Australian Government

Resources Technology and Critical Minerals Processing

National Manufacturing Priority road map

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Our Vision

Australia will become a global centre for commercialising and manufacturing cutting-edge technology products and services for the global resources sector that benefit a range of other industries.

Australia will have a strategic critical minerals processing industry that captures significant additional value, strengthens our global position downstream from our resource endowments and underpins a range of advanced manufacturing opportunities.

Our growth opportunities in Resources Technology

Develop technologies to drive operational efficiencies	Develop products that support sustainability and productivity	Develop technologies to recover value from waste	Deploy cross-cutting manufacturing technologies

Our growth opportunities in Critical Minerals Processing

Capture additional value from our critical raw materials	Build advantage through commercialisation and innovation	Leverage our world-class environmental, social and governance credentials

Our goals

2 YEARS

Improved capability to bring products quickly to market, through improved market development activities and investment made in critical enablers.

5 YEARS

Foster increased collaboration with relevant sectors and international supply chains, increase exports and private sector investment.

10 YEARS

Australia seen as a regional hub for resources technology and critical minerals processing, with significant R&D advancements, retention in intellectual capital for SMEs and significant volume and value of exports.

Unlocking our opportunities—the first two years

***FOCUS**: Significantly improve resources technology and critical mineral processing manufacturing capability by increasing commercialisation, utilising critical enablers and engaging in new market opportunities.*

Build on Australia's strong track record in resources tech and processing innovation	Invest in critical enablers	Closer collaboration between tech firms and end users
Establish operations near processing facilities	Match capability to global market needs	Create new investments with key trading partners

Contents

1. The Modern Manufacturing Strategy

The Australian Government is manufacturing a new future for our nation. Manufacturing is critical to a modern Australian economy—a key part of almost every supply chain that adds significant value to all sectors. The *Modern Manufacturing Strategy* (MMS) is led by industry, for industry, to help our **manufacturers scale-up**, become **more competitive** and build more **resilient supply chains**. The Australian Government will be a strategic investor in this, notably through the six national manufacturing priority sectors, in order to drive productivity and create jobs for Australians, both now and for generations to come.

On 1 October 2020, the Australian Government announced a $1.5 billion investment in the MMS to help Australian manufacturers be more competitive, resilient and build scale in the global market. The 6 key areas are:

	**Resources Technology & Critical Minerals Processing**
	**Food & Beverage**
	**Medical Products**
	**Recycling & Clean Energy**
	**Defence**
	**Space**

Road maps have been developed with industry to set out plans for both industry and Government to strengthen Australia's manufacturing capability. The road maps have been led by industry taskforces to identify and set a future vision for priority areas with clear goals, opportunities and actions over the next 2, 5 and 10 years. This road map is designed to be dynamic—it will evolve with the industry and with other external forces such as economic and global trends as they affect the industry. As the MMS is implemented, the Government will continue to work with industry to ensure the road map evolves over its life, to take account of emerging opportunities and actions to support the sector to scale-up, become increasingly competitive and integrate commercial solutions with global supply chains and markets. See Appendix A for more details on the road map process.

Through the MMS, the Government wants to support projects from industry that will transform manufacturing in Australia. This road map will help inform investment decisions that both Government and industry make over the next 10 years, in particular, by supporting projects that will:

- harness and build on the sector's strengths and advantages
- provide innovative solutions to overcome constraints that limit value creation and may prevent the sector achieving its full potential
- transform the sector by growing a high-value, reputable and dynamic manufacturing industry focused on resources technology and critical minerals processing.

Getting the economic conditions right

The MMS outlines the whole-of-government agenda to help grow Australian manufacturing and ensure manufacturers can harness global opportunities and achieve scale. Getting the economic conditions right to reduce costs is the first pillar of the Strategy, noting affordable and reliable energy, lower taxes, industrial relations, training and skills, and cutting red tape are key determinants of success of local manufacturing businesses.

Figure 1: Overview of the Government's Modern Manufacturing Strategy

GETTING THE ECONOMIC CONDITIONS RIGHT FOR BUSINESS	MAKING SCIENCE AND TECHNOLOGY WORK FOR INDUSTRY	FOCUSING ON AREAS OF ADVANTAGE	BUILDING NATIONAL RESILIENCE FOR A STRONGER ECONOMY
• Helping restore business confidence and recovery through the JobMaker plan • Delivering lower energy costs • Building management capability • Getting our tax settings right • Tackling red tape • Improve our industrial relations system	• Aligning research and innovation capabilities and programs to priority areas • Unlocking investment proposals through the Manufacturing Modernisation Fund round two • Backing digital transformation	• Setting National Manufacturing Priorities and developing road maps for action • Backing projects with wide reaching impacts through the Modern Manufacturing Initiative	• Making supply chains more resilient to external shocks including through a Supply Chain Resilience Initiative • Supporting global market diversification

The Australian Government is working hard on getting the economic conditions right for manufacturers, paving the way for growth and improved competitiveness in all sectors.

Manufacturers need a pipeline of skilled workers as they transform and scale. The Government is investing $7 billion this financial year to keep apprentices in jobs, to help jobseekers re-skill and to promote vocational training. We are working to ensure that we are creating the jobs of the future and that we have a pipeline of skilled workers to support new and emerging industries, including in manufacturing. The Government's reforms to higher education will boost the number of graduates in areas of employment growth, including STEM.

A gas-fired recovery will ensure Australian gas is working for local businesses and manufacturers, with a 13-point plan and $49.8 million investment to unlock supply. This complements the Government's initiatives to reduce electricity prices, boost liquid fuel security and invest in low emissions energy technology through the *Technology Investment Roadmap*.

The Government is harnessing opportunities from emerging technologies and building business digital capability, including growing Australian business cyber security resilience. Work to implement a Simplified Trade System will support Australia's exporters and importers to invest and grow local jobs by making it easier for businesses to integrate into global supply chains.

The Government is focused on making and sustaining jobs through the JobMaker scheme. This will unlock investment, expand the productive capacity of the nation through expanding the instant asset write-off and temporarily allowing businesses with a turnover of $5 billion to offset tax losses against previous profits.

Why resources technology and critical minerals processing?

Australia's resource sector is world-class. The sector is a leading exporter of energy and resources commodities, serviced by a highly regarded resources technology sector. In 2019 the Australian Mining Equipment, Technology and Services (METS) sector generated $97 billion in revenue, supporting approximately 200,000 jobs. [1] Resources technology is a manufacturing area with untapped potential that could be leveraged further, based on the capability and innovation of Australian businesses in supporting the competitiveness of our resources sector. There are also opportunities to further expand the current market footprint by adapting more of these technologies across other Australian sectors, such as defence and space, and capturing more of global markets.

Australia has significant reserves of the critical minerals and metals which drive the modern global economy. These are used to manufacture advanced technologies such as electric vehicles, mobile phones and renewable energy systems. However, because the majority of primary ores are shipped overseas for processing, Australia derives a small share of the potential overall benefit. Australia can capture greater benefit from these value chains by undertaking further value adding and manufacturing here.

Australia has a reputation as a reliable destination for foreign direct investment with low sovereign risk. We have the opportunity to leverage this reputation to become a premium destination for resources technology manufacturing and critical minerals processing. Work is underway to establish arrangements with Australia's key trading partners to attract investment. This includes the recent memorandum of understanding with India to explore opportunities to increase trade and investment in critical minerals. The United States, Japan, South Korea and the UK are also becoming increasingly active in supporting the financing of critical mineral projects.

For the purpose of this road map, resources technology covers businesses and enterprises that provide technology products and associated services. These services can be provided across the minerals and energy resources value chain and to a range of other Australian industries. [2]

Critical minerals processing covers businesses and enterprises associated with processing critical minerals for use in value added manufacturing and manufacturing products using those refined materials. Using the battery value chain as an example, this can be from processing lithium ore into lithium hydroxide or metal, through to battery assembly.

