SAPC Inquiry into South Australia's Renewable Energy Competitiveness

Potential for SA in additional processing of SA's minerals deposits

Final Report

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make history.

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1. Executive Summary

Over the next decade South Australia's (SA) energy sector will face unprecedented changes to demand for renewable energy. In light of the state's favourable endowments of wind and solar resources, the capacity of the state to drive change in the mining and resources sector is of keen interest to industry and government. This report contributes to a much larger inquiry commissioned by the South Australian Government who have tasked the South Australian Productivity Commission (SAPC) to assess SA's actual or potential renewable energy competitive advantage and identify any further actions the SA Government may take to enhance it and any consequential economic development opportunities.

To inform this inquiry, the SAPC examined a range of issues related to the current and future energy sector in SA, and its impact on the broader economy. Some of the issues being addressed required specialised knowledge and so they called upon the capacity of the energy policy research community to support their work. A joint team from the University of Adelaide's Centre for Global Food and Resources (GFAR), and the Institute for Sustainability, Energy and Resources (ISER formerly known as Institute for Mineral and Energy Resources) were commissioned to assess the scale of the potential opportunity for South Australia in additional processing of South Australian minerals deposits.

The purpose of this report is to inform the inquiry of the states' renewable energy and minerals sector's potential and relative position and how that might impact on the broader economy. We also present analysis on the scale of any potential economic opportunities that may emerge as a result of the state's minerals sector and how it may relate to the uptake of renewable energy.

The work was executed under the expertise and scientific direction of GFAR Associate Professor Liam Wagner together with additional experts from GFAR and ISER who conducted workshops and a qualitative survey with sector experts from stakeholders reviewed by the SAPC.

1.1. Iron Ore, Steel and Magnetite

The emerging demand for green steel increases the already significant opportunity for SA to expand its economy both by opening new iron ore mines and by establishing further downstream processing plant for value adding. Indeed, the state is judged to have strong potential to become a substantial exporter of high-grade, green ferrous feed/products. However, consultations with industry indicate that unlocking this opportunity is likely to require the establishment of new public-private partnerships to provide the sector with to access a stable supply of renewable electricity and net-zero hydrogen at a competitive price, together with the major infrastructure of roads, heavy rail, deep water port facilities and water supply.

All the respondents highlighted that it will be crucial for SA government to invest in establishing regional green iron hubs to fast-track development, underpin investment, support innovation and provide access to a highly skilled workforce. Government support is also needed to establish a clear and concise regulatory framework for green products, including certification to capitalise on carbon border adjustment mechanisms, and thereby attract national and international investments.

1.2. Copper

South Australia has the potential to be THE copper state given the abundance of its occurrence throughout most of the state. South Australia's copper sector generated a record $3.3 billion in gross sales in 2020–21 with three copper mines currently operating.

BHP's Olympic Dam mining-processing-smelting refining operation produces copper cathodes, U_3O_8 concentrate, and gold and silver bullion. The operation has a fully integrated metallurgical complex with a grinding and concentrating circuit, a hydrometallurgical plant incorporating solvent extraction circuits for copper and uranium, smelter and refinery (ER, EW and recovery circuit for precious metals. Annual power demand for this operation is roughly 7% of SA's total electricity consumption. BHP is set to dramatically reduce emissions when it becomes the biggest single customer for Australia's biggest wind and solar hybrid facility (the Port August Renewable Energy Park) in late 2022. OZ Minerals operates the Prominent Hill and Carrapateena Mines. Conventional crushing, grinding and froth flotation processing produces a high-quality copper concentrate which is exported.

Other players include Havilah Resources, Hillgrove Resources and Rex Minerals. EnviroCopper are looking at opportunities to recover copper from mineral occurrences and historic deposits in the Kapunda area using ISR methods. Thor Mining have identified a resource at Alford East, which is also considered amenable to copper recovery via ISR. There exists a huge potential for new discoveries in the Eastern Gawler Craton, Curnamona Craton, and Delamarian orogeny.

Issues hampering the expansion of copper production raised by stakeholders include:

- a lack of access to cheap renewable power, water, land access, shared infrastructure including port facilities,

- the need for innovation in mining processing to address complex metallurgy and exploit lower grade resources, and
- geological studies that have focussed almost exclusively on the Gawler Craton at the expense of other domains.

We asked how industry might work together to achieve additional processing of copper concentrates. Respondents cited the pooling of IP and infrastructure and co-supporting a research hub. Others stated why export concentrates at all when there is scope for downstream processing and then local manufacturing, even if power cost is the single largest enabler to achieve this.

We asked how decarbonisation of the copper production cycle from mine to plant to smelter to refinery could be achieved. Respondents argued for:

- renewable grid power;
- the availability of clean storage and carbon capture;
- mine electrification;
- autonomous drones/robots;
- low-emission mining and processing equipment;
- in-situ ore recovery;
- recycling of metals;
- remote operational methods;
- chemical/biological mining; and
- novel leaching techniques.

Water needs to be obtained from desalination projects or recycled better than today (requiring investment in pipelines and associated infrastructure). Potential low-carbon firmed electricity sources mentioned by industry include hydrogen, offshore wind or solar thermal, and long-duration storage such as pumped hydo. Some industry stakeholders also noted that there may be a role for small modular nuclear reactors which some see as well-suited to SA mining operations.

1.3. Critical Minerals

With a growing global demand for secure supplies of critical minerals to enable the renewable energy transition, there is enormous potential for South Australia to become a major producer of critical minerals. Key commodities of interest highlighted by survey participants are nickel, cobalt and rare earth elements, which is in line with the recognised mineral potential of the state. Nevertheless, many survey respondents indicated that South Australia was lagging behind other states, such as WA and QLD, with regards to investment in, and development of, the critical minerals sector. Specific suggestions to progress include initiatives to promote exploration and facilitate industry collaboration, improvements to the regulatory framework, and the development regional processing hubs.

Respondents identified several major challenges to developing a critical minerals production sector, including the small and unstable markets for most critical minerals, the lack of an expert workforce, the lack of processing technology and know-how, and global geopolitical issues. Open market forces are not seen as a viable to solution to overcoming all these challenges, and government intervention is regarded as essential. A need for national-level leadership to provide solutions to these issues is recommended, such as establishing government-backed supply chain agreements, rather than commodity supply market. Greater sovereign manufacturing capability would also improve stability of critical mineral markets.

There is significant potential for production of critical minerals as by-products of existing operations (such as existing copper-gold mines), however most respondents highlighted those costs of processing and recovery need be reduced significantly to make this commercially viable. Cost savings could come from an improved regulatory framework, innovations in extraction and processing technology, and access to shared infrastructure and facilities.

Respondents highlighted an important role for the SA Government in growing an expert workforce to underpin the sector, for delivering low cost and green energy supplies, for enabling downstream processing facilities, and for incentivizing local manufacturing and further exploration. Contributions from the research community include translation of skills and expertise from academia to industry, and development of economically viable processing technology and enhanced exploration strategies.

2. Introduction

Capturing South Australia's renewable energy advantage will be a key enabler in state economic growth and competitiveness of its largest export sectors. The rapid transformation of the energy and minerals sectors driven by the forces of decarbonisation and sustainability will have a decisive impact on the success or potential failure of industrial adaptation and renewal. The SA minerals and energy sectors account for ~$8.52B/year in production value with ~$300M in resource royalties contributing to the states operating income, and employs around 12,000 South Australians.

The Mining and energy sectors are becoming increasingly aware of the need to address the sustainability and decarbonisation goals to remain competitive within international markets. While the prospect of integrating further renewable energy sources such as hydrogen (and its associated products), solar and wind into the operations and processing of resources provides tremendous opportunities both on a market access and competitiveness point of view, it is one which will require additional planning and infrastructure.

Within SA, organisations are planning the expansion of productive of economic mineral resources which will take advantage of the changing needs in society. The growth in demand for key commodities such as copper, green steel, critical minerals are all being driven by changing technological needs and the decarbonisation of industrial processes places renewable energy expansion and integration into SA's minerals sector sharply in focus.

The purpose of this report is to explore the extent to which SA's renewable energy resources could transform the state's minerals sector by conducting a comprehensive analysis of SA's potential opportunities to expand its mineral production and processing base. In light of the SA state government'srecent Copper Strategy the state's potential to process and export refined copper and iron ore could be a great advantage to its economic development. In order to establish whether South Australia has a comparative advantage in producing "green" copper and iron ore, a thorough analysis of the key opportunities and contingencies will be conducted. This study evaluates the scope and scale of available resources and their likely economic extraction. Furthermore, additional analysis of the energy needs of new production and refining methods will also be presented in context with the state's energy system and infrastructure.

3. Background

To gauge the potential areas for expansion in the SA minerals production and processing base, this report firstly presents a background overview of the sector. This section discussed the scope and scale of operations in light of current available resources, split between the three main commodity groups within SA, namely: Iron Ore, Steel and Magnetite; Copper; and Critical minerals.

3.1. Iron Ore, Steel and Magnetite

The Australian steel industry produces approximately 5.3 Mtpa of steel, primarily for the local market, a production rate which equates to only 1% of the nation's iron ore exports – some 880 Mtpa of raw iron ore exports which, even unprocessed, are worth some $170B pa (Australian Resources and Energy Quarterly, Dec 2021). The very low proportion of upgrading, or value-adding, to the nation's ores results from the historical challenge of overcoming the competitive advantages of producing steel within nation-states with very large manufacturing bases supported by large populations and large economies, such as China, Japan and Korea.

However, the projected rapid demand for net-zero materials in the new, low-carbon economy, offers potential to shift this balance. This is because the most prospective, and furthest advanced, technologies for green steel making replace metallurgical coke as the reductant with hydrogen. Importantly, unlike coal, hydrogen is expensive to transport and store, a process that can add 50-100% to the cost of the fuel, while these costs are negligible for coal. This will shift the balance in global supply chains to perform some, or all, of the hydrogen-intensive reduction steps – that of iron-making – in those countries with a coincidence of both net-zero sources of hydrogen and iron-ore (HiTeMP Outlook, 2020). South Australia, as a globally leading region in renewable energy penetration with world-class magnetite resources, is one such region.

South Australia produces some 22% of the nation's steel (1.2 Mtpa) from its Liberty plant, but also has some 44% of the nation's estimated economically recoverable resources of magnetite (SA Magnetite Strategy). Magnetite offers two important advantages in the global supply chain for green steel, the first of which stems from the magnetic properties from which it derives its name. This feature greatly facilitates the concentration, or beneficiation, of the valuable iron ore from the unwanted gangue. The capacity to upgrade the ore at relatively low cost is more important for green steel than for conventional steel making because of the electric arc-furnace that is employed in the best-established pathway for green steel making. High grade, or beneficiated, ores require significantly less energy than their low-grade counterparts because the additional slag inhibits the arc. The second advantage of magnetite is that of an endothermic reaction in the production of ferrous feed products, such as pellets and DRI, which significantly reduces the net energy requirement of production. Hence magnetite is particularly prospective for the future potential supply of green ferrous feed to global markets.

Current SA iron ore production includes both hematite and magnetite iron ores, with more than 90% of SA's iron deposits being magnetite, located in several areas of the state, stretching from the Eyre Peninsula to the Braemar province and the Far North.

Like Direct Shipping Ore (DSO) haematite ores, magnetite requires initial crushing and screening, but then undergoes successive stages of additional processing to produce a magnetite concentrate, sinter or pellets. These can be fed directly into blast furnaces, electric arc furnaces as well as direct reduced iron (DRI) steelmaking plants. SA magnetite has unique characteristics combining low-medium hardness, large grain size and low levels of impurities potentially resulting in concentrate with comparatively lower input costs and higher grades in comparison with other Australian magnetite ores (SA Magnetite Strategy).

The Middleback Ranges is presently the main SA iron ore production site, with operations including the Iron Baron, Iron Knob and South Middleback Ranges mine sites (operated by SIMEC mining, part of the GFG Alliance). The reported 2020 production was of 11.8 Mt iron ore (South Australia's Major Operating/Approved Mines Resource Estimates and Production Statistics, 2022 Report). The majority of the magnetite is pelletised (1.3 Mtpa) and used within the Liberty steel works (approximately 1 Mt crude steel) while the hematite ore (approximately 10 Mtpa) and excess magnetite is exported. Total estimated reserves and resources are just under 250 Mt. Cu-River Mining Australia is the other large SA operating iron producer with approximately 1Mtpa of magnetite concentrate production. Peculiar Knob mine is another operating site (predominantly haematite), currently owned by Peak Iron mines, with some 1.4 Mtpa of DSO and a remaining mineral resource of 7.2 Mt of high-grade iron.

While a few new hematite projects have been recently approved, such as the Wilgerup-One Steel project (estimated production being 1.5 Mtpa of high-grade hematite DSO), a number of new magnetite mines are also under development in SA (see Table 1) and, although not yet commercial, the emerging global markets for green ferrous feed will increase their viability. However, new infrastructure will be required to unlock the investment. This will require green electricity for the grinding, crushing and beneficiation stages, together with hydrogen for any manufacture of higher-value products such as iron pellets, direct reduced iron (DRI), hot briquetted iron (HBI), pig iron or even steel.

