constant. In contrast, lithium ion batteries have copper and aluminium in the current collectors, a vast range of compositions in both the anodes and cathodes and a range of binders and electrolytes. Lithium ion batteries have complex casings (a combination of metals and polymers) solder, wiring, and battery management systems to cope with in the recycling process. Ternary cells based on lithium, nickel, manganese and cobalt have dominated the development of recycling technologies. Lithium is relatively easy to recover as it is remains soluble at very high pH and the other metals can be recovered using a range of common hydrometallurgical or pyrometallurgical techniques.

The focus on recycling of ternary cells has been driven by the value of the nickel and cobalt. This contrast markedly with LFP chemistry where the iron and phosphorus can be expensive to remove and hence the recycling cost must be covered by lithium revenue or tolling fees. The low viability of recycling these batteries has resulted in the South Korean government removing subsidies for imported LFP based EVs and battery packs. This will probably not be the case for domestically manufactured LFP product allowing time for commercial recycling systems to be developed.

The longevity of lithium ion batteries (the order of 10 years for ternary cells and 20 years for LFP) unlike lead acid counterparts, creates substantial lag from the time a battery is placed into service, to its availability for recycling. It is generally considered that in EV applications, batteries will be retired when their charged capacity reaches 80% of design. At that point the battery may be repurposed for stationary storage applications resulting in a similar second life span. In China, lead acid batteries have been phased out of telecommunication applications, and repurposed EV batteries, principally LFP, are used instead.

If recycling is to make a significant dent on supply, two things must be achieved:

- Recycling rates for lithium ion batteries commensurate with that of lead acid batteries and
- A practical commercial solution to recycling LFP

It is imperative to find a commercial solution for the recycling of LFP due to its rapidly increasing share of the battery market and likely future dominance.

CARBON REDUCTION AT THE SOURCE OF RAW MATERIALS

New or used equipment?

The carbon footprint of today's mineral production is heavily weighted towards the energy used in mining and processing and metallurgical recovery. The change from fossil fuels to renewables will have an enormous impact on the critical minerals sector's push towards zero carbon. But there are other factors that might be considered e.g. the carbon footprint associated with the initial manufacture of fleet and equipment, and the benefits gained by refurbishment rather than new equipment purchases. It is worthy of note that one major miner, Freeport McMoran, in an effort to reduce the carbon footprint associated with the supply of newly manufactured dump trucks, procure used trucks and refurbish. Freeport McMoran has not bought a new dump truck since 2006.

Fleet electrification

Fleet electrification is a primary tool in phasing out fossil fuel and subsequent reduction of carbon emissions providing the electrical power required for recharging comes form renewable, or perhaps nuclear, sources.

Fortescue Metals Group ('FMG') has lead the charge with the ambition of being zero carbon by 2030 resulting in the testing of the first, and at the time largest, electric dump truck in 2021. This has progressed to hydrogen powered blast hole rigs and hydrogen fuel cell dump trucks. The benefits can be clearly seen in FMG's Scope 1 emissions, 26% of which emanated from haul trucks and 36% from drill rigs and excavators prior to the commencement of decarbonisation[11]. Rail haulage of iron ore, from the various mining hubs, to Port Hedland for export, are also heavy contributors to Scope 1 emissions. The FMG solution is the 'Infinity Train'. The system relies on generation of electricity on the downhill loaded sections which are most of the line. That electricity is stored in batteries that fuel the locomotives for the return, unloaded journey. The system will remove the need for the installation of renewable energy generation and recharging infrastructure, making it a capital efficient solution for eliminating diesel and emissions.

Not surprisingly Rio Tinto have also been making a push into electrification partnering with Caterpillar for the development of zero-emissions autonomous haul trucks for use in the Pilbara iron ore mining operations. BHP and Freeport McMoRan have similar programs underway.

Autonomous Haulage

While autonomous haulage looks like a means of reducing labour costs, it is in fact a means of achieving greater utilisation and availability from a given fleet and hence reduce costs and emissions. The iron ore mines of Western Australia's Pilbara region are the world's leaders in autonomous haulage. This is not restricted to trucks but extends to rail.

Rio Tinto's autonomous truck haulage operations have been in operation for some time with the first unit developed and tested in partnership with Komatsu in 2017 using automation software developed by Rio Tinto. By 2018 20% of the truck fleet was autonomous resulting from the retrofit of existing Komatsu units. Today only 20% of the fleet requires drivers. Rio Tinto has been operating autonomous rail haulage since 2019. It has not been without challenges, suffering 3 derailments in the first 5 months of 2024. In 2018 BHP suffered a derailment of a driverless train, not to be confused with an autonomous train. In this case the train, hauling 268 wagons of iron ore escaped without its driver and travelled at high speed until being intentionally derailed with disastrous consequences.