1 Austmine (2020), METS Sector Survey, unpublished data

2 The minerals and energy resources value chains encompass the entire mining life cycle including feasibility, exploration, construction, operation, processing value-adding, decommission and remediation.

Industry structure: understanding the current landscape and challenges

Resources technology

Australia is a world-leader in producing and exporting a range of energy and resources commodities. Our resource industries deploy world-class expertise and technology in exploration, development, production, processing and environmental management.

- In oil and gas, Australian companies provide solutions which enable businesses to work in very remote locations, manage technical challenges and risks, and improve environmental and social outcomes.
- In minerals and metals, Australia has developed and perfected the technologies needed to operate in harsh conditions. World-leading mining equipment, technology and services (METS) companies deliver solutions designed to ensure mines remain productive, achieve high environmental standards and contribute to sustainable economic development.

While large Australian firms and international companies headline the sector, a significant proportion of Australian businesses are small to medium enterprises (SMEs). The industry is estimated to have over 6,000 companies that provide equipment, technology and services to the resources sector. Industry feedback indicated there are over 1,000 local companies that either exclusively or primarily service the mining sector. They operate across the value-chain with some operating in more than one area: [3]

- 25% operate in the exploration phase
- 30% in the feasibility phase
- 58% in the design and construction phases
- 75% in the operations phase
- 25% in the remediation phase.

Recent industry surveys indicate: [4]

- 82% of companies are Australian owned with major markets served including:
  - mining
  - infrastructure (roads ports and rail)
  - utilities (electricity, water and waste water)
  - defence
  - renewables and clean energy
  - oil and gas
  - agriculture and construction.
- 65% export goods and services with the largest destination (by percentage of companies serving markets) being:
  - United States 38%
  - Indonesia 37%
  - Papua New Guinea 36%
  - New Zealand 33%
  - Canada and Chile 32% each
  - South Africa 30%
  - China 19%.
- A third of the companies who do not export currently, intend to within the next 2 years with Chile, Canada, US and Indonesia the focus markets.
- By state, Queensland has the greatest export percentage of revenue at 29%, followed by South Australia, Western Australia, Victoria and New South Wales.

3 CSIRO (2016), Mining Equipment, Technology and Services Roadmap
4 Austmine (2020), METS Sector Survey, 2020, unpublished data

The Australian industry is highly regarded, but must continue bringing innovative technology solutions to the market that address the challenges facing the resources sector. To do this, industry must invest in projects that translate and commercialise new ideas into products and services. In order to get new products to market more quickly, Government could assist companies to demonstrate their technologies to end-customers. This would enable them to show how new technologies are commercially viable, and help to drive productivity, improve sustainability and integrate with the operating systems of their clients. Without this, many end-use customers are reluctant to disrupt their operations to adopt new technologies.

Australia's science, research and innovation capabilities are critical enablers of transformation in manufacturing, particularly in the resources sector. To build capability and scale, and to advance Australia's competitive advantage in resources technology, industry must embrace innovation, and processes and practices including automation and digital operations.

Another key challenge to scale is market design and the traditional practices of some resource and critical minerals firms where technology solutions are 'owned' by tier one miners. The sector will flourish as the market evolves to one where products and services are developed and sold to multiple customers. This will support greater collaboration between technology providers and smaller resource producers.

Through the MMS, the Government will be looking at opportunities to not only collaborate with industry and to make strategic investments, but also for industry players and businesses to work together to invest in strategic projects that will boost Australia's manufacturing capabilities and expertise in the resources sector.

Resource and critical minerals technology companies need access to finance but Australia's capital markets are sometimes reluctant to lend to this sector because end users are slow to adopt new resource technologies. This means many smaller companies struggle to commercialise or need to go offshore to raise capital and develop commercial opportunities. To attract capital, they need to broaden their customer base, reach global markets and adapt technologies for application in new industries.

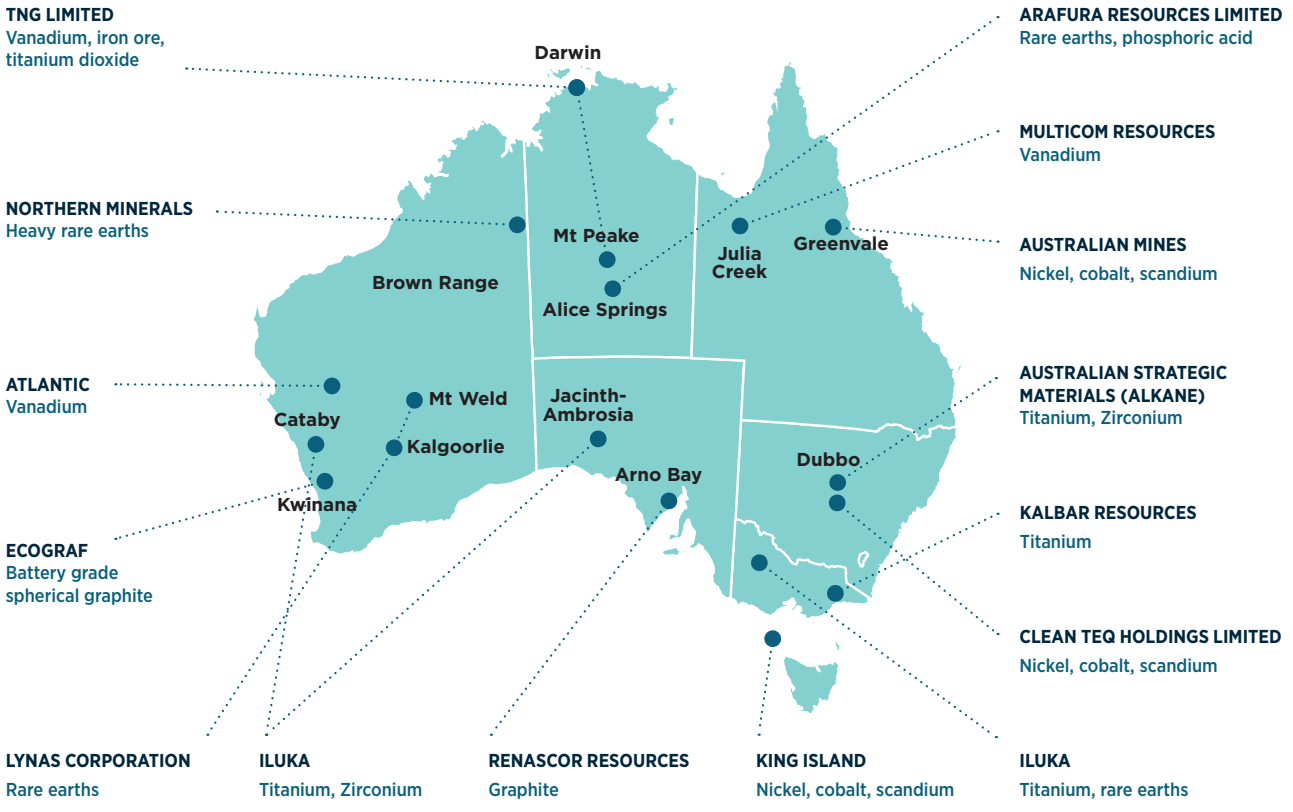
While programs are available in the market, there is still a significant gap in support provided. Better pathways for commercialising technology will help companies get products to market.

Critical minerals processing

Australia is the largest lithium producer in the world, supplying just over half of global supply, and the industry is beginning to establish a lithium hydroxide processing capability in Western Australia. Australia is also a top 5 producer of cobalt, manganese ore, rare earth elements, antimony, zirconium and titanium minerals sands, and has viable economic reserves for a number of other critical mineral resources.

Australia hosts prominent global critical minerals firms including Lynas Corporation Limited (supplying up to 30% of global rare earth elements) and Iluka Resources, a heavy mineral sand company that operates as a major supplier of processed zircon and titanium minerals. Outside of notable mid-tier firms, the sector is characterised by a number of smaller companies. These companies are exploring opportunities to develop critical minerals resources and establish cost-competitive processing operations in Australia.