Table 1 - Selected magnetite projects under development in SA (adapted from South Australia's Magnetite Strategy)

Company	Iron Road	Cu-River Mining	Magnetite Mines	Hawsons Iron
Project	Central Eyre Iron	Cairn Hill	Mawson Iron	Hawsons Iron
Resource size	4,510 Mt	570 Mt	4,920 Mt	2,400 Mt
Average Fe Grade	16%	47% (27%)	19.5%	17%
Product	Magnetite concentrate	DSO / Magnetite concentrate	Magnetite concentrate	Magnetite concentrate
Status	Mine and development approval	Operating / Advanced exploration	Advanced exploration	Advanced exploration

The energy requirements for the process are all site-specific. The energy is represented here in GJ/tonne when it is cited as primary energy (supplied by or associated with fuel) and as MWh when it is cited as secondary energy (primarily electrical energy).

The main energy inputs needed for the mining process itself are for heavy machinery needed for digging/hauling (typically some 55 MJ/t) and that for crushing/grinding (typically 75 MJ/t), together with the transport of the beneficiated material to market (typically some 0.003 MJ/km). [L. DePlacios 'Natural resources sustainability: iron ore mining', Dyna, 78, 170, 2011, pp. 227-234). In the green mining processes of the future, the diesel fuel is anticipated to be replaced by a combination of electric vehicles and/or hydrogen, while the crushing and grinding will continue to be supplied by electricity, which will need to be green to satisfy the anticipated low-carbon markets.

The reported total energy use of GFG Alliance in Australia for current iron ore mining and processing operations is 1.87 PJ, with associated total emissions being 0.165 Mt_{CO2e} (of which 0.092 are Scope 1 emissions and the remaining being Scope 2 emissions, GFG Sustainability Report 2018). In perspective, the forecasted scope 1, 2 and 3 emissions for the recently approved Central Eyre Iron Project in SA are 0.1, 1.6 and 0.0045 Mt_{CO2e}/annum, respectively (Central Eyre Iron Project Environmental Impact Statement, 2015).

The energy requirements for upgrading of the ore to a beneficiated product are much larger than that for the mining process. The typical energy consumption for crude steel in Japan was reported to vary between 4.44 and 5.83 MWh/tonne, while even that for pellets (approx. 0.3 MWh/t) is an order of magnitude larger than that for the mining process [Carpenter, A. 'CO_2 abatement in the iron and steel industry', US DoE, CCC/193 ISBN 978-92-9029-513-6]. In SA, the Liberty plant consumes approximately 7.56 MWh/tonne crude steel, with associated emissions of 2.56 t_{CO2e}/t crude steel of which 2.46 are Scope 1 emissions (GFG Sustainability Report 2018). The net site electricity consumption is some 364,578 MWh, of which 43% is self-generated. The corresponding installed capacity will be some five to ten times this, owing to the variable nature of renewable energy, together with a method to provide firm power. Hence substantial investment in green infrastructure would be needed to provide the firm contracts. Public-private partnerships are anticipated to be needed to unlock such investments.

The emergence of new markets for low-carbon products is fundamentally driven by the relatively low cost of decarbonising the raw materials relative to the final sale price of a final manufactured product, in contrast to the relatively high cost of decarbonising the material itself. For example, Mission Possible (2020) have estimated that, while the additional cost of decarbonising steel may add some 30% to the cost of steel using currently known processes, this contributes only some 1% to the price of a final manufactured product (such as an automobile) due to the value-adding that occurs during the manufacturing processes.

Furthermore, a wide range of drivers are emerging to overcome this small price difference, including customer demand, government policies, investor demand and the development of new, lower-cost technologies. In addition, the break-even cost for hydrogen in iron and steel making without subsidy has been estimated to be US$2/kg (Hydrogen Council, A Path to Hydrogen Competitiveness. 2020), which is why many countries have adopted this as a target for production cost. Taken together, these reasons explain why many companies have now also adopted the target of net-zero emissions by 2050.

Although the current cost of hydrogen production is still above the price point to be economic in current markets, it is important to move early if SA is to capitalise on the opportunity. The Finkel review estimated the 2018 cost for hydrogen to be ~$2.5/kg via SMR with Carbon Capture and Storage (CCS) and ~$5/kg via alkaline electrolysis, with the corresponding best-case 2025 costs being ~$2/kg via SMR with CCS and ~$2.7/kg (Hydrogen for Australia's Future, COAG Briefing Paper, 2018). However, it is important to recognise that Australia is not alone in having good resources of magnetite and renewable energy. Furthermore, global investment in the production of both green steel and green hydrogen is moving rapidly, with any such investments typically being tied up with long-term contracts, owing to the high capital cost needed to establish them. Hence it is important to move quickly if the state is to capitalise on its competitive advantages.

It should also be noted that the establishment of green ferrous feed and hydrogen export projects are complementary, so can offer leverage to each other to help lower costs. This is because both require similar infrastructure, spanning power generation to port facilities, and because the cost of such infrastructure per unit of output, increases with scale. Nevertheless, the absolute cost and risk, also increase with scale. Hence governments are needed to facilitate such major investments that involve cost-share, whilst also helping to overcome cost barriers through public-private partnerships.

3.2. Copper

South Australia's copper sector produced a record $3.3 billion in gross sales in 2020–21. There are three mines currently operating in South Australia from which the primary commodity is copper.

BHP's Olympic Dam mining-processing-smelting refining operation produces copper cathodes, U_3O_8 concentrate, gold and silver bullion. The operation has a fully integrated metallurgical complex with a grinding and concentrating circuit, a hydrometallurgical plant incorporating solvent extraction circuits for copper and uranium, a copper smelter, a copper refinery, including an electro-refinery and an electrowinning-refinery, and a recovery circuit for precious metals. The copper resource at Olympic Dam is the world's fourth largest, its uranium resource is number one, and its gold deposit ranks in sixth place worldwide. Copper production increased by 20% in 2021 to a record 205 kt. The mine also produced 146,000 Oz gold. Production is expected to dip to 140-170kt copper in FY2022 as a result of scheduled major smelter maintenance. The total ore reserve is 10Gt @ 0.62% copper, 0.21% U_3O_8, 0.28% gold and 1 gram/t silver.

OZ Minerals operates the Prominent Hill and Carrapateena Mines. Ores are concentrated on site by froth flotation and the concentrates exported. Its 2022 production is anticipated to be 55-65,000 t of copper and 125-135,000 Oz gold at

Prominent Hill, and 62-72,000 t of copper and 75-85,000 Oz gold at Carrapateena. Reserves are 62 Mt @ 0.9% copper, 0.6 g/t gold (Prominent Hill, 14-year mine life) and 210 Mt @ 1.1% copper, 0.44 g/t Au (Carrapateena, 23-year mine-life). Resources are 150 Mt and 950 Mt, respectively.

Havilah Resources is currently developing the Kalkaroo copper-gold-cobalt Project in the Curnamona Province, 400 km NE of Adelaide. Kalkaroo comprises a 100.1 Mt JORC Ore Reserve at a copper equivalent grade of 0.89%, capable of supporting a large-scale open pit mining operation over at least 13 years. Havilah's strategic plan to develop the Kalkaroo deposit involves an initial focus on open-cut mining of the shallow, oxidised gold-native copper ore at West Kalkaroo over an initial 3–4-year period and construction of a modular fit-for-purpose processing plant. Havilah's Mutooroo deposit (195,000 t copper, 20,200t cobalt, 82,100 Oz gold) is the subject of a feasibility study.

Hillgrove Resources owns the Kanmantoo Copper Gold Mine, 55 km SE of Adelaide, which ceased operation in 2020, enabling the company to fast track development of an underground mine targeting an 8-16 Mt high-grade copper-gold resource that can be processed using existing infrastructure at the mine.

Rex Minerals controls the Hillside project, Yorke Peninsula, one of the largest undeveloped open pit copper mines in Australia, containing 2 Mt copper and 1.4 Moz gold. Hillside's Program for Environment Protection and Rehabilitation for Stage 1 of the Project was approved by the South Australian Government. Resources in July 2020.

EnviroCopper are assessing opportunities to recover copper from mineral occurrences and historic deposits in the Kapunda area using in-situ recovery (ISR) methods. An inferred copper resource estimate of 119,000 tonnes which could be amenable to ISR is identified. *Thor Mining* have identified a 177,000 t of copper, 71,500 Oz gold resource at Alford East, which is also considered amenable to copper recovery via ISR.

South Australia hosts 66% of Australia's copper reserves, yet current production accounts for only 27% of the nation's total. There is great potential for new discoveries and several dozen companies are currently exploring across the state. The eastern Gawler Craton is a world-class highly prospective region for iron-oxide copper gold (IOCG) deposits where Olympic Dam, Prominent Hill and Carrapateena are located, contains numerous under-explored prospects and deposits and large volumes of currently sub-economic IOCG-style mineralization. Active exploration programs in that domain include *BHP*'s resource definition drilling at Oak Dam that commenced in May 2021, and *Coda Minerals*' Emmie Bluff Deeps discovery and Elizabeth Creek sediment-hosted resource.

Havilah Resources holds 16,000 km^2 of mineral tenements in the Curnamona Craton, covering some of the most prospective and under-explored geological terrain in Australia for copper, gold, cobalt and iron ore.

Hillgrove Resources holds over 6,150 km^2 of exploration licences in the Delamarian orogeny of southeastern South Australia. These include tenements near the

Kanmantoo mine but also deposit but also a range of mineralisation styles, including porphyry, skarn, epithermal and epigenetic copper +/- gold mineralisation that may share features with major recent discoveries in western Victoria.

3.2.1. Copper Extraction and Processing

BHP Olympic Dam operates an underground mine and a fully integrated processing facility that has been in operation since 1988. Plant capacity currently stands at a nominal level of 215 ktpa. The processing plant consists of: (i) Grinding and concentration, (ii) Hydrometallurgical treatment, (iii) Smelting, (iv) Acid production, and (v) Copper refining and precious metals bullion production. Grinding employs two mills (20.8 kW/t/h and 18 kW/tonne/h). There are two flotation circuits, one dedicated to sulphide flotation and the other dedicated to reprocessing of smelter slags. Recovery of copper by flotation is 91-95% depending on ore type. About 10% of the uranium present in the feed also reports to the concentrate along with a majority of the gold and silver present in the feed. The hydrometallurgical circuit comprises leaching of flotation tailings, smelter dust leach, counter-current decantation, and solvent extraction circuits, one to extract copper and another to extract uranium.

The smelter complex consists of a concentrate feed preparation plant, a 500 ktpa "direct to blister" flash furnace, waste heat boiler, gas cleaning plant, acid plant, electric furnace, two LPG-fired anode refining furnaces and a dual anode casting wheel. The waste heat boiler recovers waste energy generated from the heat in the flash furnace off gases. The acid plant also recovers waste heat. Steam produced from the boilers is used for drying concentrates, heating in the hydrometallurgical plant and the refinery. The refinery consists of electrorefining and electrowinning tank houses and a slimes treatment plant, where precious metals are recovered.

BHP is currently developing a new revenue stream through processing of scrap copper. Copper cathode and U_3O_8 concentrate products are exported from Port Adelaide. Maximum power demand for the existing Olympic Dam operation is 125 MW, and annual consumption is around 900 GWh (roughly 7% of SA's total electricity consumption). BHP is set to dramatically reduce emissions by requiring only half this total when it becomes the biggest single customer for a new wind and solar project, the Port August Renewable Energy Park. The latter is set to be Australia's biggest wind and solar hybrid facility (210 MW of wind, 110 MW of large-scale solar) when fully commissioned in late 2022.

OZ Minerals' Prominent Hill underground mine (~4.0 Mt p.a.) employs conventional crushing, grinding and froth flotation processing to produce a high-quality copper concentrate. The Carrapateena mine delivers ore to a purpose-built 4.5 Mt p.a. copper concentrator. The concentrates contain by-product gold and silver and are exported from Whyalla Port for smelting and refining overseas. OZ Minerals is aiming for electrification of the Carrapateena mine and is currently trialling battery-electric trucks for long-distance heavy haulage.

Planned operations by Havilah Resources include a modular plant at Kalkaroo, and a central sulphide ore processing hub at Mutooroo. Planned underground mining by

Hillgrove Resources at Kanmantoo will use existing infrastructure, including a 3.6 Mtpa plant. AGL plan a Kanmantoo Pumped Hydro Energy Storage Facility on-site.

3.3. Critical Minerals

The critical minerals sector in South Australia is currently relatively small but growing rapidly, given that a number of significant opportunities exist. Primary commodities of interest are heavy minerals sands (for zircon, titanium, and rare earth elements; REE), REE (other than in mineral sands), graphite, cobalt, magnesium, nickel and platinum group elements.

3.3.1. Heavy Mineral Sands

Iluka Resources exploits heavy mineral (HM) sands from its Jacinth-Ambrosia mining operations in the Eucla basin, 800 km west of Adelaide. Jacinth-Ambrosia was discovered by Iluka in 2004, brought into production in 2009, and is now the world's largest zircon mine and encompasses mining and wet concentration. Heavy mineral concentrates are transported to Iluka's Narngulu mineral separation plant in WA for final processing. The operation is capable of processing up to ~1000 tonnes of ore per hour which equates to ~120 tonnes per hour of HM concentrate. Rutile and ilmenite are produced as co-products. Total resources in the region (measured + inferred + indicated) are 342 Mt of material containing 4.8% HM (56% ilmenite, 25% zircon, 3% rutile).