Mineral Resources Ltd operates autonomous triple trailer road trains carrying 330 tonnes of iron ore approximately 150 kilometres on a private, sealed haul road from the Ken's Bore mine site to the Port of Ashburton. Autonomous road trains are being added to the fleet at the rate of 10 per month, with target commissioning of 120 units by the end of 2024.

Green fuels

Green fuels include biodiesel, hydrogen, ammonia, bioethanol and biochar. Research and development is key to the commercialisation of alternative fuel that can be used to displace fossil fuels. Government bodies within Australia are making significant investment in this field. Australia's Clean Energy Finance Corporation ('CEFC') leads decarbonisation investment in clean energy and co-funds projects having access to around A$30 billion of Australian government funding.

The Australian Renewable Energy Agency (ARENA) funds renewable energy and sustainable transport projects. Including biofuels and sustainable aviation fuel.

Significant corporate funding is being devoted to green hydrogen and green ammonia production and commercial supplies of these is imminent.

Improved mineral processing

Most battery metals are recovered by proven mineral processing techniques that have evolved over decades or more and hence have acceptable efficiencies that have developed by economic necessity. Lithium is an exception as the meteoric rise in production, to meet the demands of the battery industry, has left insufficient time for processing techniques to evolve. Until recently, with a lack of vertical integration from mine through to chemical producer, the Chinese lithium converters dictated product specification to the miners and concentrators. This created an environment where concentrate specifications made it easy for the converters but suboptimal for the concentrators. Particle size in particular was a major constraint, with conversion commencing in rotary kilns unsuitable for fine concentrate feed.

Spodumene is a problematic mineral. It has two perfect cleavages resulting in greater attrition during comminution than the associated quartz and feldspar contained within the pegmatites from which it is extracted. The resulting tendency is for generation of a large proportion of spodumene fines in the comminution process that precedes concentration. This is particularly evident in scale-up from laboratory and pilot testing through to commercial production. The trend has created a large discrepancy between recoveries used in feasibility studies and the recoveries achieved to commercial concentrate where particle size is a principal specification (Figure 10).

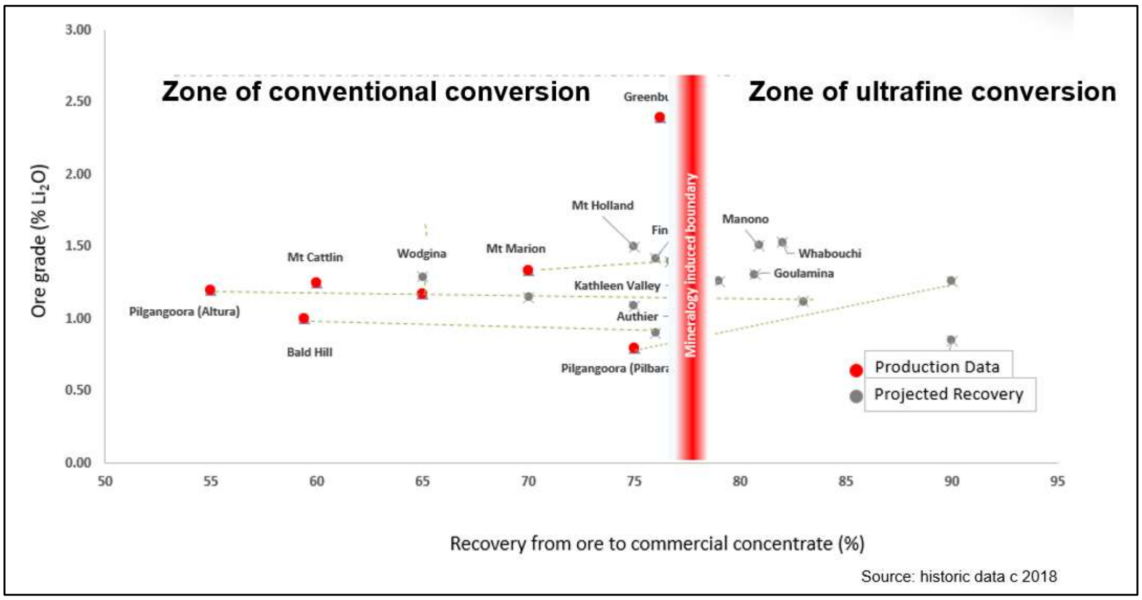
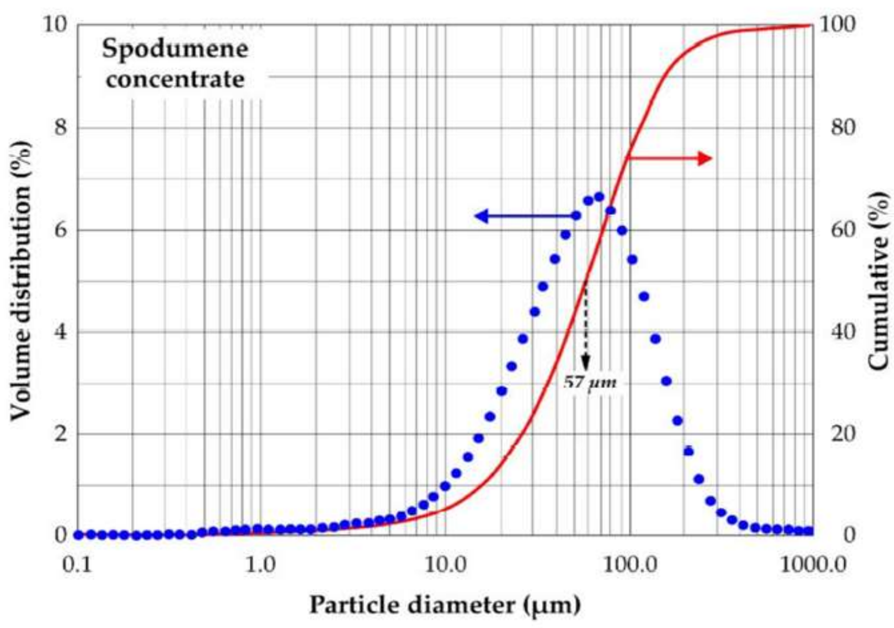