Figure 2: Selected Australian critical minerals projects



The ability to move into manufacturing is dependent on the ability to process these chemically complex raw materials competitively. There are very few established processing projects in Australia. Some companies have undertaken definitive feasibility studies and are at the stage of attracting offtake agreements and project finance, but they face technical and market barriers to scale operations. These include:

- substantial investment overheads to establish mineral processing facilities and build appropriate domestic capabilities in Australia
- the technical risk involved in highly complex and custom processing requirements
- commodity price volatility in markets that lack transparency and supply chains that are highly concentrated and with high product qualification thresholds.

To secure market share and more downstream activities, manufacturers need to demonstrate a reliable processing capability and the ability to scale to meet specific customer requirements.

These factors make it difficult to access finance without public funding and risk sharing.

2. Vision – Resources Technology and Critical Minerals Processing

Australia will become a global centre for commercialising and manufacturing cutting-edge technology products and services for the global resources sector that benefit a range of other industries.

Australia will have a strategic critical minerals processing industry that captures significant additional value, strengthens our global position downstream from our resource endowments and underpins a range of advanced manufacturing opportunities.

3. Growth opportunities

Resources technology

Driven by global demand for companies to boost productivity and environmental performance, there are opportunities for Australian resources technology manufacturers to build scale and competitiveness. Globally, mining equipment is expected to generate revenue of US$165.8 billion by 2027 with Asia-Pacific becoming the largest market. [5]

Australian companies are at the forefront of resources technology innovation. Historically, this has been driven by tier-one resources companies developing technologies in-house, or working with technology service providers on solutions which those companies own. More recently, technology manufacturers are collaborating with smaller resource producers and offering innovative solutions to a larger range of clients, including in other sectors. Resource technologies embed a high level of service application in their manufacturing products, and the export market for these services is growing.

Feedback from industry stakeholders highlighted areas of opportunity including technology products and services that:

Develop technologies to drive operational efficiencies	**Develop products that support sustainability and productivity**	**Develop technologies to recover value from waste**	**Deploy cross-cutting manufacturing technologies to other sectors**

Developing technologies which drive operational efficiencies

Digitalisation and technological advances are driving a range of cost-saving opportunities across the resource exploration, extraction and processing stages. Novel, cutting-edge technologies such as advanced data analytics and mapping software help Australian producers improve and make smarter decisions that lead to greater competitiveness. This includes energy-saving technologies for extracting and processing ores through products such as:

- ore body mapping technologies
- new geophysical tools and drilling technologies
- automated trucks and robotic equipment
- grinding and processing technologies.

Adopting these technologies offers enormous cost-saving opportunities for the resource sector. For example, miners in Western Australia using autonomous haulage technology have reported a 20% improvement in productivity. [6] In 2017, CSIRO estimated that advanced analytics applied to complex ore mapping and processing operations can lead to yield improvements in the order of $20–50 billion of additional earnings for resources companies globally. [7]

5 Allied Market Research (2019), Mining Equipment Market by Equipment Type, [Online] Available from: https://www.alliedmarketresearch.com/mining-equipment-market
6 McKinsey &Company (2018), Behind the mining productivity upswing: Technology-enabled transformation
7 CSIRO (2017), Mining Equipment, Technology and Services – A Road map for unlocking future growth opportunities in Australia

Analysis in 2015 predicted that data used to improve equipment maintenance timing could result in a 5–10% reduction in costs by 2025. [8]

Australian resources technology companies are already providing these technologies to the sector, but have the potential to greatly expand.

Increasingly, opportunities for Australian manufacturers lie in their ability to deliver premium value products and services to sophisticated markets. These may include:

- integrating technology to produce smarter solutions to problems. Examples include precision instrumentation, sorting solutions, specialised vehicles and parts, monitoring consoles, processing equipment, and drones
- providing intelligence to support efficient operations. This includes technology that monitors and improves performance such as digital twinning, predictive maintenance, data analytics, sensors and asset health. Opportunities also exist in developing and deploying technology to enhance and enable equipment performance such as autonomous systems, remote control, augmented reality, artificial intelligence and machine learning.

Australia has significant capability in these technologies and potential to grow. Australia is currently home to 60% of global mining computer software development. [9]

Developing products that support sustainability and productivity in the resources sector

Effective environmental stewardship is driving demand for products and services that reduce the environmental impact of the resources industry. Australia's high environmental standards have built a strong capability in our technology sector which could help position Australia as a global maker and supplier of technology products that improve the environmental performance of resource development activities.

This includes technologies and services that:

- extract resources with improved environmental performance
- improve ore to waste ratios in metal recovery
- lower the use of toxic or environmentally sensitive chemicals in processing
- maximise water and emissions efficiencies in operations
- help companies to monitor and address environmental problems
- assist companies to rehabilitate resource operations sites and decommission facilities at the end of life.

Australia's oil and gas decommissioning liability is estimated to be $60 billion over the next 30 years. [10] As the industry matures, decommissioning efforts will become a greater focus. Australian companies are building technical capabilities in this area, including manufacturing capabilities which are highly sought after by countries with similar requirements.

According to National Energy Resources Australia (NERA), Australia has the potential to become the Asia-Pacific hub for manufacturing equipment and technology for subsea inspection, maintenance and repair. This includes decommissioning offshore oil and gas installations.

Australia's resources technology industry is also building capabilities in deploying low emissions and renewable energy technologies which opens extensive markets in:

- renewable micro grids
- carbon capture, use and storage technologies
- hydrogen technologies.

8 CSIRO (2017), Mining Equipment, Technology and Services – A Road map for unlocking future growth opportunities in Australia

9 DISER (2018), Industry Insights , [Online] Available from: https://publications.industry.gov.au/publications/industryinsightsjune2018/documents/IndustryInsights_2_2018_ONLINE.pdf

10 Wood Mackenzie (2020), Australia Oil and Gas Industry Outlook Report

Similarly, technologies that improve productivity in difficult environments are highly sought after. Worldwide, the depletion of near-surface high-quality mineral resources and the move to extract ore bodies of increasing complexity and lower grade will drive this demand. This includes technologies which:

- improve detection of and access to resources at depth. This could include new sensing, predictive modelling and analytical methods, or advanced drilling technologies
- improve access to more refractory ores or recover metal from waste, for example, hydrometallurgical solutions
- increase selectivity in mining, materials handling and processing.

Developing technologies to recover value from waste

Waste from mining operations, such as tailings, and 'end of life' batteries, e-waste and mobile phones can still hold valuable resources. But they are technically or economically challenging to recover. CSIRO estimates that between 5–7 billion tonnes of tailings are produced globally each year. This presents an enormous opportunity for resources technology companies to develop solutions to extract value from waste. Better management of tailings could also help reduce the potential financial, environmental and safety liabilities following a tailings storage facility collapse. CSIRO estimates this liability to be as much as $5 billion, based on the 2015 Samarco dam collapse in Brazil.

There are a number of companies currently using technology that recovers value from waste in Australia. These technologies make waste material recovery economically feasible, and convert potential liabilities into new resource commodities. New Century Resources is successfully mining the existing tailings storage facility of an old mine site near Mt Isa. Companies, such as SoilCyclers, offer a technology that transforms mining overburden (the heap of earth removed from an open-cut mine) into top soil, using renewable energy. The Tailings and Mine Affected Water cluster comprises a group of companies and industry research organisations who are looking at new and innovative ways to deal with mine affected water.

Investing in manufactured products and services that can recover value from waste streams is a real opportunity for Australia and can bolster its position as a world-leader.

Deploying cross-cutting manufacturing technologies to other sectors

Manufacturing technology for the resources sector can often make an impact in other industries.

Stakeholder feedback emphasised the opportunity for Australian resources technology producers to achieve scale through exploiting cross-sector applications. This can include expanding into adjacent markets that share similarities such as defence, space or agriculture, or deploying technologies to unrelated sectors that can apply innovations in new ways.