The Mindarie mine (*Murray Zircon Pty Ltd.*, currently on care/maintenance) extracted sand containing HMs that were concentrated on-site and transported by truck and/or rail to Port Adelaide for export. There is also vast opportunity for delineation and exploitation of other HM sand resources in the Murray Basin, which straddles the SA, NSW and Victorian border region.

3.3.2. Rare Earth Elements

Australian Rare Earths (AR3) is developing its Koppamurra Project in southeasternmost South Australia and adjacent Victoria. The project centres on an ionic clay REE resource totalling 39.9 Mt containing an average 725 ppm TREO, including 32, 125, 3.3 and 19.2 ppm of high-value praseodymium, neodymium, terbium and dysprosium, respectively. The company holds 4,000 km^2 in exploration tenure or exploration licence applications in regionally analogous depositional settings and is targeting a significant increase in the resource.

Other explorers have highlighted the potential of ionic clay hosted REE resources across the state, as illustrated by recent drilling/resource definition results by *iTech Resources*, *Petratherm Ltd, Cobra Resources,* and *Andromeda Metals*. The main focus of *Andromeda Metals* is the Great White Kaolin Project, for which a Definitive Feasibility Study (DFS) has recently been completed. The company are targeting 300,000 tpa kaolinite production in years 1-5, and 600,000 tpa for the remainder of the 28-year mine life.

Elevated levels of REE found in the Kalkaroo and West Kalkaroo Cu-Co-Au deposits (*Havilah Resources*), together with the Gunsight and Becaroo REE prospects, highlight the potential for widespread REE mineralisation in the Curnamona Province of eastern SA. Igneous intrusions in the Truro-Kapunda region are also highly prospective for REE mineralisation. However, to date, there has been limited evaluation of the potential or exploration for REE in these regions.

3.3.3. Graphite

Several companies have identified opportunities for graphite production from South Australia. These include but are not restricted to the Uley Graphite Project (*Quantum Graphite Operations*, currently care/maintenance), the Campoona Graphite Project (*Archer Materials Ltd*., mining lease granted for open-cut mine and production of 10,000 tpa high grade graphite concentrate), the Siviour Graphite Project (*Renascor Resources*, mining lease granted, open pit mine planned, final investment decision expected in 2022), the Oakdale Deposits (*Oar Resources*; 13.5 Mt @ 3.3% total graphitic carbon) and the Kookaburra Gully Graphite Project (*Australian Graphite Pty Ltd.*, mining lease granted, the open pit mine will have a processing plant comprising conventional crushing, grinding and flotation to produce 25,000–55,000 tpa high grade graphite concentrate).

3.3.4. Magnesium

A number of sedimentary-hosted magnesite (magnesium carbonate) deposits from the northern Flinders Ranges (north of Leigh Creek) are considered suitable for mining for production of magnesium metal. The Leigh Creek Magnesite district (*Volatris Capital Corporation*) includes the Mount Hutton, Mount Playfair, Witchelina, Pug Hill, and Termination Hill deposits, and collective contain 453 Mt of ore at 41.4% MgO. At the current global production rate, this resource is enough to supply the globe with magnesium for more than 150 years. Other smaller deposits include the Robertstown deposits 120 kms north-east of Adelaide and, the Meningie deposits on the Coorong.

3.3.5. Critical Minerals as By-products

A number of identified orebodies represent the opportunity for extraction of cobalt as a by-product; these include the Emmie Bluff, Windabout (*Coda Minerals)* and Mount Gunson copper deposits in Gawler Craton, the Kalkaroo, Mutooroo and North Portia copper deposits (*Havilah Resources)* in the Curnamoona Province, and the Claude Hills nickel deposit (*Metal X Ltd*) in the Musgrave Region, SA/WA border). Other cobalt-rich prospects in the state include Ketchowla, Polinga and Wilawo.

Opportunities also exist for by-product critical mineral recovery (with principal interest in REE and cobalt), from complex IOCG-type sulphide ores (and tailings) at Olympic Dam, Prominent Hill, and Carrapateena. There is currently no production of critical minerals from these deposits. Recovery of tellurium from anode slimes from the Olympic Dam copper refinery is a further topic of ongoing research.

3.3.6. Other Critical Mineral Resources/Opportunities

Lithium Australia identified lithium-anomalous dykes at its Dudley prospect, Kangaroo Island Project. Anomalous tantalum, niobium and rubidium are also noted.

Lithium has until now not received significant attention from explorers in South Australia.

Investigator Resources have identified a total resource of 18.8 Mt ore @ 88g/t silver and 0.52% lead (at a cut-off of 30 g/t silver) at their Paris deposit, Eyre Peninsula, for a total of 53.1 Moz Ag and 97,600 t Pb. Several other precious/base metal deposits occur in the area. A pre-feasibility study is pending that will assess the potential for a >10-year mine life. Work has commenced on mine design, planning and scheduling aspects of the project.

In addition to Olympic Dam, South Australia hosts three uranium mining operations, all using ISR methods: Beverley/Beverley North (*Heathgate Resources*), Four Mile (*Quasar Resources*), Honeymoon (*Boss Resources*). Four Mile is currently producing, while Honeymoon is set to restart production and Beverley is on care/maintenance.

Neither nickel or platinum group element (PGEs) are currently produced from South Australia, yet there is potential, and growing exploration interest, for deposits of these metals in the Musgrave District in the north-west of the state (e.g., Claude Hills; *Metal X Ltd*) and in the Fowler Domain of the western side of the Gawler Craton (Sahara prospect; *Western Areas Ltd*).

3.3.7. Processes used for Critical Mineral Extraction and Processing

Dry mining and concentration of Jacinth-Ambrosia heavy mineral ore through gravity separation takes place on-site, generating a heavy mineral concentrate, which is then transported via the Port of Thevenard to Iluka's Narngulu mineral separation processing plant (WA), where the final products of zircon, rutile and ilmenite are made.

At the end of 2021, Iluka Resources' existing 10 MW diesel power station at the Jacinth-Ambrosia mine has been converted to a hybrid power facility. This globally unique hybrid power station incorporates both solar photovoltaics (3.5 MW solar power generation) and electric turbo compounding technology, combined with an upgraded control system. Project partners Pacific Energy promise greater efficiency in terms of lower fuel consumption while producing lower CO_2 emissions recovering waste energy. Expected savings are stated to be > 2 million litres of diesel and over 5,500 t/y of CO_2. Iluka intend the move from diesel to hybrid energy to be a template for other Australian operations as they transition to net-zero emissions.

In situ recovery of uranium utilises specially designed wellfields. A weak acid solution is pumped through the ore to dissolve the uranium minerals. The solution containing dissolved uranium pumped to the surface, loaded onto resin and transferred to an on-site processing plant that utilises ion exchange whereupon the U_3O_8 concentrate is packaged for export. All uranium oxide concentrate produced in SA is exported for generation of electricity in civil nuclear reactors (U.K., France, China, Sweden, Finland, Belgium, Japan, South Korea, Taiwan, Canada, USA, Spain). No enrichment takes place in Australia.

Planned CM operations by Havilah include production of bastnasite (REE) concentrate at Kalkaroo and a modular fit-for-purpose processing plant for the soft, oxidised, West Kalkaroo gold ore.

4. Workshop and Survey Analysis

The section below outlines the key outcomes from a survey carried out to gain insights/feedback from key external stakeholders, particularly industry, regarding the potential for SA to expand its economy by additional processing of its iron mineral deposits and by expanding further into value added iron commodities. It also includes key outcomes from one-on-one meetings with some of the respondents.

4.1. Iron Ore Steel and Magnetite

Significant opportunities exist in SA to unlock new iron ore resources and develop downstream processing, with the growing global push for 'green steel'.

Figure ***1*** presents the type of industry stakeholders engaged during this process, which were predominantly operating in the iron mining sector (39% of the total when combined with mine development sector) and in the iron processing/concentrate operations (26% of the total). Representatives of key iron/steel SA operators, WA iron operators; an Australian iron pellets producer, engineering, procurement, and construction (EPC) companies and public research agencies completed the survey (**Figure 1**).

Figure 1 - Categorisation of survey respondents by current or potential operation type for the iron/steel/magnetite sector.

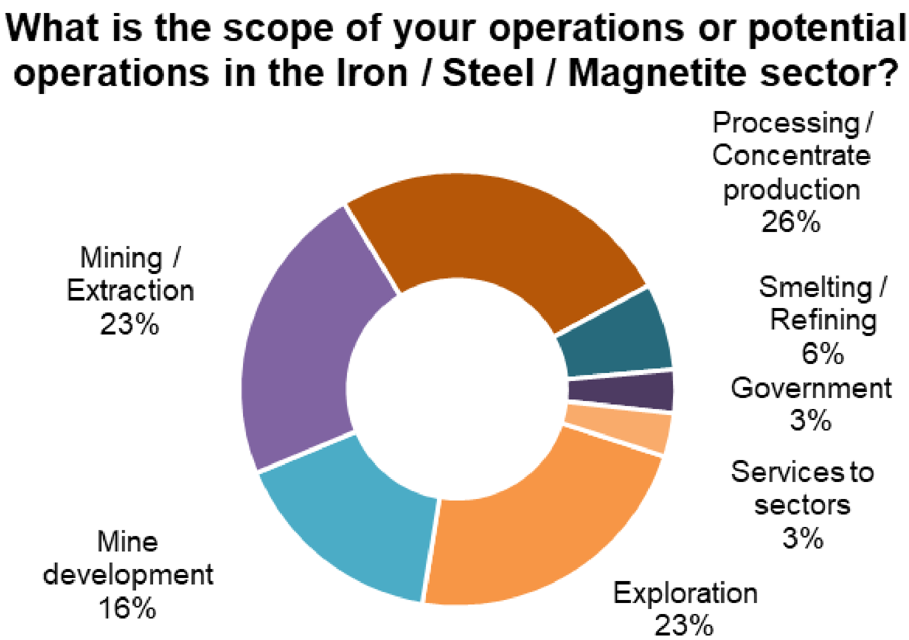
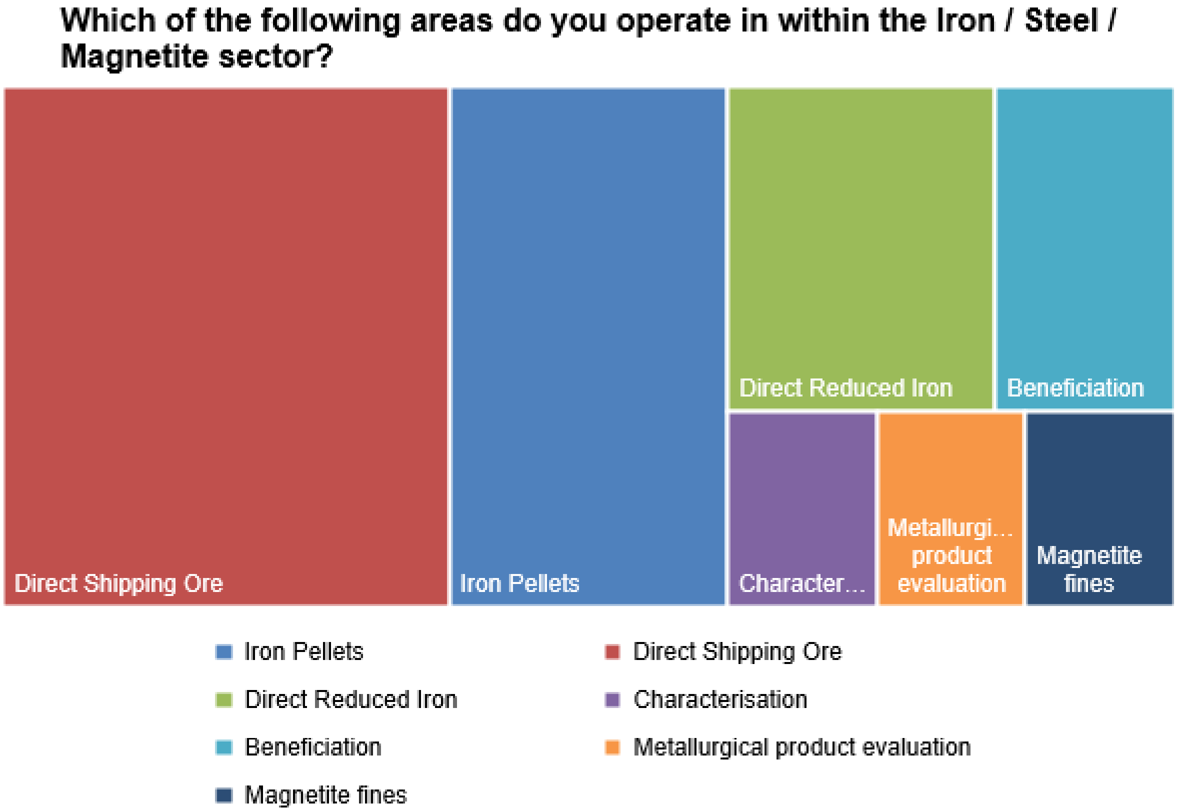


Figure 2 - Categorisation of survey respondents by current or potential scope of operations for the iron/steel/magnetite sector.



The consensus view from stakeholders is that significant opportunities exist in SA to unlock new iron ore resources and develop downstream processing, with a high potential to become a substantial exporter of high-grade, green ferrous feed/products.

Access to affordable renewable electricity and net-zero hydrogen, both with a steady supply, together with a skilled workforce and export ports are among the key needs highlighted by the respondents to support investments and unlock full potential for iron resources utilisation.