Figure 10 shows the comparison of feasibility study spodumene recovery rates to those achieved in commercial production.

The reason for this poor performance is illustrated in Figure 11 showing the properties of a spodumene concentrate from the Pilbara.



Source: Fosu, A.Y. et al. Physico-Chemical Characteristics of Spodumene Concentrate and Its Thermal Transformations. Materials **2021, 14, 7423.** https://doi.org/10.3390/ma14237423

Figure 11. Particle size distribution of a spodumene concentrate produced from pegmatite in the Pilbara region of Western Australia

It should be noted that the yield from ore to concentrate of the material depicted in Figure 11 was 85% and only 40% of the concentrate exceeds 75µm. At the time this analysis was undertaken it was not uncommon for the converter to specify 75µm as the bottom size cut.

The carbon footprint associated with spodumene production can be reduced proportionally with an increase in recovery to commercial concentrate. The key then becomes the ability to convert fine spodumene to viable lithium chemicals. Several processes are under trial to achieve that outcome which involve changes to the conversion process to enable fine material to be processed. In particular Pilbara Minerals Ltd and Calix Ltd have chosen a pyrometallurgical solution, and Lithium Australia Ltd and Mineral Resources Ltd an innovative hydrometallurgical technique (see **THE INNOVATORS** below).

Carbon Capture and Storage ('CCS')

CCS has long been mooted as a solution for carbon dioxide emissions. The concept is simple – capture the carbon dioxide, compress it and pump it into subterranean reservoirs. Clearly the success of CCS relies on access to suitable geological formation that have the permeability to receive the carbon dioxide and cap rocks to seal the system and avoid leakage. Under some circumstances the carbon dioxide will react with other component in the reservoir forming stable carbonates which will pose little risk in the future. Exhausted gas fields are a prime target as the geological conditions have proved suitable for gas containment over eons. Those reservoirs simply need to be repurposed as CCS containment.

Today there are around 40 CCS project operational around the globe including one of the world's largest off the Western Australian coast at Barrow Island. Fortunately, Australia's geological endowment hosts numerous potential CCS one of which is being developed in South Australia by Santos, and another being considered in the Timor Sear. Othe prospective locations include Queensland and New South Wales.

With most developed nations putting a price on carbon, Australia's ability to sequester carbon dioxide provides the opportunity to generate an enormous amount of revenue, simply by repurposing the gas fields from which the carbon came initially. The financial trade-offs are obvious, substituting a carbon tax at the point of the pollution, with a sequestration fee for subsequent carbon storage in Australia.This could be very attractive for nations importing Australian gas but not having the geological formations suitable for CCS.

THE AUSTRALIAN INNOVATORS

The history of developing new technologies is littered with corporate carcasses. Successful commercialisation is often a long and tortuous path which is difficult to fund let alone turn into a profitable business. The fortitude required to embark on developing new technologies is summed up well in a quote of US president Theodore Roosevelt as follows:

"Far better to dare mighty things, to win glorious triumphs, even though checkered by failure, than to take rank with those poor spirits who neither enjoy much nor suffer much, because they live in the gray twilight that knows not victory nor defeat."

Fortunately, the Australian government does provide some support for the development of new technologies and that support is widely used in the mining and mineral processing industries in addition to downstream processing. The government support is commonly used by innovators that are likely to have a positive impact on our path towards decarbonisation. Some of this support is provided through the likes of CEFC, ARENA, Austrade and the Australian Taxation Officer Research and Development Tax Incentive. The latter provides a rebate for eligible expenditure at a premium to corporate tax rates for annual expenditure up to A$150M and is rebate at the corporate tax rate beyond A$150M.