Automation, robotics and advanced data analytics are examples of manufacturing technologies that can be used by a variety of sectors. By selling their technological capabilities to other sectors, Australian resources technology companies can reach additional markets, providing manufacturers with the opportunity to scale production across a variety of markets.

The potential for growing a more broadly focused technology sector is significant. Sweden has demonstrated how to grow a successful technology services sector, off the back of its capability in resource technologies. Some large Swedish companies are world-leading manufacturers but started their lives as suppliers of mining equipment including *Epiroc AB, Sandvik AB, Volvo* and *ABB*. These companies have had a successful history of collaborating with mine operators to develop new technologies and adapting those technologies to other industry sectors.

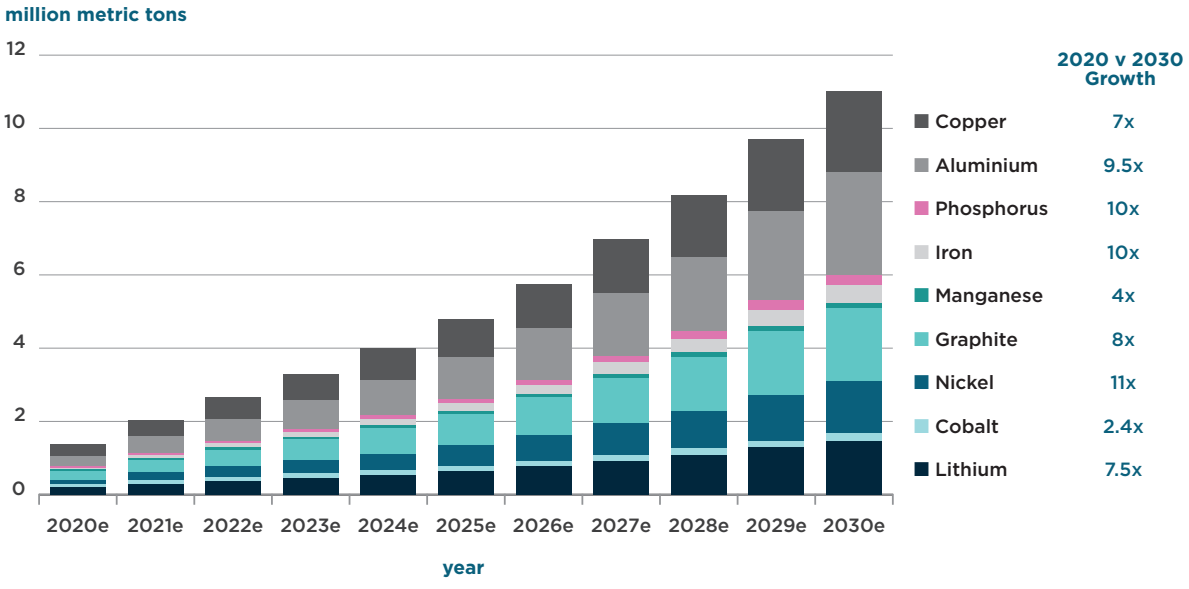
Critical minerals processing

There is a significant manufacturing opportunity in doing more advanced critical minerals processing in Australia. This processing would provide inputs into a range of future-facing technologies such as:

- batteries
- solar cells
- magnets for traction motors
- light weight alloys for aerospace and automotive industries
- wind turbine components
- fuel cells.

Significant demand growth is forecast for many minerals and metals, and will be exponential across the next 10 years.

Figure 3: Projected demand increases for Lithium-ion metals



Source: BloombergNEF
Note: Metals demand is assumed to occur approximately one year before battery demand, i.e. metals demand in 2030 is metal content of batteries deployed in 2031 (with allowances for material waste fabrication). Lithium includes material used in cathodes and electrolytes. It is expressed as Lithium Carbonate Equivalent (LCE). To convert to contained metal, multiply by 19%. Copper includes copper current collectors and pack wiring. Aluminium includes aluminium current collectors, cell and pack materials and aluminium in cathode active materials.

Globally, the supply chain 'pinch point' for critical minerals is at the processing and early manufacture stages where markets are highly concentrated. It is clear that many Australian critical minerals projects are seeking to operate in this space. This means moving further downstream into value-added oxides, alloys and precursor materials. Moving downstream will not only help diversify global supply chains, but will also generate new high-paying jobs and manufacturing activity across Australia.

Stakeholder feedback has highlighted that the opportunity for Australia to move up this value chain is time-sensitive. Taking action in the near term will put Australia in a strong position to not only become a world-leading producer of critical minerals, but also a significant market player in those value chains before global supply chains are cemented.

Capture additional value from our critical raw materials	Build advantage through commercialisation and innovation	Leverage Australia's world-class environmental, social and governance credentials

Capturing additional value from our critical raw materials

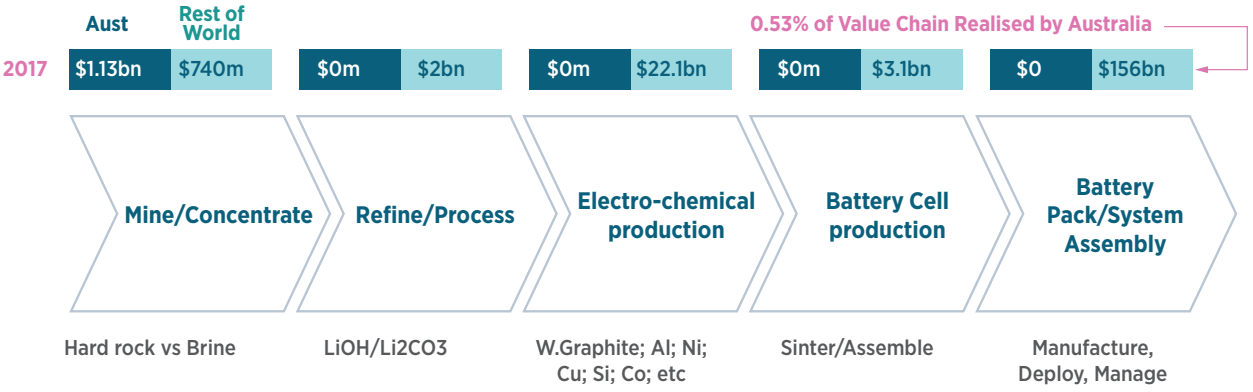
There is an opportunity to capture significant additional value by undertaking more advanced processing in Australia.

For example, an analysis by CSIRO shows that while Australia's lithium exports in 2017 were worth $1.1 billion, it represented less than 1% of the global battery value chain (see Figure 3). While in recent years, Australia has been successful in attracting a number of downstream processing and manufacturing opportunities the benefits generated from this value chain are still very small.

Exponential economic benefits can be realised if industry moves up the value chain at a time when demand is set to skyrocket. Recent forecasts suggest demand for lithium for electric vehicles alone will grow from 25,000 tonnes in 2020, to 425,000 tonnes in 2030. [11]

11 Best, A. and Vernon, C. (2020) State of Play, Australia's Battery Industries. CSIRO, Australia.

Figure 4: Battery value chain 2017 [12]



Countries can build economies of scale where minerals processing and associated manufacturing occurs at or near the mine site, or near the end-use customer. Given Australia's geological reserves, there is an opportunity to bring early and mid-stage downstream mineral processing that currently occurs offshore, back onshore.

Taskforce members, the CSIRO and the Future Battery Industries CRC [13] have identified a range of critical minerals and metals which Australia should target. Areas of opportunity for more advanced processing include:

- lithium (carbonates, hydroxides, precursors and cathodes)
- nickel (sulphates, precursors and cathodes)
- cobalt (sulphates, precursors, cathodes, heat-resistant superalloys)
- high purity alumina (HPA) (synthetic sapphire)
- vanadium (V2O5 electrolyte, redox flow batteries)
- graphite (battery anode)
- manganese (concentrate, sulphate)
- scandium (master alloys, high performance aluminium alloys)
- titanium (titanium dioxide, high purity titanium metals)
- platinum (PGM precursors, proton exchange membranes)
- chromium (high-strength alloy)
- rare earths (dysprosium, neodymium)
- silicon (high purity silicon).