4.1.1. Renewable Energy

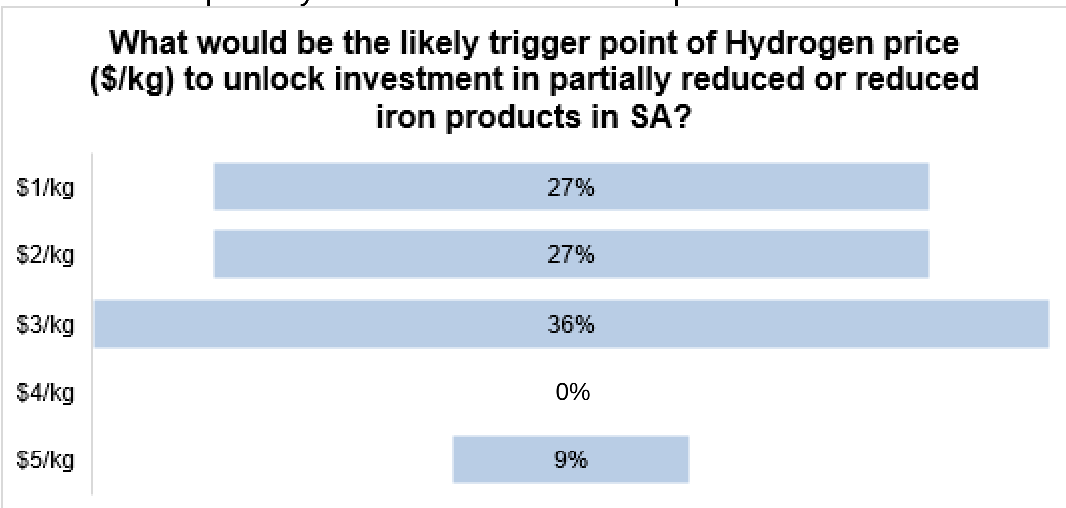
The stakeholder group provided consistent points of view on the availability of renewable energy as a critical barrier to investment for upgrading ore to higher value products. The accessibility of reliable, low-carbon energy at an affordable price is regarded as probably the biggest single issue.

Over 80% of the respondents marked that some 10 GW of green energy would be required to kick off a large-scale production of green ferrous feed. They also they identified utilisation of net-zero hydrogen as a key pathway to enable deep decarbonisation of the iron sector in both medium and long term, while process electrification (via renewables) is the preferred approach in the short term. Net-zero

Hydrogen was not considered to be a short-term solution mainly due to its present cost, with *"international investments in DRI plants mostly starting production with natural-gas, rather than hydrogen - this shows that hydrogen is not yet economic."* Nevertheless, it is also noted that some technical risk also remains in the full conversion to operate on hydrogen, notwithstanding the rapid progress that is being made to de-risk these pathways. Carbon Capture Utilisation and Storage (CCUS) of mineral processing operations were also identified as a key prospective contributor for decarbonisation in the medium term.

Stakeholders were also asked about the likely triggering point for hydrogen price (AU$/kg) to unlock investment in partially reduced or reduced iron products in SA. In line with the literature review analysis, the survey identified that these respondents judge that a cost of AU$2/$kg_{H2}$ is the most likely triggering price to unlock investment. For example, the Hydrogen Council estimates that a cost of US$1.9/$kg_{H2}$ constitutes the typical global break-even cost for the use of hydrogen in iron and steel without a subsidy.[1] Figure 3 presents the details of their view of the value of the trigger point, showing that a clear majority of their estimates of this value span the AU$1-3/$kg_{H2}$ range, with only 9% citing AU$5/$kg_{H2}$. This range can be attributed to differences in the type of product being produced, the quality of the ore bodies and the application. For example, the AU$5/$kg_{H2}$ is likely attributable to applications in transport, while the lower values are for use in the process.

Figure 3 - Likely trigger point of hydrogen price to unlock investment in partially reduced or reduced iron products in SA.



The capacity to provide a firm supply of hydrogen is very important and was again a consensus view of stakeholders. Although this may be challenging to achieve at an affordable price with renewables alone, significant cost reductions are projected with upscaling. Furthermore, with respect to the availability of renewable energy and locally sourced magnetite, it was the view of stakeholders as being a more desirable pathway given that it requires less energy use in order to process.

[1] Hydrogen Council. (2020, January 20). *Path to hydrogen competitiveness: A cost perspective*. https://hydrogencouncil.com/wp-content/uploads/2020/01/Path-to-Hydrogen-Competitiveness_Full-Study-1.pdf

Further discussions explored the potential use of nuclear energy sources as a longer-term option. Most notably as a source for energy firming. The direct production of hydrogen from nuclear power could also be proposed, which would provide electricity for electrolysis in the immediate term and via high temperature thermal processing in the longer term.[2] (Sahin and Sahin, Int. J. Hydrogen Energy, 46 (57) 28,936-28,948: 2021). Nuclear power may offer continuous production without any CO_2 emissions, while the high temperature Generation 4 reactors, could potentially offer a significant increase in thermal efficiency by bypassing electricity production. Nuclear may not offer a solution within the timeframes being considered by industry, as Generation 4 reactors are still at the trial rather than commercial production stage.[3]

4.1.2. Access to Expanded Infrastructure

The key industry stakeholders were also asked about their preferred characteristics of a regional hub in SA to augment capacity in production and supply of green ferrous feed products, and if it would be useful for the SA Government to invest in such a hub. All the respondents replied that it would be crucial for SA Government to invest in regional hubs as this will fast track development and underpin further private investment. This is particularly critical given the remote location of resources relatively to power generation and water supply points.

The hub characteristics more specifically identified are as follows:

- Abundance of affordable, green energy.
- Infrastructure for the potential expanded operations.
- Close proximity to the iron ore coupled with processing plant access.
- Access to sufficient water for electrolysis.
- Community engagement and support.
- Skilled workforce

4.1.3. Government Policy

Finally, the industry stakeholder group were asked what role government can play in assisting in partnership with the sector to develop green iron ore and ferrous feed. Firstly, the view that first mover advantage is of significance to the sector and was reinforced by the belief that other large iron producing nations have already commenced the move to access green markets.

It was strongly proposed by industry stakeholders that the SA government can assist with the aforementioned enablers through establishing planning and through taking on some of the commercial risks through public-private partnerships. Establishing a green supply chain composed of renewable energy production, storage and hydrogen production may not viable for a single consumer, it needs to be done through a large-scale in a consortium, which greatly reduces the system costs.

[2] Sahin, S., & Sahin, H. (2021). Generation-IV reactors and nuclear hydrogen production. *International Journal of Hydrogen Energy, 46*(57), 28936-28948. https://doi.org/10.1016/j.ijhydene.2020.12.182
[3] https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/generation-iv-nuclear-reactors.aspx

Investment is also needed to establish green regional iron hubs via upgrading/expansion of power, water, and transport infrastructures.

4.1.4. Human Capital Requirements

The industry stakeholders highlighted that a highly skilled workforce is required for unlocking both new iron ore mining and additional processing/beneficiation of these ores. In addition, new skilled workforce from technical to management levels equipped with up-to-date regulations/standards of handling hydrogen will play a significant role in the risk mitigation of converting natural gas-based technologies into hydrogen as well as infrastructure supply chain at scale.

4.2. Copper

The recurrent themes expressed by stakeholders during our engagement with the copper sector are closely aligned with those of the Iron Ore, Steel and Magnetite sector. The sector is at a crossroads with respect to expansion of its production base and the global opportunities presented by the electrification of transport and the wider economy. This acceleration in the global demand for copper will likely surpass that of the industrial revolution and the electrification of rural America during the post-depression era. To capture this rapid growth in the demand for copper, a number of factors have been identified as: i) the availability of renewable energy; ii) access to expanded infrastructure; iii) government policy; and iv) human capital requirements.

4.2.1. Renewable Energy

For SA’s copper sector to capture the rapid growth in global demand the primary focus of the industry stakeholders engaged for this analysis was access to gigawatt-scale renewable energy. For the sector to remain competitive in a global market which will require the rapid decarbonisation of its primary materials, the key focus of their planning will be access to affordable renewable energy.

Mine electrification is a key objective of many operators and an important element of the roadmap published in the Warren Institute’s ‘Zero Emission Mine of the Future’ report commissioned by the International Copper Association. This report identified five key target areas for technological innovation to reduce and ultimately eliminate mining emissions: exploration, movement of materials, ventilation, processing, and water use. Smart mines are possible but a cultural change in approach during feasibility studies is required. One imperative of the kind of cutting-edge innovation needed will be collaboration across policy and regulatory bodies, industry networks, capital enablers, and the research community.

Furthermore, industry stakeholders brought enthusiastic responses with respect to the prospect of premiums which could be expected from ‘green copper’ and the roles government policy and promotion of the export of SA green copper to the world. For example, one stakeholder expressed the view that “*This prize is very large. The world needs green copper”* and another noted *“The generation of green copper in SA could become a sought-after product that manufacturers in this space could be* *expected to pay a premium for given that their final products are designed to accommodate the societal push to low carbon future".*

Distilling the industry views on renewable energy can be perceived as a set of common issues with respect to industrial transformation. The availability of renewable energy resources within the state are very high and provide SA with a comparative advantage with its potential to deploy significant gigawatt-scale generation assets. The accessibility of renewable energy hinges largely on the scale and reliability of infrastructure as a conduit for a more acceptable energy source that can position SA firmly in green copper markets. Finally, the price of electricity was also discussed regularly throughout our investigation.

In order to achieve SA's prominence within the green copper space, the state will need to adopt a more focused emphasis on a secure energy system, one which can deliver the required:

- availability of supply;
- accessibility of green energy to current and prospective developments;
- affordable pricing of electricity as a primary input into the mining and processing systems; and
- acceptability to customers for use in a rapidly decarbonising global market.

4.2.2. Access to Expanded Infrastructure

Discussions on the timely expansion of infrastructure for exploration, extraction, processing, and export were a major theme mentioned throughout our investigation with copper industry stakeholders. The respondents focussed their discussion clearly on the potential for 'hub and spoke' mining and processing of resources in the state. The opportunity to build/develop common use infrastructure in key areas of the state to support resource development is one which presents a number of opportunities for development of hitherto sub-economic deposits.

The main role seen for government policy intervention by the copper sector is with the establishment of common downstream infrastructure which will be key to unlock deposits challenged by complex metallurgy via industrial co-operation/symbiosis facilitated by industrial hubs. This shared infrastructure could be achieved by the renewable energy/heavy industry hub model which would de-risk investment so that assets are not developed in isolation and can be used to facilitate broader state development.

4.2.3. Government Policy

The sector views the machinery of government as one of the keystones in the development of resources within the state. Several issues were identified by stakeholders that warrant further investigation in partnership with government, industry, and the research community. Firstly, the availability of information, and more specifically exploration by the Geological Survey of South Australia (GSSA), was mentioned on numerous occasions by the sector. Sustained geological exploration/deposit characterisation on behalf of the state in conjunction with tenement holder requirements to explore is a uniform desire that will allow the full productive potential of resources to be realised.

The timeliness and tempo of the approvals process for exploration and mining of copper was also thoroughly discussed. The rate at which approvals were granted was seen as a major bottleneck for development and the department should be given the means to undertake these processes in a timelier manner.

4.2.4. Human Capital Requirements

Industry views were uniformly focussed on labour requirements for the copper sector. The need for a well-trained and adaptable workforce will be the penultimate factor in delivering green copper resources. Stakeholders expressed the need to engage with government, TAFE and the higher education sectors and their role in establishing a larger well-trained workforce. With rapid developments in new extraction and processing technologies, several sector members expressed the need for skills development and knowledge transfer. The adoption of these newer low carbon methodologies is seen as a pathway to development of the state's resources and broader state economic growth.

4.3. Critical Minerals

Globally, the association between the clean energy transition and the development and extraction critical minerals has thrust the need to find new regions that can supply the increasing demand for these materials. The critical minerals sector within SA is less established than its iron ore and copper counterparts but faces a similar set of issues which we will synthesize within this report. As discussed above in the background sections, whilst there are many areas of commonality with iron ore and copper, critical minerals face a more diverse technical and economic landscape and therefore a wider range of issues. This includes geopolitical considerations which could mean Australia's strategic allies (i.e. USA, UK, Canada and EU) could be willing to pay a premium price to enable critical minerals supply from more geopolitically stable region. Respondents also discussed how a SA-driven critical minerals sector could help ensure a downstream supply chain.

While the resources differ in their abundance and dispersal throughout the state, a holistic approach is to be taken here where we identify the common areas of discussion. The sector's development and ability to enter these strategically important markets we have identified the following areas for discussion, namely: i) human capital requirements; ii) access to expanded infrastructure and iii) government policy; and iv) the availability of renewable energy.

4.3.1. Renewable Energy

The stakeholders within the critical minerals sector echoed many of the discussions on the availability, accessibility, and affordability of renewable energy for extraction and processing. As with our previous discussion on the copper sector, renewable energy was viewed as the primary mechanism to creating a green mining operation. The discussion on transitioning to zero emissions for the critical minerals sector was embraced and stakeholders highlighted the need for certainty on energy policy and infrastructure costs.

4.3.2. Access to Expanded Infrastructure

In order for SA and Australia more broadly to secure its supply of critical minerals a number of key opportunities and potential bottlenecks were identified by industry stakeholders. With respect to the potential to develop a national stockpile and in turn a more secure supply, respondents also discussed the ability of a SA-driven critical minerals sector to ensure a downstream supply chain.