Many Australian innovators, not all of which have been successful, have targeted a reduction in carbon emissions for development of commercial technologies. Some of these are briefly outlined below. The list is far from exhaustive and is not intended to provide any ranking.

Future Battery Industry CRC ('FBICRC') – battery research and development

The Future Battery Industry Cooperative Research Centre was established in 2019 through the Australian Government's cooperative research program that amalgamates government, research institutions and industry. The FBICRC is one such program covering 15 research projects (https://fbicrc.com.au/projects/). Collectively the projects are valued at $120M with funding provided by industry and topped up by the government. The projects and span the entire battery value chain value chain from mining through to processing, manufacture, services and the recycling and reuse of batteries. This provides the opportunity for is participants to gain commercial opportunities through application of the knowledge base developed by the CRC.

Lithium Australia / Mineral Resources JV – improving spodumene utilisation

Lithium Australia was a first mover in the field of lithium processing, identifying a number of supply problems and developing the processing solutions to mitigate their impact and to capitalise on underutilised lithium resources. Lithium Australia developed the SiLeach® process for the recovery of lithium from micas, and the LieNA® process for the hydrometallurgical recovery of lithium from spodumene.

The LieNA® process is a caustic conversion at elevated temperature and pressure. Spodumene is converted to synthetic lithium sodalite which is subsequently leached and the lithium precipitated in choice of forms – hydroxide, carbonate or phosphate.

At present the LieNA® process is focused on fine spodumene otherwise not suitable for conventional processing. This is feed available at marginal operating cost as mining and much of the separation cost has been covered in producing the coarser commercial concentrate which is the feed for conventional converters. That fine spodumene may be 50% or more of all the lithium units mined or not recovered. Even with efficient concentrators the fine material is usually more than 25%. Commercialisation of the process is being undertaken in conjunction with Mineral Resources Ltd.

Commercialisation of the process will provide licensing opportunities with the potential to return revenue to the Australian owners of the process while optimising the carbon footprint of the users of the LieNA® process.

Pilbara Minerals / Calix – utlisation of fine spodumene

Pilbara Minerals was one of the first companies involved in the production of spodumene concentrates to address the poor recovery inherent in the industry. Their solution was to form a JV with Calix is developing an innovative 'mid-stream' refining process for sustainable lithium production. The process utilizes the fine spodumene generated during the concentration process, that cannot otherwise be fed to conventional convertors (the processing plants converting spodumene to lithium chemicals) because of fine particle size. The project is advancing towards the construction of an on-site demonstration plant that will be located in the northwest of Western Australia. The plant will use Calix's patented electric calcination technology. The project is supported by A$20m in Australian Government funding announced under the Modern Manufacturing Initiative.

VSPC – cathode powder production and LFP recycling

VSPC has patented technology to produce nano powders, LFP in particular, and been in operation for over 20 years. The VSPC process is a single pass operation with relatively low energy consumption and little waste. Powders are manufactured by mixing metals in solution at the stoichiometric proportions required in the final product, mixed with a surfactant, to produce particles that can be spray dried and calcined to produce the final product, cathode powder. The process is composition agnostic and capable of producing ternary cathode powders, LFP and catalysts.

In 2020 VSPC together with CSIRO, UQ and others was awarded government support in a $5 million CRC-P programme to develop fast-charge lithium-ion batteries for use in new generation trams. Battery-powered trams eliminate the need for overhead power lines, which are expensive, visually polluting and potentially hazardous.

VSPC has samples of LFP and LMFP being evaluated by battery producers and is planning to build a demonstration plant for material qualification.

The ability to effectively set and forget the composition of the powder produced by the VSPC process provides significant quality control advantages when compared with competing processes. It also provides a potential to recover Li, Fe and P from spent LFP batteries by dissolving the powder, polishing the solution and reprecipitating the cathode powder. This may be the solution to one of the battery industry's greatest challenges, finding a commercial means of recycling LFP.

Envirostream – lithium ion battery recycling

Envirostream, a wholly owned subsidiary of Lithium Australia, has been in commercial operation since 2017 and is Australia's premier lithium ion battery recycler. It operates an extensive collection network and two processing plants located in Melbourne. Batteries are shredded and components separated. Metal from the current collectors, primarily copper and aluminium, is sold into the metal recycling market. The 'mixed metal dust' otherwise known as 'black mass' is sold to specialist refiners.

The sophistication of Envirostream's operations and the safety standards built into handling of hazardous materials, including the mitigation of fire risk, are second to none. The systems have been developed in-house and have export and partnering potential on a global basis.

