WA'S FUTURE IN THE LITHIUM BATTERY VALUE CHAIN

Chamber of Commerce and Industry WA

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FULL REPORT

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Executive Summary

There is cause for both excitement and caution

There is broad agreement that Western Australia is well positioned to benefit from rapid and sustained growth in global demand for lithium-ion batteries. Our production base of battery minerals is rapidly expanding, and current and planned investment in downstream processing capacity will see some of these minerals converted to chemicals for the global lithium-ion battery supply chain.

Understandably, there has been a lot of enthusiasm about the potential to continue progressing further down the lithium-ion battery supply chain. In this context, Western Australia's mixed historical success in value-adding to its mineral production and comparative disadvantage in low margin manufacturing are reasons for caution. However, there are characteristics of the lithium-ion battery supply chain that suggest the opportunities in processes that are downstream of primary production are arguably different from those in which Western Australia has previously experienced limited success.

Understanding Western Australia's competitive advantage in the rapidly-evolving lithium-ion battery industry and focusing our efforts on securing and optimising this advantage will be crucial to attaining full, sustainable value from this opportunity.

This is the focus of this study.

OPPORTUNITIES FOR WESTERN AUSTRALIA

Global megatrends and the Australian market

Global demand megatrends are driving the opportunities for Western Australia in the lithium-ion battery supply chain. By all accounts, global demand for lithium-ion battery technology is expected to grow at an unprecedented rate for the foreseeable future. This demand is derived from demand for products that is being driven by a combination of global decarbonisation policy, rapidly changing mainstream customer values and an appetite for business productivity growth.

Demand for personal and portable electronic devices, energy storage systems and particularly electric vehicles is expected to result in orders of magnitude increases in demand for minerals used in the manufacture of lithium-ion batteries. As an established and expanding producer of some of these minerals for the global lithium-ion battery supply chain, Western Australia stands to benefit from these megatrends.

This presents significant opportunities, but some caution should be taken regarding the ability of Australian domestic demand to drive local industry development. The Australian domestic market for battery product applications will grow, but we will remain a relatively small market for most lithium-ion battery product applications by global standards due to our population and industry limitations. Accordingly, Western Australia's competitive advantage, and therefore participation in the lithium-ion battery supply chain, will very likely remain export oriented.

Battery technology: a stable platform, but continually evolving space…

Lithium-ion battery technology is very likely to remain the platform technology for most rechargeable battery applications for the foreseeable future. The emerging dominance of nickel-manganese-cobalt (NMC) cathode chemistry in electric vehicles favours Western Australia's existing battery minerals production base. In turn, this supports the case for the immediate downstream production of high quality lithium hydroxide, nickel sulphate and potentially cobalt sulphate technical-grade chemicals.

Western Australia and production of battery minerals

'Critical' battery minerals

A subset of the minerals used in the manufacture of lithium-ion batteries have been determined to be 'critical' by various jurisdictions that host downstream industry. This is based on the perceived market supply risk, rate of recycling and extent to which those specific minerals can be substituted in the battery chemistry.

The fact that Western Australia produces or has resources of many of these critical minerals ***means the State is well positioned to benefit from current and new opportunities in the global battery supply chain***. However, given the investment in developing these mineral resources across the globe, and Western Australia's typically mid-range cost profile, we should not take this competitive advantage for granted.

Lithium

Forecasts suggest that demand for lithium will increase dramatically out to 2025, with battery derived demand increasingly dominating the global lithium demand profile. Western Australia accounts for a significant portion of global lithium reserves, the vast majority of hard-rock primary lithium production, and as a result of recently commissioned projects, currently around half of total global primary lithium production.

Western Australian production of lithium pregnant spodumene concentrate measured in terms of lithium carbonate equivalent, while the lowest cost hard-rock producers, sits at a mid-point in the global cost curve, with particularly the larger Latin American brine producers demonstrating a significant primary production cost advantage. This, combined with the different process flows, renders Western Australian primary production uncompetitive as a feedstock for the manufacture of lithium carbonate, but competitive with respect to the manufacture of lithium hydroxide.

If all of the more advanced pre-production projects identified in this study come on stream, Western Australian lithium concentrate production will increase to approximately 4.1 million tonnes per annum. The extent to which this production will be converted to lithium hydroxide through domestic processing capacity or exported to conversion plants in the People's Republic of China (PRC) will be a function of the extent to which the planned domestic conversion capacity materialises, as well as individual company decisions with respect to the best strategy for optimising shareholder returns.

Nickel

In response to expanding demand for nickel-rich battery chemistries, demand for Class 1 nickel feedstock from nickel sulphate conversion plants will increase substantially.

The Class 1 nickel briquettes and powders that are more readily convertible to nickel sulphate inputs to the lithium-ion battery supply chain comprise approximately only 10 percent of global nickel production. Western Australia is a major producer of this important subset of Class 1 nickel product, accounting for approximately 45 percent of the 230,000 tonne of Class 1 nickel briquettes and powders produced globally.