The ability to maintain the reliability of supply of these materials (such as rare earth elements), would not only benefit SA directly, but also provide an alternate supply into a market exposed to significant geopolitical risk. Sustaining the supply of critical minerals domestically is also of significant national importance. If Australia wanted to develop sovereign capability to extract and process critical minerals domestically the development of energy generation, processing and transport infrastructure for down and mid-stream supply chain segments may need to be supported. It may also require the identification of purchasers who are willing to pay a premium for more secure supplies to offset geopolitical risks in order to overcome any potential cost disadvantages of Australia's more robust environmental and safety regulations.

The development of that infrastructure however is susceptible to higher risk premiums for funding should the assets be developed in isolation for mine-specific access. Similar to the minerals sectors discussed earlier, the main driving force seen by industry is government led partnerships around common use infrastructure. Furthermore, key industry respondents discussed the need for longer term alignment in parallel investment and support for the overall supply chain. Going further, there were several suggestions of public–private partnerships to reduce risks to industry of investment in the development of the critical minerals supply chain (in particular for heavy haulage/rail transport routes) by having the government bear some of the commercial risk. In summary the intentions of key industry stakeholders to engage with government on the development of regional energy/minerals hubs was uniformly positive.

4.3.3. Government Policy

Given the operational overlap critical minerals and copper have; key stakeholders have identified a number of areas in which policy can be implemented in order to advance the sector.

The timeliness of the regulatory process associated with the approval for new exploration and development was highlighted as a key risk by these stakeholders. Some discussion on this point was seen by the collective as a risk which delayed funding and final financial approval. The state was viewed as a partner who could contribute to mitigating these risks associated with development.

The partnership between stakeholders and the machinery of government in providing geological information and data was also seen as a key to facilitating the development process. Government supported exploration programs and building capacity within the GSSA was also seen as vital to the future of the sector.

4.3.4. Human Capital Requirements

During interactions with key stakeholders, one of the leading factors seen as a significant risk to the development of the sector was the availability of human capital. These concerns were raised independently during one-to-one interviews and at an industry focused workshop. Industry expressed a number of concerns which highlights Australia's lack of existing expertise domestically.

It was further discussed by industry stakeholders that building a skilled workforce in the areas of minerals processing, rare earth and hydrometallurgy will ensure the successful discovery and development of the sector. A consensus view of the engaged partners was that education will be pivotal in fostering a highly skilled human capital base in critical minerals. This skills base will facilitate the expansion and operation in mining and will play a significant role in the risk mitigation of technologies needed to cross both the critical minerals and infrastructure supply chain at scale.

5. Economic Analysis

Following our extensive engagement with industry stakeholders and government agencies, there emerged a number of key overarching themes. While international competition is seen to be fierce in the resources sector, several factors were believed to in the state's favour that will place it at the forefront of global market competitiveness.

SA's renewable energy potential presents the mining sector with a myriad of opportunities that if exploited in a timely fashion, would put the state at the forefront of green resource production.

The economic advantages to the state of expanding its renewable energy generation base and the adoption of hydrogen for heavy industry have been discussed extensively by the South Australian Centre for Economics Studies (SACES) at the University of Adelaide.[4] This quantitative study of the effects of export scale green hydrogen production highlights the prospective increase in Gross State Product (GSP) of 1.4% by 2029/30 and the additional need for 4,600 skilled workers to the state. Furthermore, for the additional processing scenario which examined the potential impact of an additional non-ferrous ore (i.e., copper, and critical minerals) production facility, an additional 0.3% is added to GSP which encompasses an addition 2,400 skilled workers.

This expansion of human capital requirements within the state, should either scenario eventuate, is one that will require skilled migration and the creation of training programs which can deliver a labour force to service new industries. It is important to reiterate the industry stakeholders concerns with respect to the availability of skilled human capital which is flexible and deployable within the minerals and renewable energy sectors. While the renewables sector is a mature one within Australia, the new technologies being proposed for zero emissions mining and for the processing of critical minerals are relatively new. Furthermore, given the likely competition for skilled labour in the hydrogen supply chain, industry stakeholders are also of the view that the training needs for the sector should be provided within the state. This is an important role for government (state and Commonwealth).

The urgent need for renewable energy within the mining sector to meet its sustainability goals is further highlighted by the likely international competition the sector will face. South American copper, mainly from Chile and Peru, is a key player within the global market.[5] Despite the ramping up of supply from such regions, global copper demand is unlikely to slow with the rapid transition to net-zero emissions.[6] It

[4] Hancock, J., & Halim, S. (2022). *Potential economic impact of transitioning South Australia's heavy industry and mineral sectors*. Report to the South Australian Productivity Commission.

[5] Sandell-Hay, C. (2021, April 9). *South America's Copper Domination Remains in Place Despite COVID Hits*. The Assay. https://www.theassay.com/articles/feature-story/south-americas-copper-domination-remains-in-place-despite-covid-hits

[6] Holmes, F. (2021, June 1). *The Race For Copper, The Metal Of The Future*. Forbes. https://www.forbes.com/sites/greatspeculations/2021/06/01/the-race-for-copper-the-metal-of-the-future

is important not to speculate here as to Australia's likely capacity to enter or remain competitive in international markets without a comprehensive review of production and processing costs in developing nations. Reliable data on costs and investment risks are usually only commercially available from third parties.

While international competition is likely to have an effect on the growth of the sector domestically there are a number of mitigating/ameliorating factors which industry stakeholders have raised. The exposure of international commodities to environmental trade regulations and willingness of national governments to address climate change will be a major factor in determining the competitiveness.

The European Union's proposed Carbon Board Adjustment Mechanism (CBAM) is one of the key risks to commodities exporters. Its purpose is to account for Europe's Scope 3 carbon emissions embodied within goods imports. The main producing nations whose raw materials will be assessed on the nation's capacity to institute adequate greenhouse gas and other environmental pollutant controls. While major competing countries may be able to address carbon emissions, the risk(s) associated with renewable energy projects in mines within developing nations is far higher. This risk is directly seen in higher financing costs for developing nations within the mining sector.[7] If Australia as a whole can return to emissions reductions trajectories that are consistent with being exempt from the CBAM, this could represent a competitive advantage relative to other major copper producers. If Australia remained on a slow emissions reductions trajectory there would be no relative advantage as Australian exports would also be potentially in scope for the CBAM.

The ability for the mining sector within SA to reduce its exposure to environmental and financing risks is one of the key points of collaboration with government. Industry believes that government support for the establishment of shared infrastructure via the development of integrated hubs across the state will facilitate the expansion of the mining sector.

[7] Damodaran, A. (2009). *Ups and Downs: Valuing Cyclical and Commodity Companies*. http://dx.doi.org/10.2139/ssrn.1466041

6. Conclusions

A number of challenges must be addressed for the SA minerals and processing sector/s to capitalise on the emerging markets for low-carbon products and assert its potential competitive advantage as a powerhouse in the supply of net-zero-carbon commodities. Industry stakeholders and key informers have been used to better estimate the scale and nature of the investment, policy and economic conditions that are needed to overcome the barriers that might otherwise prevent the expansion of SA's resources sector to access these global markets.

One of the main priorities identified from the survey is the need to establish sufficient infrastructure to supply GW-scale green energy at a competitive price, notably for green regional electricity and transmission projects, together with net-zero hydrogen. This transition to GW-scale renewable energy will require planning and investment to ensure a reliable energy supply by incorporating storage and/or net-zero hydrogen.

In particular, if the state were to establish a green iron sector through the export of DRI or pelletised magnetite, there would be a requirement for an additional consistent supply of around 10GWh of firm net-zero electricity (over six times the current average generation in South Australia). Such a large-scale expansion of net-zero electricity would require the consideration of all options for firming, targeting first the regions where new investments are most prospective. The estimated cost of this 10GW of renewable energy capacity firmed with storage of >200GWh would be of the order of ~$90 billion. As an estimate of the real capacity required of wind and solar would be in the order of an addition 18GW and 14 GW respectively.

Further discussion also highlighted stakeholder concerns with respect to the availability in the near future of technology that can achieve the cost-effective production of green commodities at an industrial scale. There is a potentially important role for government in supporting R&D activities to identify and test potential green mining and processing technologies suited to South Australian mineralisations and conditions. The need for additional human capital was also highlighted, together with further support to partner with research and development organisations within the state. That is, the deployment and maintenance of new technologies will require additional workforce training to be planned or undertaken.

Transhipment and export accessibility were of concern to the stakeholders, a number of whom identified the need for the upgrade and expansion of deep-sea ports. Without the ability to access additional port facilities that can accommodate the rapid expansion of green commodity exports from the state, the sector would face a significant barrier to market entry. In particular green iron ore and its derived products would be at a disadvantage in global markets. Hence a plan to establish, or augment, such facilities should be undertaken.

Market access to sufficient water resources within the state will also be vital in, or a potential limiting factor to, the further expansion of the iron/steel sector in SA. Water is expected to be a limiting resource for the production of net-zero hydrogen via electrolysis and for the beneficiation/upgrading of iron ore. Hence a plan to address this resource is also needed.

New government partnerships, such as via public-private partnerships around infrastructure, were also identified as being necessary to attract the investment needed to unlock these new markets for green mineral products. The risks associated with the cost of investing in infrastructure and renewable energy generation were identified to be significant by all sectors. Hence it is recommended that new options for public-private partnerships and state collaboration be explored to identify preferred options to de-risk such investments.

Appendix 1

Appendix 1 consists of the survey questions and the responses received from the industry representatives.

Iron Ore Steel and Magnetite:

We asked about **the scale of the potential economic opportunity for South Australia in unlocking both new iron ore resources and additional processing/beneficiation of these ores** for exporting high-grade green ferrous feed products. Several respondents marked that significant opportunities exist in SA to unlock new iron ore resources and develop downstream processing, with a high potential to become a substantial exporter of high-grade, green ferrous feed/products. The need to access cheap renewable electricity (steady supply), net-zero hydrogen, skilled workforce and export ports are among the key needs highlighted by the respondents to support investments and unlock full potential for iron resources utilisation.

- *"SA has around 6bt of magnetite resources and 65% BF pellets are currently trading at $180p/t and concentrate at $136p/t. DRI grade or HBI/Pig iron is considerably more. As offshore steelmakers strive to reduce carbon emissions, high grade product premiums are likely to increase further."*
- *"Significant opportunities exist in SA to unlock new iron ore resources and develop downstream processing, the growing global push for 'green steel' does present an opportunity for SA, combined with existing facilities and capability for power and port."*
- *"Transformational. The CEIP alone has a 3.7Bt reserve and the current flowsheet will produce 12Mtpa of 67% Fe concentrate, over an initial mine life of 23 years. Additional proximate orebodies would more than comfortably double this mine life to in excess of 50 years."*
- *"Based on initial exploration of currently owned mines and sites, we believe that GFG alone can increase the production of Magnetite Concentrate to +15Mtpa. Depending on the availability of cheap renewable power the Magnetite Concentrate can be converted to Green DRI by utilising Hydrogen as a reductant, but this will require substantial investments in renewable energy sources, Hydrogen Electrolysis, and DRI production facilities."*
- *"10 to 20 mill tons pa in both hematite and magnetite, high grade concentration with additional processing for direction reduction iron products."*
- *"South Australia has potential to become substantial exporter of high grade, net zero, magnetite concentrate. Our internal ambition is to be exporting 5mtpa of concentrate in 5 years."*

We asked about **the scale of infrastructure required, through government co-investment, for shifting towards a large production of these products.** We also asked about **the most prospective short-term, medium-term and long-term decarbonisation pathways for the SA iron sector**. Over 80% of the respondents marked that some 10 GW of green energy would be required to kick off a large-scale production of green ferrous feed. Also, they identified utilisation of net-zero hydrogen as a key pathway to enable deep decarbonisation of the iron sector in both medium and long term while process electrification (via renewables) being the preferred approach in the short term (Figure 3). Net-zero Hydrogen was not considered to be a short-term solution mainly due to its present cost, with *"international investments in DRI plants mostly starting production with natural-gas, rather than hydrogen - this shows that hydrogen is not yet economic."* Carbon capture utilisation and storage (CCUS) was also identified as a key prospective contributor for decarbonisation in the medium term.