Neometals -

Neometals was first mover in the Australian lithium industry once owning the Mt Marrion spodumene mine near Kalgoorlie in Western Australia. In later years Neometals focused on downstream processing and recylcling and now has four divisions:

- Lithium ion battery recycling – commercial
- Lithium chemicals – pre-commercial
- Vanadium recovery – pre-commercial, and
- Precious metal recovery – R&D

Battery recycling is EU based through a joint venture ("Primobius GmbH") with German Company SMS group and focuses on the processing of ternary batteries finishing with the separation of the metal salts for return for the regeneration of cathode material.

The Pilbara iron ore producers – electrification and autonomous haulage

Australia's iron ore producers lead the way in mine electrification and autonomous equipment. The latter extends beyond haulage and includes drilling and loading. The miners are also leaders in the field of microgrids as most operations are self sufficient in power, and now many are transitioning from hydrocarbons as an energy source, to renewables on a large scale, supported by wind and solar generation.

Fortescue Future Industries ('FFI') – green hydrogen and ammonia

FFI is part of the Fortescue Metals Group. The Group was on schedule to burn 100 billion litres of diesel annually by 2030, but with innovation plan to drop that projected consumption to zero.

Fortescue has Australia's largest gas and liquid hydrogen refuelling plant. Fortescue has developed the world's first ammonia powered ship, is developing ammonia powered rail locomotives and has the "Infinity Train" under design. The Infinity Train is an iron ore haulage set that resembles perpetual motion. The train set charges all of its battery requirements from the downhill run from Fortescue's Pilbara iron ore mining operations, to the port loading facilities at Port Hedland. The return journey, unladen, is completely powered by the energy harnessed from the downhill run. This is carbon neutrality at its most sophisticated and a system worthy of duplication wherever loade transport legs are followed by an empty return journey.

FFI is involved in the production of green hydrogen and ammonia and recently acquired the Phoenix Hydrogen Hub in the US. FFI commenced construction of the world's largest electrolyser facility in 2022 as the first stage of its Green Energy Manufacturing Centre (GEM) in Gladstone Queensland. GEM will be powered by green energy and become a major new pollution-free green manufacturing hub. Planned growth includes the development of green manufacturing technology such as, batteries, wind turbines and solar panels. This has huge potential for domestic and export markets.

Iluka Resources – separated rare earths

The Australian Critical Mineral Facility has provided loan of A$1.25B loan to Iluka Resources to develop its Eneabba Rare Earths Refinery 280km north of Perth, Western Australia. The refinery will produce separated rare earth oxide products including praseodymium, dysprosium, neodymium and terbium used in permanent magnets electric vehicles, clean wind turbines and telecommunications, medicine and defence. Feed will initially be from existing monazite stockpiles generated during separation of mineral sands from Iluka's own mineral sands mining and separation operations. The refinery will also take third party feed, including xenotime concentrates from Northern Minerals' Browns Range deposit.

Renascor Resources – vertically integrated graphite production

Renascor received a A$185M loan from the Australian Critical Mineral Facility for development of its Siviour Graphite Project located on South Australia's Eyre Peninsula. Siviour hosts the world's second largest Proven Reserve of graphite. The project will establish a vertically integrated graphite and processing facility to produce purified spherical graphite for lithium-ion batteries.

Thorion Energy – sedimentary vanadium to flow batteries

Thorion Energy is Australia's first vanadium redox flow battery manufacturer. It also owns the Richmond vanadium project which has the largest known sedimentary vanadium deposit on earth. Richmond is located 400km east of Mt Isa in Queensland. Definitive feasibility has commenced with plans to produce around 13,000tpa battery grade V_2O_5 flake. The company is well placed to service their own supply requirements, and other domestic users one of which may be the Queensland government which, in 2021, announced it would build and own a new vanadium common user facility in Townsville. This facility will be used for downstream refining of vanadium concentrate to vanadium pentoxide suitable for battery use. This is part of the state's plan to make Queensland a leading producer and exporter of new-economy minerals.

The infrastructure, natural resources and technology provide leverage for Australia in decarbonisation.

Avenira – from mining to LFP production

Avenira is proprietor of the Wonarah phosphate project located on the Barklay Highway, east of Tennant Creek in the Northern Territory. The project has a direct shipping rock phosphate component, at start up. Beyond that production of yellow phosphorus is planned and ultimately thermal phosphoric acid for LFP production and other uses.

Avenira and Aleees, the latter being the largest producer of LFP outside China (albeit not far outside – Taiwan) executed a binding Licence and Technology Transfer Agreement in 2023 granting Avenira the right to use Aleees' intellectual property for the manufacture and global distribution of LFP cathode active material from the Company's proposed LFP battery cathode manufacturing plant to be developed in Darwin. Production of LFP in Darwin potentially opens the US market, complete with financial benefits provided by the US IRA.

LFP production out of Darwin, using technology with end user acceptance provides a a potential first mover advantage into LFP hungry markets which are yet to establish domestic production.