Australia can position itself as a preferred supplier for key manufacturing inputs by supporting firms, including mid-tier resources companies, to invest further downstream where there is additional value to be captured. This will capture significant economic growth and job opportunities in the process.

12 Best, A. and Vernon, C. (2020) State of Play, Australia's Battery Industries. CSIRO, Australia
13 Ibid.

Table 1: Examples of Australia's critical minerals with high development potential [14]

Critical Mineral	Geological potential	Economic reserves ranking	Production ranking
Cobalt	High	2nd in the world	3rd largest producer
Graphite	Moderate	8th in the world	No production
Lithium	High	2nd in the world	World's largest producer
Rare earths	High	6th in the world	2nd largest producer
Titanium	High	Ilmenite – 2nd in the world Rutile – 1st in the world	Ilmenite – 3rd largest producer Rutile – world's largest producer
Tungsten	Moderate	2nd in the world	Minimal production
Vanadium	Moderate	3rd in the world	No production
Nickel	High	1st in the world	4th largest producer

Building this capability in Australia will also allow us to provide processed critical minerals as feedstock for domestic advanced manufacturing supply chains. This includes defence, aerospace, batteries and medical technology. There are also opportunities to develop export relationships with countries looking to partner with Australia to develop alternative supply chains.

In the battery technology value chain, the Future Batteries Industries CRC has completed a detailed audit of Australian businesses' industrial activity and capability to secure more of this value. It believes Australia can compete effectively in a number of areas including: [15]

- Refining chemicals (global value $2 billion (2018)): BHP is progressing a nickel sulphate refinery at Kwinana, Western Australia. Projects from other companies are at a pilot or technology development stage.
- Electro-chemical/pre-cursor and engineered materials production ($22 billion): no current commercial production of electrolytes, cathodes and anodes is occurring but several projects are at the piloting and demonstration stage.
- Battery cell production ($31.1 billion): There may be niche applications for Australia to develop battery cells for our specific climatic conditions and in mining, defence and utility applications.
- Battery assembly ($156 billion): Some domestic assembly is currently occurring (e.g. Magellan Power in Western Australia and Feline in Queensland) and some projects in the pipeline could expand as the energy transition occurs.

14 Critical Minerals Facilitation Office and Geoscience Australia
15 Best, A. and Vernon, C. (2020) State of Play, Australia's Battery Industries. CSIRO, Australia.

Figure 5: Opportunities in the battery value chain

	Production Stage	Example area of target opportunity
	**Mining and concentrating**	Mining and concentrating for domestic and international markets.
	**Refining to chemicals**	Manufacturing battery-grade chemicals, e.g. Lithium hydroxide, cobalt sulphate, nickel sulphate, manganese sulphate, refined graphite etc. Australia can compete in the international market for supplying these products as well as used to feed into domestic supply chains.
	**Precursor manufacture**	Manufacturing precursor products and active materials (cathode, anode, electrolytes and separators) that can be exported as well as used in domestic supply chains.
	**Cell manufacture**	Manufacturing and testing of battery cells with properties that meet the demands of a range of speciality domestic applications.
	**Battery Assembly**	Small-scale assembly and testing of high-value battery packs that are specifically designed for domestic deployment needs in niche industry applications (e.g. defence, mining etc.).
	**Deployment**	Deployment of batteries for a number of domestic industries such as defence, mining and utility. E.g. industrial scale deployment of batteries for green hydrogen production, renewables and energy storage.
	**Recycling**	Building domestic capability to extract valuable resources from spent batteries.

Building advantage through commercialisation and innovation

Australia has a strong track record in minerals processing innovation. The Australia's Nuclear Science and Technology Organisation (ANSTO) is a recognised world-leader in rare earths processing innovation. The CSIRO has a demonstrated ability in novel processing technology that could provide Australia with competitive advantages. There are also a number of industry-research collaborations in the critical minerals processing space that are supported by Cooperative Research Centre project grants. Projects include a trial of a battery-grade manganese production pilot-plant, developing a new commercial-scale process for producing high purity graphite, and producing a 99.95% pure vanadium product for redox battery applications.

With the right funding and support mechanisms in place, Australia can leverage existing expertise and capability to commercialise new processes. This will help Australian projects compete with low-cost global producers. An example is the creation of Coogee Titanium by Coogee Chemicals and the CSIRO to commercialise and develop the TiRO process [16] that produces titanium powder.

16 TiRO® process is a continuous technology for the direct production of titanium powder using a fluidised bed reactor.

Leveraging Australia's world-class environmental, social and governance credentials

Sustainable sourcing and supply chain transparency is becoming more important for Australia's export partners. Potential customers are looking to purchase key manufacturing inputs (such as battery metals, precursor chemicals and advanced metals) from more environmentally sustainable and ethical sources. This includes prominent mineral end-users and original equipment manufacturers who are beginning to deliberately source processed minerals from a 'trusted' third-party. This presents an opportunity for Australia to situate itself as a key global supplier of processed critical mineral manufacturing inputs.

Australia has world-leading environmental, social and governance (ESG) credentials with a reputation as a resources sector operating to the highest standards. Australia can further leverage its ESG credentials to create market advantage for Australian firms over the next decade. Business development and marketing is required to build Australia's reputation in these areas and establish a viable market which is prepared to pay a premium for products sourced from ethical production jurisdictions.

Promoting technological innovations can further enhance this brand premium. This includes through:

- using renewable energy sources to cost-effectively value-add our critical minerals
- switching to electric and hydrogen powered mining fleets and methods of material transport
- increasing selectivity, sensing and engineering to improve ore to waste ratios and minimising waste including quantified reductions in emissions and water use
- dry stacking tailings or zero tailings mines
- in-situ methods for metal recovery.

ESG brand recognition could also be enhanced through building Australia's position as a leader in sustainable retrieval of critical minerals from tailings and existing products. For example, the Future Battery Industries CRC sees significant potential for Australia to develop technical capability in battery recycling which would extract critical minerals or reconfigure batteries for other applications. Companies such as CleanTeq are actively developing technology to handle recycling streams from spent batteries as well as metals recycling from their products.

4. Potential

Collaboration with end customers will increase commercialisation and translation

The resources sector is becoming increasingly knowledge-intensive. Significant industry challenges can only be solved by companies across the value chain collaborating, generating new and innovative products, and accelerating technology adoption. Leveraging and translating Australia's world-leading resources technology innovation will also support more efficient forms of mining and processing. This is vital to ensuring the future competitiveness of Australia's critical minerals processing industries.

A key step in commercialising a resources technology is convincing an end customer that the technology being offered will provide real value to the company using it. For example, a sensor is only of value to a company if it is integrated with a platform for analytics or combined with an engineering solution that helps customers optimise their processes. This often requires close collaboration between the technology provider and the end customer.

While there is a large amount of collaboration between companies, the focus is largely on meeting the needs of a single customer such as a large resources firm. This is a missed opportunity to offer technology products and services to the broader commercial market. To grow the sector, technology companies will need to change their business model. This could be by designing their products to service a range of clients or by commercialising their technologies to sell to a larger group of customers. This will help those companies bring their products more quickly to market, build their customer base, attract finance and build scale. Increasing collaboration will also help to build a more open marketplace which supports technology companies to grow.

Success in this high-value manufacturing area requires demonstration of capability to meet customers' rigorous, and often custom specifications. Resources companies are typically very conservative and often slow to adopt new resource technologies unless they can be de-risked by demonstrating their performance. Application of resource technologies to other sectors may also require adaptation to deliver on the needs of new customers. Australia currently lacks test mines and facilities, which allows this demonstration to occur, which slows the timelines for getting products to market.

Demonstration of processing capability is needed to integrate with domestic and international supply chains

Generating more value from our critical mineral resources relies on processing ores onshore rather than overseas. However, critical minerals processing can be highly customised, technically complex and risky to implement. This makes securing offtake agreements and project finance difficult.