Cobalt

Lithium-ion battery supply chain demand for cobalt has increased three-fold over the past five years, with demand derived from battery manufacture now accounting for approximately 40 percent of global cobalt demand. Demand for cobalt is expected to double again by 2025. Due to its current lack of substitutability, concentration of primary production in the Democratic Republic of Congo (which presents sovereign risk and product acceptability risk) and the concentration of cobalt refining in the PRC, cobalt is listed as 'critical' by both the European Union and United States.

The Murrin Murrin nickel laterite operation in Western Australia produces significant volumes of cobalt as a co-product, with other Western Australian nickel projects producing smaller volumes of cobalt by-product.

REASONS FOR CAUTIOUS EXCITEMENT

Other battery minerals

Western Australia produces a range of other minerals that are used in the manufacture of lithium-ion batteries such as copper, alumina and several rare earths. However, these minerals undergo extensive downstream processing and manufacturing into various products such as copper and aluminium foils and electrolyte formulations via established offshore supply chains before they are suitable for use in battery manufacture.

Western Australia also hosts resources of other minerals that are used in the manufacture of batteries, such as graphite. However, these are yet to be commercialised and typically face significant cost competition from established production and over-capacity in other minerals provinces.

Western Australia also host projects that are commercialising emerging battery minerals such as vanadium and kaolin that is converted to High Purity Aluminium.

Western Australia and the lithium chemical conversion sector

The PRC hosts the vast majority of the world's lithium conversion plant capacity, with approximately half of that capacity producing lithium carbonate, a quarter lithium hydroxide and a quarter lithium metal. Around three-quarters of the feedstock for these lithium conversion plants is spodumene and spodumene concentrate, the majority of which is sourced from Western Australian production. Over 90 percent of Western Australian spodumene concentrate is exported to the PRC for conversion into technical grade lithium chemicals, with additional offtake agreements with PRC conversion capacity underpinning the financing of much of the expanding spodumene concentrate production base in Western Australia.

As a result of inefficient retrofits to legacy infrastructure designed to meet increasing demand, many existing PRC conversion plants are operating well below their nameplate capacity, resulting in a current bottleneck in the production of technical grade lithium chemical. To address this bottleneck and rising demand for lithium chemicals, several operators of these plants (including the world's leading lithium chemical companies) are investing in significant further brownfields expansion, as well as new conversion capacity in the PRC. Much of this new capacity has and will continue to source feedstock through offtake agreements with existing and emerging Western Australian spodumene production.

The recent significant investment in lithium hydroxide conversion in Western Australia has been underpinned by a variety of factors, including escalating global demand for lithium in hydroxide form, increased local feedstock availability, some operating cost equalisation, the processing bottleneck in the PRC and strategic reasons to invest in capacity outside of the PRC. Tianqi is currently constructing a plant in Kwinana and Albemarle is navigating the approvals process for a plant in Kemerton. Other lithium mining projects in Western Australia also have plans to establish local conversion plant capacity.

By 2021 lowest cost lithium hydroxide manufacture in Western Australia is expected to have a similar operating cost profile to that in the PRC.

Western Australia and the nickel and cobalt chemical conversion sector

Nickel sulphate chemicals used in the lithium-ion battery supply chain are supplied by around at least 15 chemical suppliers, approximately 75 percent of which are located in in East Asia across the PRC, Japan and Taiwan. Once Nickel West's Western Australian nickel sulphate plant is at full capacity it will be one of the largest producer of nickel sulphate globally.

Currently, approximately 80 percent of refined forms of cobalt suitable for battery use (including sulphates) are produced in the PRC. If Nickel West's plans to develop cobalt sulphate at its Kwinana refinery materialise it will likely be a significant ex-PRC supplier of cobalt sulphate.

It is likely that the nickel and cobalt sulphate materials produced in Western Australia will be of high quality, becoming increasingly important as the battery industry continues its quest for higher intensity, lower cost nickel-rich battery chemistries. Nevertheless, competition from East Asian production capacity will remain a competitive threat.

Western Australia and the cathode precursor sector

This is a particularly opaque sector of the lithium-ion battery supply chain. Much cathode precursor manufacturing capability is either integrated with conversion capacity or with downstream facilities that produce cathode active material.

While technically complex and requiring discrete supply chain relationships, the ability to leverage from existing reagent suites and operations means it is not an insurmountable step in process to convert domestically manufactured technical grade chemicals into some specific battery grade compounds in Western Australia.

This represents an opportunity for Western Australian industry to further advance its emerging technical grade chemical industry to battery cathode precursor chemical manufacture.

Western Australia and the downstream battery manufacturing sectors

Processes in the manufacture of lithium-ion batteries downstream from the manufacture of cathode precursor chemicals include the manufacture of cathode and anode active materials, electrolytes, separators, battery cells and assembly of battery packs. Competing internationally in these sectors of the lithium-ion battery supply chain presents Western Australia with a much more significant challenge.