Hazer – carbon negative methane cracking

The University of Western Australia developed and patented a methane catalytic cracking process now being commercialised by Perth based Hazer Group Limited. As part of the commercialisation process, the Australian Renewable Energy Agency (ARENA) provided part of the funding to construct a groundbreaking hydrogen production facility in Munster, Western Australia. Feed to the plant is biogas produced from the treatment of sewage. The Hazer Process converts bio-methane to renewable hydrogen and graphite using an iron ore catalyst, creating an alternate hydrogen pathway to the traditional approaches of steam methane reforming and electrolysis.

The demonstration plant achieved first production in January 2024 and heralds Australia's involvement in the global hydrogen market while potentially providing graphite for battery production and other applications.

Utilization of this technology provides an international opening into carbon negative clean energy and benefits to Australia through the production of green hydrogen and internationally by employing the Hazer process commercially.

Cobalt Blue – primary cobalt production

Cobalt Blue Holdings Limited occupies an uncommon position in the market. Its Broken Hill Cobalt Project, located 25 km west of Broken Hill is cobaltiferous pyrite, with very low levels of other base metals. Cobalt Blue has patented processes to produce elemental sulphur, iron oxide and a mixed metal hydroxide from the ore. The hydroxide will be transported to Perth where it will be refined in a Cobalt Blue facility based in Kwinana engineered to produce cobalt sulphate for the battery industry. The Kwinana facility is planned for commissioning on third party feed in 2025 and to process the mixed hydroxide from Cobalt Blue's Broken Hill facility in 2027.

Being a primary cobalt producer, Cobalt blue can potentially contribute towards filling the cobalt supply deficit without affecting the supply balance of other battery metals such as copper and nickel. This provides great potential as there is little competition in the field of primary cobalt production.

International Graphite – vertical integration from mining to micronized graphite

International Graphite is a Perth based company that owns the Springdale graphite project located near Hopetoun on the south coast of Western Australia. Springdale will be the feed source to produce micronized graphite to be produce in International Graphite's plant in Collie about 400km east of the planned mining operation. The Collie plant will form part of the Western Australian Government's planned Collie Battery and Hydrogen Industrial Hub.

International Graphite Limited has successfully wet commissioning of its new 200 tonnes per annum graphite micronising plant. The qualification-scale microniser is the largest in Australia and is ultimately planned for scale up to a commercial capacity of 4,000 tonnes per annum at an estimated capital cost of $12.5M.
International Graphite will mitigate risk by servicing markets outside the battery industry including polymers, lubricants, conductors, and alkaline battery cell producers.

In a climate of tough capital markets, International Graphite has excelled in attracting government support in the form of grants now totalling A$13.2M, mitigating the impact to shareholders of raising R&D funding in the equity markets.

Although not unique, the production of downstream products for the battery industry provides potential leverage for the company and the Australian economy.

Reedy Lagoon – green pig iron

Reedy Lagoon Corporation Ltd is a Melbourne base explorer with interest in gold, lithium, and iron ore. It is the proprietor of the Burracoppin iron project, located on the transcontinental railway line 260km east of Perth. The iron occurs as magnetite within a metamorphose banded iron formation and can be liberated by coarse grinding (P_{80} 150μm) resulting in concentrates of 67-70% Fe. The concentrates are around 3%SiO_2, 0.5% Al_2O_3 and very low phosphorous (around 0.005%).

The company has a HIsmelt license and is evaluating the use of biochar as a reductant to generate green pig iron for feed to domestic or offshore green steel producers. HIsmelt is Australian technology which was sold and commercialised in China. The application, under licence, in Australia can provide an entry into the green steel market. The use of such processes is an imperative in the steel industry which currently accounts for about 8% of global CO_2 emissions.

Sunrise CSP – mirrors to produce high temperature heat

Sunrise CSP's 'Big Dish' technology was developed by researchers at ANU. It was commercialised in 2088 and generates electric power by using mirrors to concentrate energy from the sun and convert it into high-temperature heat.

The technology developed an instant export opportunity with the first application being heating in an iIndian hospital Since then Sunrise has partnered with Indian Engineers Limited to roll out the technology in other Indian applications.

THE OPPORTUNITIES

The opportunities available provide the leverage of Australia as the world advances towards carbon neutrality. The opportunities are abundant commencing at the mine site, advancing through mineral processing, the development high-end products from the processed minerals, manufacture of final products for consumers and industry, and recycling those products. There will be significant commercial leverage, and environmental advantages derived by the **INNOVATORS** commercialising the processes they are currently under development.