Beside these three potential pathways, the responders also highlighted the following pathways:

- *"Increased scrap utilisation."*
- *"Increased use of magnetite, as magnetite concentrate is exothermic, which requires less energy inputs (less fuel)."*
- *"Use of nuclear energy sources as long-term option. Nuclear (thorium or uranium) green energy for water and energy supply for extraction and production. An example being NEOM plan in Kingdom of Saudi Arabia."*
- *"Alternative processes. One of the major sources of CO_2 in the Steelworks is the consumption of large amounts of coke as reductant in the Blast Furnace process. By replacing it with an alternative process which can utilise net-zero hydrogen as reductant, such as DRI Shaft Furnace, the overall CO_2 emissions can be reduced by >80%."*
- *"Use of alternative carbon sources including waste and bio-char."*

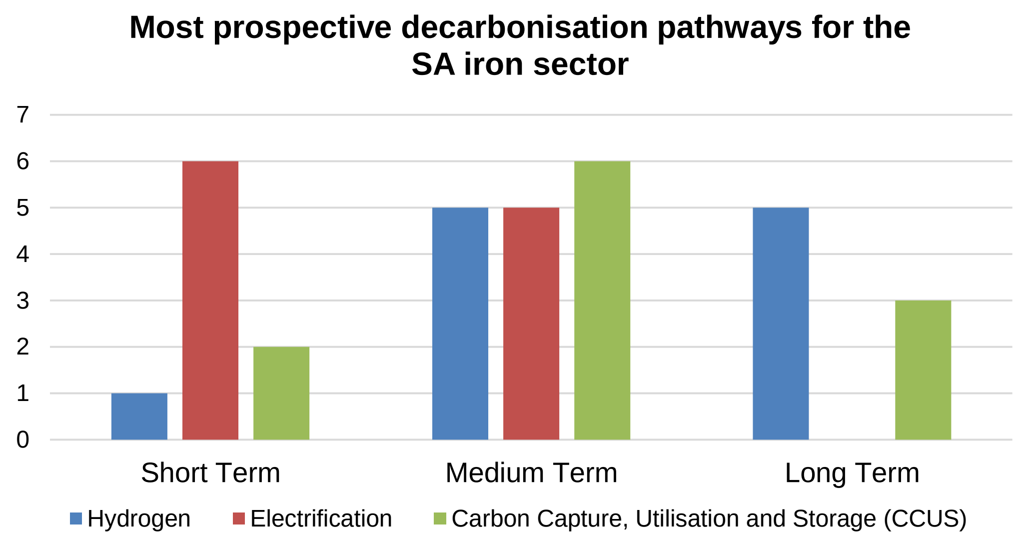


Figure 4 - Number of respondents anticipating most prospective decarbonisation pathways for the SA iron sector

We then asked about **how SA's actual (and future) renewable and sustainable resources could provide a competitive advantage**, especially for beneficiated iron processes. Over 50% of the respondents identified a globally competitive combination of solar/wind and penetration into the electricity grid as a key competitive advantage of SA. Some respondents highlighted that *"they have already invested in solar energy but consider that grid upgrades are needed to connect low-cost wind, which is not sufficiently co-located, so that the electrical network would need significant upgrading to be competitive".* The survey also identified the presence of a supportive government in terms of environmental regulation/policies as another advantage. Beside wind/solar power, some respondents also considered good access to low-carbon hydrogen options (15% of total response), nuclear green energy (6%) and pumped hydro (3%) as other potential competitive advantages. In particular, some respondents have also highlighted the synergies between hydrogen and nuclear energy as well as the need to better understand how to provide a firm supply of net-zero electricity at lowest cost.

- *"The capacity to provide a firm supply of hydrogen is very important. This is challenging to do at an affordable price with renewables alone with current technology. For example, Newcorp Steel (North America's biggest steel producer), who have just built a DRI plant, is also investing in nuclear energy for this challenge."*
- *"International investments in DRI plants are mostly starting production with natural gas, rather than hydrogen. This shows that hydrogen is not yet economic. Scandinavia is the exception, because it has access both to cheap hydro and nuclear, which provides firm hydrogen at sufficiently low cost."*
- *"SA Government and Australia in the broader context need an independent debate to understand how to provide a firm supply of net-zero electricity at lowest cost. Micro-nuclear should be on the table for the provision of the firming capacity, noting that the establishment of nuclear submarine capability could open the door to the establishment of small nuclear reactors."*

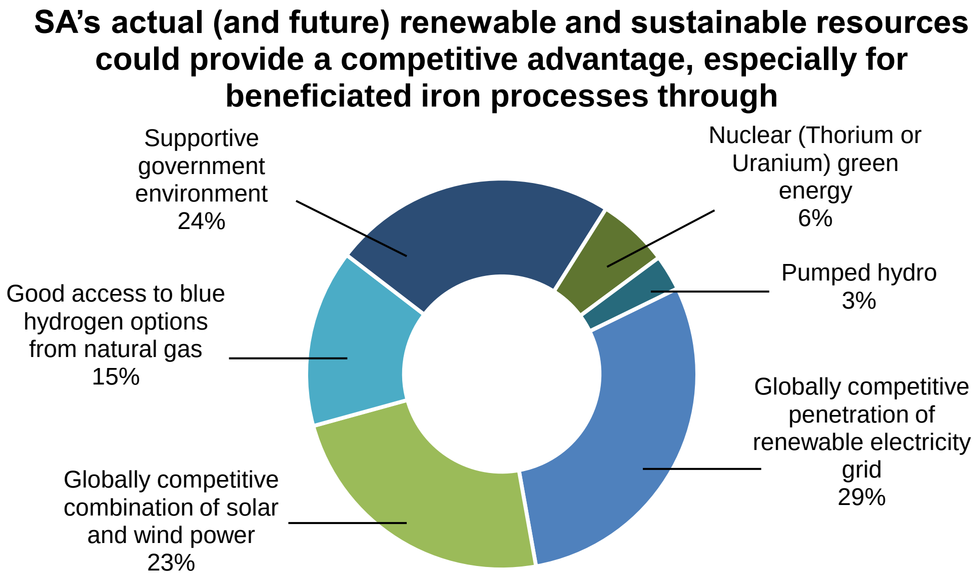


Figure 5 - How SA's actual (and future) renewable and sustainable resources could provide a competitive advantage for beneficiated iron processes

We also asked to **rank a series of risks and uncertainties that would make these opportunities more or less likely to be realised**. The data reported in Table 2 highlighted that the unavailability of commercial technologies within the given timeline together with locking in long-term contracts for competitive green energy resources and/or high value products are among the highest risk factors. When asked **to list the medium and long-term planning and monitoring actions to minimise these uncertainties/risks,** we received the following feedback:

- *"New green technologies will increase costs, not decrease them. Implement any actions to address this."*
- *"Projection of pellet premiums, accurate techno-economic assessment of unexploited resources, Life Cycle Analysis from pellet to steel making production."*
- *"Continuing support research for new or improved technologies for all aspects of green hydrogen production. Support the establishment of local manufacture for green hydrogen equipment. Implement a green certification system for hydrogen production. Continue to engage with global players in the decarbonisation space."*
- *"Assistance with Social License to operate and commercial solutions (lower cost)."*
- *"Government support and investment is crucial to make any renewable energy or hydrogen project viable at this stage as the technologies available and renewable power are relatively expensive. Without a clear understanding of the regulatory framework and local demand for green products (magnetite concentrate, pellet, DRI or steel) it is difficult to formalise a concrete business case for investment."*
- *"Assistance/assurance within the area of emissions quantifications for scope 1,2,3 as well as governance structures for green energy options. Legislation through to distribution is still an area that has more questions than answers for industry."*

Uncertainty	Very low risk	Low risk	Medium risk	High risk	Very high risk
Unavailability of commercial technologies in time	2	2	5	2	-
Lack of investment to drive the projects	6	4	1	-	-
Locking in long term contracts for high-value green products	-	5	4	2	-
Locking in long term contracts for competitive green energy resources	-	3	4	4	-
Uncertainty in regulatory framework	4	6	-	1	-
Uncertainties in social licence to operate the project	4	3	4	-	-

Table 2 – Number of respondents ranking the risks and uncertainties that would make competitive SA iron-based opportunities more or less likely to be realised

We then asked the respondents **to provide recommendation in terms of potential actions/strategies to the SA Government to overcome barriers arising from potential supply chain challenges and/or required substantial infrastructure upgrading due to an increased, future production volumes of top-grade iron ore products.** The key suggestions/feedback are around certainty in regulation/demand for green products in Australia as well as co-investments in cheap green infrastructure for power, water and transport (heavy rail, port). In details, the responses are as follows:

- *"Investigate combined state/federal solutions, combined heavy freight/transport options to include other commodities or sectors that could benefit from such developments."*
- *"Assist in facilitating the development of modern and efficient deep water port infrastructure, e.g., Cape Hardy that will have demonstrable positive impacts for multiple industries and economic growth opportunities for SA. Assist in supporting future rail infrastructure (where net benefits are clear) to integrate with planned port developments."*
- *"Investment in cheap green infrastructure including power, water and transport (heavy rail and port), while encouraging the development of downstream processing."*
- *"As South Australia has great renewable generation capabilities, but the best locations are generally vast distances from the end users a strong and reliable electrical network is essential for connecting the renewable energy sources with the users. If we don't have certainty in the regulation and demand for green products in Australia most of the future increased production will be exported to Europe or other green economies as Magnetite Concentrate or Pellets. This will also deplete the opportunities in the renewable energy sector."*
- *"Strong logistics contacts with off-takers and end smelters, developing more specialised and diversifies end users using specialised products."*
- *"Investment/co-investment in rail infrastructure to ensure road networks are not overloaded would be a great first start. Then also the supply side of things, Electrical and water infrastructure is crucial to operational processing plants - these need to be considered and medium-term investment need to support supply of these critical infrastructure pieces to make investment decisions easier for prospective projects."*
- *"Providing a transparent approval processes with statutory timelines for approval. Resolving land tenure issues to create unencumbered logistic and service corridors. Commitments to co-invest in common user infrastructure"*

We also asked about the **likely triggering point for hydrogen price ($/kg) to unlock investment in partially reduced or reduced iron products in SA**. In line with the literature review analysis, the survey highlighted that 2 $\$/kg_{H2}$ would be the most likely triggering price to unlock investment (Figure 3), with 1-3 $\$/kg_{H2}$ being the most likely triggering range price. Regarding triggering hydrogen price and hydrogen production/utilisation, respondents also highlighted the following:

- *"Industry is agnostic to the source of net-zero hydrogen - be it green, blue or turquoise. They simply want access to a secure supply of certified energy. Industry would prefer not to produce the hydrogen themselves, but rather they want to purchase it."*
- *"There is not a simple answer. International investments in DRI plants are mostly starting production with natural gas, rather than hydrogen. Scandinavia is the exception, because it has access both to cheap hydro and nuclear, which provides firm hydrogen at sufficiently low cost. This implies that the cost of $2/kg should be based on the cost of a delivered, stable resource. That is, this price should be after storage."*
- *"Liberty GFG first stage is upscaling its mining capacity to 15 Mtpa magnetite, with plans well underway - already beginning to implement some of the*

equipment, and detailed engineering plans are also beginning. Second stage is to upgrade to pellets but also keen to upgrade further to DRI and/or HBI with hydrogen. This would scale to 10 Mtpa of DRI product. However, the cost of hydrogen is presently too great to go to DRI/HBI. The trigger point for the price of hydrogen is approx. AUD$2/kg based on Australian market. Some markets may open at a higher price. For instance, in the European market it could be higher than this - perhaps at AUD$3/kg. Which option occurs will be influenced by the extent to which the government co-invests."

Beside hydrogen, we also asked **what other trigger points are needed for investment towards upgrading of green ferrous feed for global supply chains and actions that SA Government could take to incentivise companies to invest further**. Main, common feedback were:

- *"Introduction of premium for green, decarbonised products, carbon border adjustment mechanisms or similar regulatory mechanisms to make these projects economic."*
- *"Legislation to support transport of Green Hydrogen (framework already in place for NG). Trades and training to ensure industry is capable of support."*
- *"Clear and concise regulatory framework. Certainty of offtake or further downstream manufacturing, onshore low interest loans and/or grants, reduced tax and/or royalties for start-up periods."*
- *"Address the issues of transport and storage of hydrogen – probably through ammonia".*

Finally, we asked about the **preferred characteristics of a regional hub in SA to augment capacity in production and supply of green ferrous feed products, and if it would be useful for the State to invest in such a hub.** All the respondents replied that it would be crucial for SA Gov to invest in regional hubs as this will fast track development and underpin further private investment. This is particularly critical given the remote location of resources relatively to power generation and water supply points. Regarding the hub characteristics:

- *"Huge quantities of energy are needed, and there must be a means to provide "firming" of that energy (e.g., NG, nuclear)."*
- *"Access to cheap utilities (power/water/waste disposal etc.), suitable infrastructure for access / delivery/exporting, available resource base, R&D capability, METS sourcing suitability."*
- *"Grinding, classification, magnetic separation, pellet production, metallurgical evaluation for BF and DRI processes. This exists in Australia, but not centralised in SA."*
- *"Cheap green power and water and transport with access to high skilled workforce."*
- *"Regional hubs capable of supplying required amounts of green energy. Supported by infrastructure and maintenance."*
- *"Close proximity to Iron source. Good electrical network from best renewable energy locations. Access to sufficient water for Electrolysis. Community disposition and support. Skilled workforce."*

Copper

We asked about the **short-, medium- and long-term potential opportunities and risks for increased copper production in SA**? Several respondents remarked on the need for land access, infrastructure support, downstream processing facilities with cheap power and water, skilled workers, and export port availability.