The ability to demonstrate a reliable processing capability which meets the specific requirements of different customers is a critical step in on-shoring manufacturing. This typically requires pilot scale demonstrations, for example, constructing a pressure acid leach pilot plant that runs from ore beneficiation through to the refining of high purity metal, reconstructing the entire flow sheet at pilot scale.

If this final stage demonstration occurs offshore, the chances of securing the scaled-up advanced manufacturing is very low. Companies can often struggle to access funding to enable this step. Many Australian critical minerals processing projects are therefore 'stuck' at this stage of the project development pipeline.

Shared infrastructure precincts have been successful in attracting investment

Australia's critical mineral processing industry is at a very early stage. While capability in secondary processing exists within some companies and the research and engineering communities, there are very few operational projects. Industry needs to build the capability from the bottom up and attract foreign companies who can bring that capability with them. Australia's metal smelting industries were largely developed in this way.

With a skilled and capable resources sector with low sovereign risk and substantial geological potential, Australia has an opportunity to attract advanced manufacturers and mineral end-users to establish operations in Australia. This will help create a domestic market for processed Australian critical minerals products, onshore higher value-added stages of production, and help build alternate supply chains for advanced manufactured goods in Australia.

Overseas experience suggests developing industrial 'plug and play' parks can attract foreign investors. Similar initiatives in competitor countries (e.g. the UK, Germany, Malaysia, and Indonesia) have attracted investment from critical minerals processing companies seeking to offset their capital and operating costs. For example, the Indonesian Morowali Industrial Park has created a hub for mining, metal processing, steel manufacture and battery materials production. Investing businesses get the benefit of the port, power stations, and other infrastructure that were established to service Tsingshan's steel operations.

A number of state governments have identified potential clusters which could support advanced processing and downstream manufacturing close to known mineral deposits.

5. Goals

The road map's vision is based on leveraging our current expertise and capabilities in our world-class resources sector. It seeks to grow the local manufacturing of resources technology and processed critical minerals here in Australia. This growth will be underpinned by:

- commercialising more technologies
- providing opportunities for companies to scale up
- lowering barriers to access capital
- creating the right business environment for companies to compete.

The future state of manufacturing in resources technology is one where SMEs are able to grow quickly due to their hard work and innovation. To do so they must be able to translate more innovative ideas into high-value commercialised products, and manufacture more of these products in Australia. Manufacturers will have access to the capital they need to scale-up with support to demonstrate and test their technologies. A market for associated technology services will evolve. It will be based on companies supplying their products to a larger market across different sectors and countries, and will include software, digital and analytical applications.

A strategic critical minerals manufacturing industry in Australia will develop, with increasing capabilities for more sophisticated and advanced minerals processing. Australia will cleverly invest in extending our critical minerals value chain and will seek to grow disruptive technologies and capture as much additional market share as possible—without compromising competitiveness or strategic interests.

To track the progress of our efforts and actions, a number of qualitative and quantitative goals will provide markers across 2, 5 and 10 year timelines.

Manufacturing sector	Success at 2 years – by end of 2022	Success at 5 years – by end of 2025	Success at 10 years – by end of 2030
1. Overarching	• Australia has made co-investments to set up resources technology manufacturers and critical minerals processers for long-term success. • Supported by Government, the sector is unlocking more commercialisation opportunities through co-investments in translation, integration, Resources Technology and Critical Minerals Processing and collaboration. • There are growing rates of private sector investment in the resources technology and critical minerals processing sector.	• Greater local manufacturing capability is being developed in the resources technology and critical minerals processing sector. • Growing rates of domestic manufacturing and processing is building on investments in translation, integration and collaboration. • Small companies have begun to scale and there are more mid and large sized companies active in Australia. • Scaled companies are making more globally competitive products and providing them to the international market.	• Our manufacturers are globally competitive thanks to stronger rates of commercialisation, integration and collaboration. • There has been significant growth in the sector, driven by Australian companies successfully scaling. • Australia has an increased number of successful mid and large technology companies selling solutions to the global resources sector and other parts of industry. • A range of successful critical minerals processing projects have secured finance and are operating at scale. • These activities are driving increased jobs in the sector and delivering transformational economic outcomes for local communities.

Manufacturing sector	Success at 2 years – by end of 2022	Success at 5 years – by end of 2025	Success at 10 years – by end of 2030
2. Support greater translation and commercialisation Helping businesses to bring their products, services and solutions more quickly to market and build their customer base, attract finance and build scale	• Australian resources technology and critical minerals processing companies increase commercialisation of technologies and establish new processing projects onshore. • Government and industry co-investment are helping companies to demonstrate technologies, speed up commercialisation of good ideas, and integrate with international supply chains.	• Co-investments in translation, collaboration and integration have enabled a greater number of high-impact companies to overcome barriers to scale and competitiveness. • An increasing number of businesses, who were previously commercialising products overseas, are now doing so in Australia.	• There has been significant growth in the resources technology and critical minerals processing sector. Our resources technology manufacturers are delivering high-impact and cutting-edge technology products and services that meet complex challenges in the resources sector and other industries. Our critical minerals processors are highly competitive and recognised as a world leader. • Small and medium-sized Australian manufacturers are retaining intellectual capital for innovative and novel solutions, leading to a more competitive and innovative market for resources technology and critical minerals processing.
3. Support critical minerals projects to demonstrate their processing capability and integrate with domestic and international supply chains Helping to develop manufacturing opportunities by processing ores onshore that meet customer requirements	• A number of pilot projects have been developed to demonstrate technologies, showcase manufacturing capabilities, and help critical minerals processors to secure finance and offtake agreements.	• Manufacturing coalitions with relevant domestic sectors and partner countries are being developed through collaborative projects based in Australia. These support offtake qualification and product demonstration, creating a pathway to project finance.	• Advanced critical minerals processing in Australia is growing and companies are manufacturing key inputs in Australia for future-facing technologies, including inputs into batteries, solar panels, energy storage and wind turbines. • Significant economic potential is being delivered across the value chain for a range of critical minerals being processed in Australia.

Manufacturing sector	Success at 2 years – by end of 2022	Success at 5 years – by end of 2025	Success at 10 years – by end of 2030
4. Attract investment through shared infrastructure precincts which supports collaboration Helping to develop co-located infrastructure for the benefit of the sector to reduce costs and facilitate new investment	• Co-investments have been made in critical enablers of resources technology manufacturing and critical minerals processing at targeted points of value chains. • Industry and government have progressed market development activities and are engaging in opportunities to diversify and leverage existing and new partnerships.	• Private investment in domestic manufacturing capability is growing, with increased numbers of resources technology products commercialised and critical mineral processing projects commenced. • Exports of resources technology and processed critical minerals products are growing, with the capability to integrate and capture additional value from domestic and international supply chains. • There is improved confidence and investment in supply chain capability, with access to the inputs firms need. Companies are distributing their outputs to market in a way that maximises value for Australia.	• Local manufacturers of resources technology and processed critical minerals products have scaled and increased the volume and value of their exports. Australia has strengthened its position as a regional hub for essential resources technology and critical minerals processing, and global suppliers have established manufacturing facilities in Australia. • Advances are underway in R&D, design, logistics, production, distribution, sales and services. This cements Australia's global position as a leading manufacturer of advanced and high-value resources technology and processed critical minerals products. The number of high-tech, highly-skilled jobs in the sector is growing and Australia is attracting international talent based on the industry's reputation for quality and innovation.

6. Benchmarks of success

Australia's Resources Technology and Critical Minerals Processing sector will grow and transform to position Australia as a regional hub for products and technology.

The Resources Technology and Critical Minerals Processing road map will play a vital role in achieving these objectives, focusing on creating new jobs and businesses that grow Australia's resources manufacturing capabilities.

To measure our progress against the vision set out in the road map, the following will be monitored over 2, 5 and 10 year periods, dependent on data availability:

- number and value of jobs in resources technology manufacturing and critical minerals processing
- new businesses and companies in resources technology and critical minerals processing manufacturing
- growth in exports of resources technology and critical minerals processing
- activities, profitability and investment in resources technology manufacturing and critical minerals processing
- number of new resources technologies including critical minerals processing brought to market.