Australian innovation in the mining and processing sector has been prolific over the years. Examples include:

- recovery of gold from leach liquors using carbon, commencing in the 1809s and leading to the development of contemporary CIL/CIP,
- perfection (not necessarily the invention), of froth flotation to gain greater value from the sulphide ores at Broken Hill in early 1900s and now adapted globally as a preferred method of separating sulphide,
- commercialisation of pyrite smelting by Robert Stitcht at Mt Lyell in the 1890s,
- IsaSmelt – an energy efficient smelting process developed by Mt Isa Mines and CSIRO during the 1970s 80s and 90s,
- HIsmelt – direct reduction of iron ore developed by Rio Tinto in the 1980s and sole to Chinese interests in 2017,
- the atomic absorption spectrometer (‘AAS’) developed in 1952 and still one of the most widely used chemical analytical instruments, and
- the wine cask (Thomas Angove – 1962) enabling comfort, relaxation and enjoyment to much of the minerals industry by providing easy access to the contents of anaerobically stored alcoholic beverages,

just to mention a few. It is interesting to note that albeit not a development driver, each of the above processes probably reduced the carbon emissions of other competing processes at the time. Even the wine cask eliminated the carbon footprint associated with producing glass for bottle manufacture.

Electrification and autonomy

Examples in the preceding section (**THE INNOVATORS**) clearly show that Australia leads the way in mining efficiency through electrification and autonomy with much of the technology being developed in our own back yard by Australian companies. There is a great opportunity to take this technology and know-how to the rest of the mining world and develop the supporting systems for a global industry. Furthermore, these technologies can be extended to transport applications outside the mining industry.

Processing technology improvement

New processing technologies can improve sustainability of existing orebodies and the licensing of such technologies can provide an advantage to the environment, a reduction in carbon emissions, and a revenue stream back to Australian companies through licensing fees, royalties, or equity interests in the projects in which they are employed. These technologies may even turn Resources into Reserves by reducing operating costs of the metal units produced.

Remanufacturing

The Australian mining industry is one of the world’s largest consumers of drilling, blasting, loading and haulage equipment. The units are usually large, heavy and have a high carbon footprint at the time of delivery. Following the Freeport McMoRan example, refurbishment, rather than replacement, could have a significant impact on carbon emissions, not to mention improved capital utilisation. Because of the high concentration of equipment in specific mining jurisdictions e.g. the Pilbara, the NSW and

Queensland coal fields and Western Australia's goldfields, regional refurbishment centres could be established to service these localities with long term environmental benefits.

Training

The Western Australian Caterpillar dealer. Westrac, has been supplying services to the mining industry in Western Australia, NSW and the Australian Capital Territory since the 1990s. It operates training institutes, primarily for apprentices, in Western Australia and NSW and recently opened the Westrac Technology Training Centre (WTTC) in Collie, about 220 kilometres south of Perth. The centre is the first of its kind in the Southern Hemisphere, delivering training courses to technicians of autonomous equipment, such as haul trucks used in the mining industry. Caterpillar operates a similar facility in the US but it is clear there is an opportunity for the industry to develop training courses, not only for domestic personnel, but also for other participants in the global mining industry.

Value added products

Australia can leverage its position in the supply chain and reduce the carbon footprint associated with product transport, by producing a range of products downstream from mining and concentration. This can take many forms. In the case of rare earths, Iluka is proceeding to the production of separated rare earth oxides, greatly enhancing value and enabling an alternative supply chain to the dominant route through China. With separated rare earth oxides available domestically there is potential for Australia to develop a magnet alloys and to service the EV industry, power generation, electronics, defence and communications industries.

Turmoil in the nickel industry has been putting significant pressure on Australian nickel producers. While BHP awaits a decision on the future of its subsidiary, NickelWest, it has at least capitalised on some of the value add, by making nickel sulphate from a large proportion of the nickel it refines in Kwinana, Western Australia. This is used as a feed stock in lithium ion battery industry. BHP is involved with others, through the FBICRC developing mixed nickel/cobalt precursors for cathode production. Longer-term the availability of these precursors could lead to an Australian NCM cathode powder industry.

Two companies aspire for local production of LFP cathode powders, Lithium Australia, through its wholly owned subsidiary, VSPC, and Avenira. The former is based on home-grown technology while the latter has a licensing agreement with Aleees, the largest LFP producer outside China. Today more than 98% of LFP is produced in China and the success of either lithium Australia or Avenira will provide alternative supply chains for battery producers, and greater competition. The commercial competitiveness of thes products be somewhat problematic as Chinese production does have a low cost base. But global paranoia of supply chain security and diversity may well win over cost.

CONCLUSION

Australia’s commercial leverage to decarbonisation in the critical minerals sector is not simply supply, but also the development of downstream industries providing secure supply chains for Australia’s trading partners. Australia has an abundance of critical minerals the development of which must be controlled to improve supply chain security and reduce carbon footprints. Downstream processing is a positive step in removing unnecessary energy consumption in the transport of low-grade, or low-yield products to other jurisdictions. Ideally concentrating and refining of critical minerals should be accomplished as close to the raw material source as possible. This reduces the carbon footprint associated transporting manufacturing waste. This has been exemplified in the Australian lithium industry which has seen a rapid transition from direct shipping ore, to concentrates and further downstream to the production of lithium chemicals. To leverage this opportunity, more value can be added by the production of other battery precursors, or the cathode powders themselves. This could make Australia an indispensable link in the battery supply chain.