- *"In the long-term, new discoveries and higher metal price. Technological advancements which can reduce all-in sustaining cost per tonne of copper - this may be in mining, processing and transport. Ensuring 100% renewable energy grid such that SA can market ESG credentials. In the medium-term, ensuring that state government does not play politics with the Resource sector as occurred with the 2022 State election where land access was a key agenda item. Increasing workforce participation in resource industry. This starts by breaking down negative perception of resources sector which is that of environmental destruction and repositioning the resources sector as the key sector to lead the energy transformation. Embedding the importance of the resource sector into school curriculum would go a long way as school kids are impressionable with major influences being school teachers and parents, both of which can ignorant as to the importance of resources sector and can put their own negative views into the way resources is portrayed with regards to society and environment. In the short term, development funding opportunities are restricted by the Foreign Investments Review Board and backdrop of Australia deteriorating relationship with China, particularly in WPA. Repairing this relationship is critical to economy."*
- *"Creating hub and spoke mining / processing facilities for deposits/projects that cannot carry the standalone development costs. Opportunities to build/develop common use infrastructure in key areas of the state to support resource development - access to common power/water (cheap green power etc.) Risk: aging facilities, as some major sites do not lend themselves to common usage, assets developed in isolation without considering broader state development."*
- *"Short term is really brownfield expansion, medium term is re-development of known copper provinces and long term is exploration of under explored but prospective ground in South Australia. The potential is large in all time frames".*
- "*Land access and approval times are a key risk in SA, reprocessing of existing mined material, concentrate benefaction and wire production"*.
- "*With advances in in-place mining techniques (in-line, in-mine and in-situ) the opportunities for South Australia are huge. There are a large number of already identified occurrences and deposits that are not currently economic with conventional mining techniques. Advances in low cost, in-place mining techniques will mean that a large percentage of these should become available to be mined profitably with much less impact on the environment opening up a large range of opportunities"*.
- "*Common issues with impurities and contaminates in concentrates to SA copper ores that need to be resolved. The opportunities are demand increasing, and margins that can pay for overcoming these hurdles*".
- *"The operating sector is dominated by a small number of large, well-funded players. Exploration, and therefore the future potential of any expansion pipeline behind the main players, is in the hands of a range of smaller companies, many of whom are not well funded"*.

- "*Access to funding in exploration is highly competitive, investors have a short-term attention span so any delays in work plan approvals, grants and processing times for tenure applications can make SA less competitive. Companies need to get moving quickly otherwise access to capital dries up*".
- "*The primary risks to increased SA copper productions are; (i) depth of cover; SA is a challenging place to explore geologically, (ii) land access becoming increasing challenging, (iii) access to accommodation, drill rigs and skilled staff. This is generally more challenging than in some areas such as WA, and (iv) Timeframes to production. Average timeframes from discovery to production are generally more than 10-12 years. As such, anything that isn't well down the development path already will not be in production by 2030. Government approvals and access to power and water are often a primary critical path factor. The primary upside risks and opportunities are investor interest can be strong for SA, it is known for big discoveries, large areas remain under explored (although this can also be a challenge given lack of data and remoteness) and SA has one of the most proactive and switched on government departments in Australia. This helps retain investors.*"

We asked **what challenges need to be overcome to exploit lower grade, previously / currently sub-economic resources**. Respondents again commented on the need for better shared infrastructure, improved land access, reduced power costs, and access to water and power, as well as advances in mining techniques, smelter capacity, and low-cost extraction and beneficiation technologies including spirals and flotation.

- *"Productivity: $/t copper production. Input costs: labour, energy. Exploration focus: the GSSA has not undertaken any serious sustained exploration outside of Gawler Craton in last 25 years which has severely limited exploration. Tenement squatting: explorers and producers sit on large swathes of land without any genuine exploration expenditure, and DEM does not force relinquishment, reducing competitive exploration process*".
- "*Strong focus in sustained and continued R&D targeting some of these issues requires commitment from industry/government (processing, transport, operational parameters etc). It also requires the regulatory framework to allow alternative development methods for some of these deposits (sub economic resources), mechanisms to shift development timeframes - not technically focussed.*"
- "*cost - capital cost required to build and develop operations and the operating cost. This requires new approaches to both mining and processing that have not been implemented at scale, particularly if they are to be done in a manner that meets ESG goals and expectations".*
- "*In-place mining removes about 50-70% of the costs associated with copper production allowing a much lower grades to be mined. Areas that need to be addressed include creating access to the metal within the rock - this could be addressed with a "hybrid" mining approach that combines some aspects of conventional mining with those of in-place mining. Other challenges with in-place mining include confidence with environmental issues and regulatory framework*."
- *"To expand to a Pilbara-scale export market will need considerable infrastructure in materials handling and energy supply. Water security and supply will be an*

issue requiring new leaner options for treatment and processing. Labour market constraints also impact on expansion."
- "*Geological depth of cover and geothermal gradient (temperature of rocks at depths)".*
- *"Ensuring access to infrastructure, power and water are key but will not alone unlock a sub-economic discovery. There may be some scope to unlock deposits challenged by metallurgy for example working to build common downstream processing. Governments could facilitate but really the market needs to work to overcome this issue.*"

We asked **what was the scope for additional processing of copper concentrates** (production of a greater proportion of refined copper than at present by increased toll treatment or construction of additional smelters, and if so, what enablers are required for this to occur, and whether there is capacity for in-state manufacturing)?

- *"Smelting requires large capital so need long term feed stocks for smelters. Opex also high with predominant costs being energy and labour".*
- *"Significant scope for downstream processing and then local manufacturing - power costs are the single largest enabler."*
- *"Should be looking at any value adding process or activity that generates additional opportunities along the value chain, production of refined copper in SA could lead to the creation of new high technology manufacturing industries being established in SA Enables for this could include shared infrastructure, ability to access cheap power, water etc."*
- *"The scope for downstream processing is enormous. Currently we export either concentrate or ingots of metal, where there could be refining or smelting to remove and turn into value many of the additional metals and minerals (some seen as penalties) including critical minerals. In addition, there is scope for further processing of the copper into fine wire production and even into windings and finished goods."*
- *"It comes down to cost = cost to build, cost to run and cost to toll."*
- *"Smaller high volume smarter plants, more advanced kilns using direct induction increased 3D printing of metals for specialized manufacturing"*
- *"There is tremendous scope for increased production of both copper and associated products (wire, piping, electric motors etc.) Sharing facilities can help spread the large capital costs. The possibility of utilising mobile plant that can be re-used might also be considered".*
- *"The main focus will be cost of energy and capex investment for scale expansion and value improving export values."*
- *"Huge scope exists. Many SA deposits are metallurgically challenged but don't have scale to develop the large back-end processing required".*
- *"A smelter to take such concentrates providing economies of scale between companies could be game changing."*

We asked **how industry might work together to achieve that**. Several respondents commented on the need for shared IP, infrastructure (access to power supply, including road, rail and additional export port facilities), logistics and markets, even if it is not always possible, for metallurgical and/or geographical reasons, to share infrastructure. Key is developing an understanding of the commonalities -

where scope and synergies exist to combine deposits to provide feed and being prepared to support a third-party build if necessary. The proposed nickel-cobalt pressure oxidation plant in Kalgoorlie was mentioned as an example of what SA might aim for.

- *"Sharing of critical infrastructure makes sense where it exists, and where it does not, the construction of corridors [would] enable this".*
- *"Establishing a combined hub precinct model which includes sharing major works between companies and government such projects (the cost of establishing) could be shared across sectors mining / agriculture etc."*
- *"To achieve the scale necessary to fund the capital needed some sharing might be needed".*
- *"Developing a consistent model for land access for approved projects to access reserves. The current system has no established pathway for an authorised development to gain land access, landholders can delay projects and hold developments to ransom through time delays".*
- *"Industry can obviously cooperate where there are multiple deposits close together in a geographic area. The government may also want to contribute to this model, government stamp batteries built around the early days of the gold rush allowed any number of miners or producers to process there ore. This model would work equally as well present day if the government could contribute to the cost of processing infrastructure".*

We asked **what the enablers for SA industry are to generate higher quality concentrates for export**. Responses identified processing technologies to clean concentrates of uranium and other impurities, promotion of exploration and development in non-uranium rich areas such as southeast of SA, financing and expertise, logistics, new beneficiation technologies, collaborative government and industry partners, access to cheap renewable power, infrastructure, and energy. Respondents made it clear, however, that concentrate quality is ultimately a function of deposit metallurgy and that a better approach would be to refine to metal and then process the metal into semi-finished or finished goods, and not have to export concentrates at all, noting "*Downstream processing would be key- finished copper and battery mineral inputs are far more valuable than concentrates" and "Industry should look at producing products other than concentrates i.e., value add products from copper cathode, copper sulphate and other copper products (wire, piping etc.)".*

The questions of **what premiums can be expected from 'green copper' and whether state government could promote the export of SA green copper to the world** brought enthusiastic responses. One answered "*There are already a large number of industry consumers that show preference and will pay a premium for green, sustainably produced copper. Production of green copper is also likely to further attract significantly more investment in the state from groups and funds that want to invest in green, sustainable copper production*", while another noted "*in the future the premium will be to find a market, some markets won't take copper unless it is green - but green copper needs to be defined and certified. There won't be a premium there will be a requirement*". A third stated *"This prize is very large. The world needs green copper and ethical cobalt, graphite and other battery inputs" and another noted "The generation of green copper in SA could become a sought-after product that manufactures in this space could be expected to pay a premium for* *given that their final products are designed to accommodate the societal push to low carbon future".*

Production of green copper would be assisted by energy transition to 100% renewable grid which may also include hydrogen yet may require better processing and smelting technology than currently in use. Ultimately the panel expect a price difference - either premium for 'clean and green' or a tax / penalty for not. Alignment with supply chain will determine where value is higher than commodity values. Industry bodies may influence future pathways.

We asked **how the copper production cycle from mine to plant to smelter to refinery can be decarbonised**. Companies are asking for renewable grid power including clean storage and carbon capture. Mine electrification is a key objective of many operators and an important element of the roadmap published in the Warren Institute 'Zero Emission Mine of the Future' report commissioned by the International Copper Association. This report identified five key target areas for technological innovation to reduce and ultimately eliminate mining emissions: exploration, movement of materials, ventilation, processing, and water use.

There is interest in autonomous drones, robot machinery, the use of low emission mining and processing equipment, electricity generated from renewable methods, in-situ ore recovery, input of recycled metals into the refining process, and remote operational methods reducing the need to large onsite footprints, as well as chemical and biological mining and novel leaching techniques rather than physical and mechanical methods used today. There are already plans for in situ copper recovery in SA. This technique produces half or less of the greenhouse gas emissions of conventional mining. Other responses have cited the potential role of nuclear energy and for smart smelters using hydrogen power, as well as for possible pumped hydro operations on disused pits. Smart mines are possible but a cultural change in approach during feasibility studies is required. One imperative of the kind of cutting-edge innovation needed will be collaboration across policy and regulatory bodies, industry networks, capital enablers, and the research community.

On the question of **reducing use of water and energy in copper production and how this might be achieved**, our respondents indicated that there was potential, some offering that if power were much cheaper, we could reclaim more water than currently. Others stressed that this would require a rethink of the way we mine and process completely and tackle the whole value chain. That might include smarter smelters (direct induction furnaces). To adequately tackle this would need a well-funded and resourced R&D sector to focus on this and companies incentivised to take up and test new technology. Setting targets and measuring results could be one approach, as could a greater emphasis on better ore sorting and pre concentration, or course particle separation. In place mining techniques can significantly reduce energy consumption. In place mining removes the digging, hauling, crushing grinding and comminution sides of copper production. Similarly, in situ copper recovery - recycling lixiviants and using saline 'industrial' ground water.

We asked **where future water and energy resources will come from, and what major infrastructure development is needed to bring faster and cheaper electrification to the copper industry**. Our industry panel agreed that future water needs to be obtained from desalination projects or recycled better than at present, removing the demand on natural water sources. This would however require significant investment in pipelines and associated infrastructure. This could be powered by low carbon electricity sources such as hydrogen, offshore wind, solar, or thermal, etc. The industry panel was divided on new energy sources. Some suggested hydrogen and a move towards 100% renewable energy, stressing that clean and green grid power must be a first priority – and that this must include ability to store clean power (e.g., pumped hydro as storage). Other respondents argues that nuclear energy will be needed as a long-term stable base load source of zero carbon energy and that small modular nuclear reactors would be well-suited to SA mining operations.

We asked **how can SA's copper strategy be best realised**, apart from major corporate investment. Respondents seek long-term committed spending in exploration and infrastructure, as well as government backing of major infrastructure ("*there is no one company big enough to do this and most will struggle to work together without a lead")* and government and private consortia with shared benefits and investment in infrastructure and energy. A second common thread was support and assistance by regulators, specifically concern about Government setting a land access process ("*Once a Mining Lease has been granted the landholder should be forced to either pay the required lease fees and establish a process of paying the equivalent royalties or do a deal with a mining company holding the lease on land access and payment of royalties*") and increasing turnover of exploration licences so companies do not hold unexplored prospective ground.

This process is already slowly happening with recent changes to the Mining Act. Government is asked to "*remove all of the obstacles for mine development, including the regulatory hurdles, assist innovation by providing test mine facilities that are freely open to researchers and METS companies", "offer R&D breaks and tax holidays, offtake agreements with international partners to stabilise the price" and offer "shortened timeframes to production. Facilitate access to infrastructure and maybe downstream processing".* Some respondents were confident that the development of cheap in place mining will allow a large number of junior mining companies to bring some of the many currently undeveloped resources into production. These juniors would need to adapt to a slightly different mindset in which they would all need to work together to develop a group of geographically close deposits utilizing shared infrastructure to keep individual capital costs down.