Many of these activities will be in new and emerging sectors and activities. New and innovative approaches are under development and may be used to identify and capture this activity.

7. Make it happen—key actions

This road map focuses on growing manufacturing activities, capabilities and specialisations in the resources technology and critical minerals processing sector. To achieve the vision of Australia being the global centre of commercialising and manufacturing resources technologies, producing cutting-edge technology projects and having a strategic critical minerals processing industry, we have identified key actions that will be implemented as part of this road map.

The key actions have been informed by the Modern Manufacturing Initiative, which is designed to unlock private sector investment for Australia's manufacturing sectors across 3 targeted streams.

- Manufacturing Translation Stream that will help manufacturers translate good ideas into commercial outcomes. It will also encourage investment in non-R&D innovation.
- Manufacturing Integration Stream to help manufacturers integrate into local and international supply chains and markets.
- Manufacturing Collaboration Stream that is designed to support business-to-business and business-to-research collaboration, to build economies of scale.

Key actions to support the vision are below.

Actions to support greater commercialisation and translation

Investment that will assist resources technology manufacturers to partner with larger firms, research organisations and end-use customers (such as mid-tier resources companies) to:

- **demonstrate and commercialise products and associated services for the resources sector and critical mineral processing**
- **adapt resources technology products and associated services for use in other sectors**
- **break into international supply chains.**

This action will directly enable resources technology manufacturers to commercialise great innovations and scale-up. Companies will achieve this by collaborating with larger firms, research organisations and end-use customers to demonstrate and refine their technologies. This will enable companies to de-risk their products, show how they can integrate with end-customers' existing operations, and support those customers to purchase them.

Commercialisation support could also assist resources technology manufacturers to adapt their technologies for application in other sectors such as defence, space and agriculture, and sell their products into international supply chains.

Enabling technology producers to sell their innovations to a larger market will enhance and build scale in resources technology companies. This will attract greater investor interest and reduce the risks of the resource sector's economic cycles.

Investment could assist companies to access commercial technology demonstration facilities to enable resources technology manufacturers to demonstrate their products to customers and how products will integrate with customer processes

Australian resources technology manufacturers are currently lacking access to mines, offshore oil and gas sites, or testing facilities where they can demonstrate and test their technologies. This slows down the pathway to commercialisation and prevents companies from demonstrating the effectiveness of their technologies to a range of end customers.

Competitor countries such as Canada, Sweden and the United States have demonstration facilities. These enable their companies to develop, test, and demonstrate innovative and emerging technologies in an operating environment.

Co-funding these types of facilities will allow companies to:

- prove that their technologies are effective
- deliver the service the end customer is seeking
- secure contracts which enable them to access commercial finance and
- scale their manufacturing businesses.

By providing these test facilities, resources technology companies can quickly validate their business case and gain customer confidence. Industry feedback suggests that test facilities can reduce the development to commercialisation cycle from 10-15 years down to 12-18 months. With higher certainty on investment decisions this translates to a dramatically faster return on investment.

Actions that support critical minerals projects to demonstrate their processing capability and integrate with domestic and international supply chains

Investments targeted at helping manufacturers with advanced critical mineral processing projects to demonstrate scaling-up capability and undertake offtake qualification and product demonstration will create pathways to offtake agreements and securing project finance, and access to markets and supply chains.

This action will help Australian critical mineral processing projects to refine minerals and metals processing, chemical precursor or other advanced customised manufacturing processes to meet offtake customers' specifications.

This scaling-up, offtake qualification and product demonstration process is an important step. It helps Australian projects prove their capability to end customers, lock in offtake agreements and secure project finance. This finance is the key to bringing new domestic processing projects online and building manufacturing scale in Australia. If this refinement step of the project occurs overseas, the scaled-up operations are also likely to be located overseas.

If Australia is to build capability to process critical minerals in Australia, working with businesses to enable these refinement activities is very important.

Attract investment through shared infrastructure precincts which supports collaboration

Co-investing in shared or common-user infrastructure and technology parks could assist the sector to attract investment from companies to base their advanced processing projects in Australia.

Co-investment in infrastructure precincts which co-locate services such as energy, water, waste and chemical reagent storage facilities can reduce capital and operating costs for project proponents.

Co-located facilities can support scale by reducing the cost of key inputs. This helps improve the economics of capital-intensive critical minerals processing projects. Centralised or common-user infrastructure will help support junior projects in particular by:

- lowering the capital requirements needed to establish large-scale processing operations in Australia
- providing access to science and technology capability and facilities
- providing access to common engineering and digital skills to support scale.

Providing shared or co-located infrastructure can also help minimise hazardous materials transport. It will incentivise ancillary service industries to establish operations near processing facilities, further reducing project operating costs. It could also support downstream manufacturing opportunities.

This will make Australia more attractive to potential investors, allow us to compete globally and encourage investors to locate processing projects here.

Ideally these investments are collaborations with state governments and industry. This leverages available funding and ensures they are complementary to state-based development strategies, the location of existing mineral deposits, and links to other important infrastructure and export facilities.

This will complement ongoing actions being undertaken through Australia's Critical Minerals Strategy by the Critical Minerals Facilitation Office, Geoscience Australia, CSIRO, ANSTO, Department of Foreign Affairs and Trade, Austrade, and state and territory governments. The Strategy aims to promote investment into Australia's critical minerals sector, and to explore downstream processing opportunities that can be built into new technology parks or industry precincts.

8. Engagement and partnerships

International partnerships

Expanding our international partnerships in the resources technology industry will be a vital path to ensure manufactures are able to scale-up. An industry survey recently revealed that 65% of METS firms in Australia export goods and services and generate, on average, 25% of revenue from exports. The top 8 markets (in order) for Australian METS exports are:

1. the United States
2. Indonesia
3. Papua New Guinea
4. New Zealand
5. Canada
6. Chile
7. South Africa
8. China.

The survey also indicated that a third of companies who do not currently export today intend to in the next 2 years, with Chile, Canada, the US and Indonesia as focus markets.

Establishing new and expanding existing international partnerships is an important priority to build Australia's reputation as a regional hub for critical minerals processing and a resources technology manufacturing industry. For critical minerals processing, establishing new partnerships is critical to attract the capital and skills needed to allow manufactures to move up the value-chain.

The Australian Government is working to establish and expand key international partnerships to help create demand for Australian processed critical minerals products and strengthen global markets. Developing and diversifying critical mineral supply chains requires a highly integrated approach to trade and investment activities, with governments playing an essential role to align supply and demand signals and establish alternate supply chains. On the demand-side this requires foreign governments, large-scale end-users and original equipment manufacturers to either be involved:

- directly in securing alternate critical minerals supply
- indirectly by imposing procurement requirements that prioritise security and other criteria such as ethical and environmental considerations, over low cost.

Three main areas of focus include:

- encouraging strategic partners to sign long-term offtake contracts with Australian proponents
- working with international partners to develop integrated end-to-end supply chains
- developing international standards to ensure a level-playing field for Australian producers.

The Australian Government with Standards Australia has also developed a proposal for a new ISO standardisation area to ensure a more holistic approach to developing technical standards for critical minerals. The need for ethical certification and good standards for the industry is partly driven by increasing ESG awareness amongst end-users and emerging market requirements. The Future Battery Industries Cooperative Research Centre is funding a suite of R&D to establish technical competencies. These will create market advantage for Australian critical mineral firms that are required to comply with international ethical certification schemes. Establishing capabilities to comply with international ethical certification schemes is part of Government's comprehensive strategy to:

- open up market access, particularly to EU members
- offer assurance to customers that they are using ethically and responsibly sourced materials in their manufacturing processes
- demonstrate the high standards that Australian projects already meet
- level the playing field for all producers by having a high standard across the industry.

9. Collaboration

This road map has been developed in collaboration with industry. It outlines a 10 year vision, and a range of barriers and opportunities to achieve scale in manufacturing in the resources technology and critical minerals processing sector.