Constrained markets in graphite also present a high-leverage opportunity for Australian graphite production to be vertically integrated adding enormous value. This is progressing in a number of locations.

Australia is at the forefront of developing technologies required for more efficient production of raw materials. That is evident in automation, electrification of mining operations improving efficiency, reducing cost and minimizing environmental impacts. Application of Australian expertise in these fields is a great commercial opportunity that will have the potential to streamline mining operations on a global basis

Utilization of our mineral resources can be improved with advance processing technologies providing greater yield for marginal additional cost. This adds to sustainability while reducing the carbon footprint required to deliver value added products. The Australian technologies developed in mineral processing is likely to lead the world as has been the case in the past.

Australia is now showing its ability to provide advanced solar technologies for the production of renewable energy, and green hydrogen, and green ammonia is no longer a thing of the future – it is here and built with Australian know how.

Australia has demonstrated the reality of carbon capture and storage and should look to provide our trade partners access to the abundant and suitable geological formations in the country to sequester their carbon dioxide – particularly if Australia provided the gas the generated the carbon emissions.

There are many areas for Australia to leverage its commercial and environmental outcomes as we progress towards carbon neutrality. There seems to be some government impetus to support that leverage but alas, the government contribution remains modest in comparison with the EU and US and the programs stretched over far too much time. Changes of government remain a political risk in our own jurisdiction and it is up to industry to prove its point and gain the government support it requires.

Political policy remains a concern to maximise the leverage Australia has to decarbonisation. The Australian market is too small to enable self-sufficiency in many of the required developments and government policy must focus on export outcomes to reap the benefits of the abundant opportunities. Such ‘export’ is not only hard goods, but intellectual property, knowhow, and education. The clean energy lobby, including the critical minerals sector, needs to maintain pressure on the government and demonstrate the additional tax revenue that can be created by stimulating the industry.

Australia has a lot to offer the world as an integral part of decarbonisation and will gain enormous leverage by providing the materials required to meet global climate change targets.

REFERENCES

1. Australian Government, 2023. Critical Minerals Strategy 2023-2030. 64pp

2. International Energy Agency, 2023. Prohibition of the export of nickel ore. https://www.iea.org/policies/16084-prohibition-of-the-export-of-nickel-ore (accessed May 2024)

3. Climate Rights International, 2023. Nickel Unearthed - The Human and Climate Costs of Indonesia's Nickel Industry. 138pp

4. International Energy Agency, 2021. GHG emissions intensity for class 1 nickel by resource type and processing route – Charts – Data & Statistics - IEA (accessed May 2023)

5. Madhumitha Jaganmohan, 2024 Global nickel mine production 2023, by country. https://www.statista.com/statistics/264642/nickel-mine-production-by-country/#:~:text=In%202023%2C%20Indonesia%27s%20mines%20produced%20an%20estimated%201.8,nickel%20from%20mines%20worldwide%20by%20a%20large%20margin. (accessed May 2024)

6. Wood Mackenzie, 2024. Lithium market faces a transition as demand growth slows. https://www.woodmac.com/press-releases/lithium-five-things/ (accessed May 2024)

7. Amnesty International, 2016. Is My Phone Powered by Child Labour? https://www.amnesty.org/en/latest/campaigns/2016/06/drc-cobalt-child-labour/ (accessed May 2024)

8. International Energy Agency, 2021. Total copper demand by sector and scenario, 2020-2040. https://www.iea.org/data-and-statistics/charts/total-copper-demand-by-sector-and-scenario-2020-2040 (accessed May 2024)

9. Bloomberg News, May 1, 2024. US, Philippines eye agreement to cut China nickel dominance. US, Philippines eye agreement to cut China nickel dominance - MINING.COM (accessed May 2024)

10. The South Korean Times, Feb 2024. Tesla, Chinese battery firms hit by Korea's new EV subsidy rules. https://www.koreatimes.co.kr/www/tech/2024/02/419_368375.html (accessed May 2024)

11. More, P. 2021. International Mining: Fortescue Future Industries begins testing of hydrogen powered mining truck & blasthole drill rig. https://im-mining.com/2021/08/30/fortescue-future-industries-begins-testing-hydrogen-powered-mining-truck-blasthole-drill-rig/ (accessed May 2024)

12. Blain, L, March 2022. New Atlas: Battery-electric "Infinity Train" will charge itself using gravity. https://newatlas.com/transport/fortescue-wae-infinity-train-electric/ (accessed May 2024)