We asked **how can SA's research community contribute to increase efficiency and competitiveness of the copper sector in the state**. Responses indicated strong support for the R&D community "*R&D plays a key role in this by tackling the challenges that the private sector won't (for whatever reasons). The R&D sector should be working hand in hand with key points along the value chain to identify technology issues and work collaboratively to solve these".* Research groups should, however, undertake work that industry wants, and which benefits industry, as well as focus on the key problems defined by industry and collaborate with global researchers to build capacity. Industry would welcome an Innovation Hub (or CRC) in geology, metallurgy, and mining that brought together and focused some of the knowledge that currently exists in a range of individual companies with research institutions to look at solving key issues in the copper production cycle.

Specific research directions mentioned include better science in beneficiation, mining and smelting and manufacturing technology to make the industry nimbler in specific supply niches, fleet automation and electrification, increased state-wide bandwidth, work demonstrating the efficacy of use of renewables, innovations in copper smelting, and new technologies like in-situ leaching, hydrometallurgy specifically targeting the chemical/biological leaching of metals. Researchers might also address barriers to investment and decisions that govern that progress.

Asked whether **administrative bottlenecks can be minimised, and procedures simplified to enable new projects to get off the ground while demand for copper is so strong**, the panel responded yes, or maybe, mindful that the average of 15 years to develop a new mine has become too long, even if projects still need to meet hurdles and pass regulatory necessities.

- *"There probably are steps that could be taken along the pathway to new projects being developed, however there needs to be a robust, transparent and sustainable process so that projects are not approved if they don't meet defined criteria / necessary approval gateways."*
- *"Definitely – the current system needs major overhaul and needs to be digital, - proactive not reactive and negative".*
- *"Mine to boat approval processes so the full supply chain and approvals are addresses as a single outcome approach".*
- *"A template approach for approvals that enables a more "tick box" approach would speed things up. Although each project is different and will have different impacts, a lot of impacts are similar for most projects, these could be captured in a template and you only have to adjust that section if your projects impacts differ substantially from the "default".*
- *"The good news is that the supply elasticity of copper is very inelastic so the copper price will likely be very high for a very long time."*

Other issues raised by the panel include:

- *Native Title and Land access are key risks to SA projects getting off the ground plus land use competition from renewables - solar farms and wind turbines being approved & built over current copper resources and prospective exploration ground.*"
- *"From a productivity point of view in SA there is an impediment place on the mining industry for performing what I would call "like activities" - things like grading tracks are much, much more expensive and time consuming for mining companies because of the amount of regulator overhead and paperwork that must be completed before the activity can be undertaken compared to that placed on other industries".*

Critical Minerals

Responders signalled interest/potential in the following commodities: rare earths, graphite, cobalt, nickel, tungsten, molybdenum, zircon, monazite, rutile, ilmenite, lithium, high-purity alumina, uranium, potassium, phosphate, manganese, and vanadium. A holistic approach was suggested, as is being done in other states: technical studies but also looking at the regulatory framework that would be required for development of different resources. The potential for production of highly valuable medical radio isotopes was also raised.

When asked: "**What is the broader economic context for sustainable long-term critical mineral production in SA?",** responses stressed that SA is lagging behind its competitors in the sector

- "*There is great potential in SA to develop a rare earth mining/processing hub, just like WA has done in lithium*"
- "*South Australia has the opportunity to be a part of the growing critical minerals sector across many fronts. We have some identified resources and projects but are behind other states in terms of operational projects. An opportunity exists for SA to develop critical minerals along the value chain and link this to the evolution of the copper sector*".
- *"SA makes up a considerable proportion of the worlds known critical minerals, particularly REE, but minimal in production*".
- *"I think SA has significant potential for sustainable long term critical mineral production".*
- *"SA has the potential to provide ethical, sustainably powered critical minerals. The economical imperative of developing a robust local industry is enormous".*
- *"Sustained demand, driven by energy transition, net zero and emerging battery minerals. Opportunity is to build national security of supply not just of commodities, but of the downstream supply chain elements that reach consumer markets such as steel, battery materials or specialist metals".*

Most responders agreed that critical minerals are used in such a wide range of consumer products that having a secure supply of them would guarantee income for the state. Others noted that SA does need to discover large high-quality deposits to create a sustainable industry and that there is a lack of exploration skills and experience in this area. Moreover, exploration remains a key risk. More data and more exploration releases are needed.

We asked **about the major factors influencing the risks for critical mineral markets, and how could these be overcome / minimised?** Among the factors identified were the shortage of human capital with requisite metallurgical expertise, the small international markets and almost non-existent Australian market (making capital raising difficult), global geopolitics, developing sovereign capabilities, and a need for national leadership to develop solutions. Greater sovereign manufacturing capability would provide stable markets for critical minerals (domestic battery, electric motor and semi-conductor production), although unknown changes in battery and electrolyser technologies may disrupt planned revenues. Government backed supply chain agreements and flexibility in maintaining ROI for private partners are key to investment, as is adding value back to the social needs of communities.

Factors impacting on long-term sustainability of a critical minerals industry in SA include stable commodity prices, technology to concentrate and the environmental impacts of refining, supply/demand volatility, land access, lack of access to access to development capital, favourable foreign exchange, and current levels of inflation around current level, and the ability to achieve low-cost, high-quality production. Risk mitigation could however build from supply chain agreements rather than commodity supply markets.

Regarding the **option of by-product recovery from existing operations** those asked believed there is potential for value adding. Some responders considered that suitable extraction metallurgy would be needed (and that expertise is lacking) and that critical minerals are not the core business of the larger miners "*Can be seen as a distraction and not a big value lever*". One mentioned that "*the best grades of critical minerals might not coincide with economical mine design for base metal operations*". Others saw opportunity in the cheap production of critical minerals using existing infrastructure but indicated that impediments are regulatory.

There is a need for a regulatory framework to enable efficient by-product production to take place, shared infrastructure and facilities (maybe requisite complete extraction of value as part of approvals process), as well as innovation in metallurgy and recovery. It may only be viable if the overall cost of processing and delivery could be decreased and a return on investment guaranteed. By-products are perceived as challenging economically due to underlying main commodity prices and dynamics of overseas deposits. Others asked about leveraging existing infrastructure and minerals processing activities to fast track access to key minerals in existing waste streams - as well as green field opportunities of shared infrastructure.

We asked industry **what are the economic drivers and what are the risk factors involved in critical minerals (compared to traditional resources like copper or iron)?**

- "*The single largest risk factor is developing the metallurgical know-how to extract rare earth minerals from the ore. This IP is closely guarded by China. SA's mineral deposits are unique in that the rare earths are hosted in clay, which are easy to excavate, contains no radionuclides, and occur in large volume near surface. Market demand fundamentals are very strong given the structural change in the rare earth industry triggered by EVs and wind turbines".*
- *"Critical mineral extraction (e.g., cobalt) can't/won't compete with the investment thesis of larger market commodities (e.g., copper) - can be a distraction and high risk investment to try and recover these elements. Recovery of cobalt from IOCG deposits is possible but the returns are marginal, the market small and volatile, making it hard to build an investment case"*
- *"Drivers are the global demand for climate change and the green high technology that requires critical minerals to build them. Geopolitical instability and the rise of sovereignty across the developed world also is driving the need for countries to secure their own (or partner with allied countries) mineral sources".*
- *"Economic drivers are driven by scarcity and the level of (and difficulty and cost) of processing needed to refine the product and geopolitically much of the capacity of refining the metals is not available in the west. Iron ore by comparison is essentially*

dug up in an unprocessed form and shipped to customers for processing. The economic rent for iron ore is in the deposit whereas the economic rent for critical minerals is in the downstream processing. In dollar terms the market for critical minerals is tiny by comparison to iron ore, thus the incentive for the large mining companies to invest is not there".

We asked **what key infrastructure is missing to achieve a sustainable critical minerals industry in SA?** There were calls for key infrastructure (road/railway access, power lines and substations, communication towers, clean water, cheap energy), pilot and demonstration scale test facilities, the availability of low cost reagents (e.g., sulphuric acid), and some degree of state incentivisation. While agreeing that water and energy (green baseload) are pivotal factors, the lack of labour for engineering, construction and skilled operations workforce is also seen as a potential problem. There also needs to be development of advanced processing technologies, downstream processing facilities and capabilities that could include leaching and chemical or biological processing. There would need to be encouragement for miners to adopt downstream processing and for the extraction of all of the value from ore and waste.

We asked **how can the SA Government show leadership and support development of critical minerals in South Australia and how they might de-risk investment in the critical minerals field?**

- *"Gain a better understanding of the critical importance of rare earths. Without, EVs and wind turbine production will be restrained. The industry generally understands nickel, lithium, and graphite are needed for batteries. However, there is insufficient awareness that Pr, Nd, Dy and Tm are critical for electric motors for EVs and generators for wind turbines. The financial benefit to SA is small at present (compared to copper) but represents an opportunity to develop expertise, people and plant, and become a national leader in the process"*
- *Infrastructure leadership support. Enable lower cost energy. Enable downstream processing / manufacturing to incentivize local need. Note; if we extract cobalt now we will be selling into an international volatile competitive market...*
- "*Identify the opportunity by clearly defining the current known resources contained within the state including that which is currently deemed to be waste (e.g., in tailings from current operations). A new mine in the West Musgrave region will be developed but ore is most likely to be concentrated and shipped out via WA What would it take to bring the product into SA and process it here to metal. Green power is a big part of that*".
- *"Provide incentives for exploration and define a method around land access and compensation".*
- *"Examine the feasibly of regional processing facilities (e.g., for cobalt or REE) to service multiple companies, that individually cannot set up their own processing plants"*
- *"Investing in both research and exploration - research to look at how they may be produced as part of other mining processes and exploration by providing models and data focused on this sector. The government could also look at the risk profile it applies to early stages of projects, at the present stage the risk profile applied to what are effectively very low impact activities is set too high."*

- *"Longer term alignment in parallel investment and support for the overall supply chain in the region. (production, construction, energy and water). De-risk the investment in the critical mineral production is the aim. Remove barriers and make an environment for longer term operational investment from the private sector".*
- *"DEM could do basic mineral systems research and investigations into these metals. For instance, there are many copper prospect in the Adelaidean rocks of South Australia that contain rare earth elements, but this has never been fully investigated. With the advent of portable XRF devices that can quickly and easily analyse for these elements the Geological Survey should commence a state-wide program of visiting copper prospects and getting a better understanding. This state-wide project is not something an explorer could do as it requires the ability to span across large geological provinces"*
- *"Simplified approvals and improved approvals timeframes, more exploration releases, more data "*
- *"Support the early stages of development and develop a framework that fosters academia, government and the private sector working hand-in-hand. We do not need another government program. We need specific collaborative joint ventures."*
- *"Remove red and green tape, make grid based (baseload) green power available to the miner locations, water available and secure as well as other basic infrastructure."*
- *"Address land access issues and support offtake agreements, create rehabilitation bonds from Royalty payments, and establish long term government to government collaboration on storage and supply"*
- *"Develop a process for land access that is predictable."*
- *"Being involved in research and exploration by contributing funding and personnel and encourage an atmosphere within the regulator not to be so risk averse towards new technologies and projects. The government needs to be more of a promoter than a regulator"*
- *"State ownership is an option, but not necessarily attractive to any party. hoping 50 private and independent ducks line up is a miracle, but a government guaranteeing they will fund the last three missing ducks will motivate the other 47 private ducks to step up to the line."*

We asked **what can the research community do to catalyse innovation in exploration for, and the economic recovery of, critical minerals?** Responses indicated that more skills and expertise need to flow though from academia and that economic recovery is the most important area of processing technology that needs to be evolved.

- *"Examine new methods for identification, processing, recovery and downstream value adding opportunities".*
- *"Build human capital/expertise, particularly in mineral processing and hydrometallurgy. Consider joint ventures, sponsored by industry and government with institutions outside SA who possess world class expertise in rare earth metallurgy"*
- *"Look for new and cheaper (capex and opex) methods of mining and extraction processing and purification".*
- *"Government supported exploration programs and reduce statutory spend"*

- *"Advanced manufacturing capability, including specialised manufacturing of spherical graphite, 3D printing lithium batteries etc."*
- *"A cooperative research group working towards to key goals in the economic recovery of critical minerals"*
- *"Academics/researchers could focus at understanding the principal problems and bottlenecks for industry, and then how these issues may be addressed, including what could government do to solve those problems"*
- *"Education will be pivotal in the resourcing of skills to expand and operate, and they will have a role in the risk mitigation of technologies needed cross both the critical minerals and the infrastructure supply at scale".*

We then asked **what partnerships among industry (pooling of resources) might increase SA's competitiveness against other jurisdictions**? Although some responses emphasised how industry is not good at partnering when they are competing, others suggested approaches that would involve centrally located hub and precincts that include processing, manufacturing and R&D aspects, downstream processing collaboration, sharing exploration data and expertise, increase transport networks for heavy haulage, centralised sales processes, secure long term off-takes with strategic allies, and the development of more export ports. In essence, our responses indicate the wish for an ecosystem of players to cooperate. Funding the motivations and removing barriers for that collaboration would be a key enablers. Mining and METS companies need to collaborate with one another and to lead the research community.

We asked how can the copper industry best partner with new (non-copper) critical mineral explorers/potential producers? Suggestions included enabling partnerships with other entrants through earn-ins and JVs, the supply of sulphuric acid, sharing of technology to solve energy reduction and waste minimisation, mining efficiencies, majors allowing third parties access to their waste products for further extraction, leadership, share advances in in place mining techniques, sharing of IP, product development and merged supply chain processes, sharing infrastructure, and off take treatments. This would enable transition from mineral producers to mineral asset collaborators.