Implementing these actions will require ongoing engagement between all levels of government and industry. The Government is committed to implementing a collaborative and integrated approach to growing the resources technology and critical minerals processing sector.

Supporting greater levels of collaboration between government, businesses, venture capitalists, industry experts and researchers will ensure Australia realises the benefits of innovation, harnesses our world-class research capabilities and translates our great ideas into commercial outcomes. Businesses are more likely to grow and attract investment when they are supported by a thriving business environment. The Government is focusing its investment on projects that will:

- create collaborative environments
- encourage the market to invest
- facilitate collaboration between business, research organisations and state and territory governments.

By developing these road maps the Government is ensuring science and technology work for industry by fostering the environment needed to improve collaboration to support the resources technology and critical minerals processing sector. Through strong collaboration across industries and between government and the private sector, we will help to create the pathway forward for the manufacturing sector to leverage economies of scale, share knowledge and drive innovation. By working together, Australia will become a global centre for commercialising and manufacturing resources technology, creating an ecosystem of innovative companies producing cutting-edge technology products and services for the global resources sector that benefit a range of other Australian industries.

Appendix A

Road map in context

On 1 October 2020, the Australian Government announced $1.5 billion to be invested over the next 4 years in the Modern Manufacturing Strategy (MMS) to help Australian manufacturers become more competitive, resilient and build scale in the global market.

The centrepiece of the MMS is the $1.3 billion Modern Manufacturing Initiative which will allow government to invest in projects within 6 National Manufacturing Priority areas. The 6 National Manufacturing Priority areas are:

Resources Technology & Critical Minerals Processing

Food & Beverage

Medical Products

Recycling & Clean Energy

Defence

Space

This road map outlines:

- a vision for building the scale and competitiveness of manufacturing in resources technology and critical minerals processing
- opportunities that Australian businesses could target, based on our competitive strengths, emerging industry trends and future market potential
- actions for how industry and government can work together to address barriers to scale and capture opportunities. This includes government support which improves the commercialisation pathways for companies that want to get their products and services to market and grow their manufacturing operations in Australia.

The road map development process

Road maps have been developed with industry to set out plans for both industry and government to strengthen Australia's manufacturing capability. The road maps have been led by 6 industry taskforces to identify and set a future vision for priority areas with clear goals, opportunities and actions over the next 2, 5 and 10 years.

Members of the industry taskforces were selected based on their expertise across the priority areas and were supported by technical experts from the Commonwealth Science and Industrial Research Organisation (CSIRO), the Department of Industry, Science, Energy and Resources (the department) and Industry Innovation and Science Australia (IISA).

Taskforce deliberations focused on current and future issues, challenges and opportunities to grow Australian manufacturing and identifying actions that businesses and government can take to support scale, competitiveness and resilience in the sector in the next 10 years.

Government has also been working with industry beyond the taskforce to understand the manufacturing needs of the resources technology and critical minerals processing sector. A public consultation process was held between 23 October 2020 and 9 November 2020 which received 340 responses, including 88 focused on resources technology and critical minerals processing.

The road map was also informed by more detailed discussions held with industry representatives including Austmine and the Association of Mining and Exploration Companies (AMEC) as well as IISA, National Energy and Resources Australia (NERA) and METS Ignited, bilateral meetings with key stakeholders, and research conducted by the department.

Building on existing findings

Recognising the valuable work already completed in this area, development of the road map also drew upon relevant strategies including but not limited to:

- National Resources Statement which includes a 5 point action plan to deliver the most globally attractive and competitive investment destination for resources projects; open up new industries and resources regions; better focus the sector's innovation, research and development on long-term sectoral growth; develop and retain the world's best workforce; and deliver better outcomes for stronger and more engaged communities.
- Australia's Critical Minerals Strategy which targets actions in 3 areas: promoting investment in Australia's critical minerals sector and downstream processing; providing incentives for innovation to lower costs and increase competitiveness; and connecting critical minerals projects with infrastructure development.
- CSIRO's METS Road Map which recommends an aligned, efficient and agile industry ecosystem for the METS sector with a high degree of collaboration, global leadership in innovation and a growing share of global markets.
- METS Ignited's Sector Competitiveness Plan which identifies a number of key opportunities to boost the METS sector, including robotics, automation and analytics; environmental and energy innovations; and improving the sector's ability to commercialise and sell into international supply chains.
- NERA's Sector Competitiveness Plan which outlines priority areas of action to accelerate the commercialisation and adoption of digital and automation technologies across the energy resources sector; fast-track advanced and low-emissions technologies; develop more technology-driven SMEs; scale-up supply chain communities; and remove regulatory barriers to future growth.

Appendix B

Barriers to Scale

This road map seeks to support the resources technology and critical minerals processing sector to achieve its full potential by overcoming barriers to scale. While it is a developed sector in some areas, government investment and support to improve overall value add will be key to achieving growth.

The resources technology and critical minerals processing taskforce sees the Government's work to get the economic conditions right for all manufacturers as an important opportunity to improve competitiveness for the sector, particularly in:

- Talent and Skills: the resources technology and critical minerals processing sector is knowledge driven. While we have a skilled and capable workforce, the sector relies on STEM and vocational skills to support emerging technologies, such as robotics and automation. It also relies on the advanced manufacturing skills needed for downstream critical minerals processing, such as chemical engineering.
- Access to capital: as it can take years to get projects to full-scale production, de-risking projects and improving access to debt and equity finance are important. Policies which go to the investment environment, send signals to investors, or more actively provide risk tolerant finance will encourage greater investment.
- Standards development: ethical certification helps strengthen Australian manufacturers' ability to boost their export markets. Active engagement in developing, applying and aligning standards is particularly important for businesses in this priority area.
- Investment attraction: capital is mobile in this sector, and Australia needs to continue competing with countries who are targeting this mobile private sector investment.

The key barrier the Australian resources technology sector faces in achieving scale is the translation and commercialisation of ideas into products and services that resource firms and critical minerals customers want to buy. The sector needs to demonstrate how their technologies are commercially viable and can drive productivity, improve sustainability across the resources value chain, and integrate with existing operating systems. [17] Without this, many end-use customers are reluctant to disrupt their operations to adopt new technologies.

Another key barrier to scale is market design in the resources technology sector. It needs to continue evolving from a traditional structure of technology firms providing solutions 'owned' by tier one resource producers. Instead, technologies need to be developed and sold to multiple customers across a vibrant marketplace, which then supports greater collaboration between technology providers and smaller resource producers.

Resource and critical minerals technology companies need access to finance. Australia's capital markets are often reluctant to lend to this sector and end users are slow to adopt new technologies. This means some companies struggle to commercialise or need to go offshore to raise capital and develop commercial opportunities. To attract capital, they need to broaden their customer base, reach global markets and adapt technologies for application in new industries. This will allow them to attract finance and build resilience to market fluctuations in resources and critical minerals.

While programs are available in the market, there is still a significant gap in support provided. Better pathways for commercialising technology are needed to help companies get products to market.

In critical minerals processing, the ability to move into manufacturing is dependent on the ability to process chemically complex raw materials competitively. There are very few established processing projects. Some companies have undertaken definitive feasibility studies and are at the stage of attracting offtake agreements and project finance, but they face technical and market barriers to scale operations. These include:

- substantial investment overheads to establish mineral processing facilities and build appropriate domestic capabilities in Australia
- the technical risk involved in highly complex and custom processing requirements
- commodity price volatility in markets that are lack transperancy and supply chains that are highly concentrated with high product qualification thresholds.

These factors make it difficult to access finance without public funding and risk sharing. This road map, through continued government support and collaboration, seeks to overcome this barrier by building greater capability within the manufacturing sector to demonstrate a reliable processing capability and the ability to scale to meet the needs of different customers.

17 The minerals and energy resources value chains encompass the entire mining life cycle from feasibility, exploration, construction, operation, processing value-adding through to decommission and remediation.