With the exception of primary production of raw materials (which is largely dependent on the geography of natural resources), almost all mid-stream and the vast majority of downstream lithium-ion battery supply chain is concentrated in East Asia (Japan, Republic of Korea and particularly the PRC). Current trends in investment strongly indicate that this will continue to be the case for the foreseeable future. The dominance of East Asia in the lithium-ion battery supply chain is the function of a number of fundamental factors, namely:

- **Economics associated with first mover advantage** – As part of the industrial ecosystem that supports East Asia's dominance in the portable and personal electronic devices manufacturing industry, East Asia has been manufacturing lithium-ion batteries for over two decades. This has resulted in substantial installed capacity, ample opportunity for lower cost brownfields expansion of production capacity, a large relevant industrial ecosystem, substantial intellectual property and an appropriately-skilled workforce.

- **Very large regional markets** – Due to the scale of their population and industry, an emerging middle class and carbon reduction policies, East Asia a very large (if not the single largest) market for lithium-ion battery products. There are substantial logistics and inventory cost advantages in locating downstream production processes in close proximity to end-user markets.

- **Alignment of regional cost structure with the competitive dynamics of the supply chain** – The barriers to entry in midstream sections of the lithium-ion battery supply chain are relatively low. This means that competition in mid-stream sectors (cathode active material, anode active material, electrolyte, separator and cell assembly sector) is more intense, leading to lower margins. As production increases and markets equalise, further margin pressure will occur along the supply chain. The typically large multinational chemical and manufacturing firms that compete in these mid-stream sectors organise their global product platform to ensure that margins are optimised by appropriate manufacturing cost structures, which reside primarily in low cost manufacturing jurisdictions in East Asia. In this sense, the lithium-ion battery supply chain is no different to most other mass product manufacturing supply chains.

- **Facilitative and reactive industry policy** – East Asian nations, as well as multiple jurisdictions across North America, South America, Europe and South East Asia implement relatively aggressive industry development policy designed to attract investment into and grow key elements of the lithium-ion battery supply chain. Furthermore, the government structure of the PRC enables almost instantaneous policy responses to market conditions, allowing it to adjust its policy framework as opportunities and threats to its battery industry arise.

The dominance of East Asia and its inherent competitive advantage in the mid-stream lithium-ion battery supply chain ***is a reason to be very cautious***. However, the fact that expanding Western Australian upstream production is an integral part of the dominant East Asian lithium-ion battery supply chain ***is a reason to be excited***.

How far can Western Australia go?

Western Australia has an established and competitive production base in the key lithium-ion battery cathode material minerals – lithium, nickel and cobalt. However, it is not the lowest cost producer of these minerals and investment in primary production of these minerals is occurring in other minerals provinces, often as the result of direct investment by or offtake agreements with global downstream operators in the lithium-ion battery supply chain. While Western Australia should remain a major supplier of these minerals for the foreseeable future, it should not take its competitiveness in this sector for granted.

Similarly, all things being equal, the emerging domestic technical grade lithium hydroxide and nickel sulphate production sector should evolve into a major large-scale source of high-quality technical grade material for the lithium-ion battery supply chain. However, history tells us that we should not take this for granted either, particularly given the investment in new lithium conversion capacity that is currently underway in the PRC and Western Australia's mixed historical success with sustaining the competitiveness of downstream processing investments.

While technically complex, the conversion of technical grade lithium, nickel and potentially cobalt chemical products to battery precursors is not a major step from an economic perspective and is potentially viable in Western Australia.

The likelihood of Western Australia being competitive in the global lithium-ion battery supply chain in sectors downstream from battery precursor manufacture decreases dramatically. The main reasons for this are as follows:

- **Western Australian raw material and imminent chemical production is a key input to the East Asian downstream supply chain** – The downstream lithium-ion battery supply chain is heavily concentrated in East Asia and this is likely to remain the case for the foreseeable future. Western Australian production is deeply and increasingly integrated with this supply chain, with most existing and future production of concentrate and chemicals underpinned by offtake agreements with the East Asian supply chain.

- **Small domestic market for lithium-ion battery products** – As discussed previously, the vast majority of the end-user market for lithium-ion batteries is not located in Australia, and Australia is and will remain a relatively small market for lithium-ion battery based products.

- **Unsuitable mid-stream and downstream cost structure** – Even in advanced manufacturing sectors, the Australian manufacturing industry has a fundamental total product cost disadvantage compared to the international benchmark. As a result of this and other factors such as the volatility of the Australian dollar, Australia's manufacturing industry is one of the World's most volatile. This means that it is highly unlikely that Western Australian based industry would be competitive in sectors of the lithium-ion battery manufacturing supply chain downstream from precursor production that are characterised by relatively low barriers to entry and as a result, low operating margins.

- **Uncompetitive policy framework** – Many of the policy instruments that are used by other nations to attract investment in mid-stream and downstream lithium-ion battery manufacturing capacity are not consistent with Australia's rules based, open economy policy practices and norms, and as such would unlikely be implemented by an Australian government. Nor is the Australian policy development and implementation system as flexible and responsive as those in East Asia, particularly the PRC.

It is important to note that there are strategic drivers for both PRC and ex-PRC downstream operators to establish mid-stream and down-stream production capacity outside of the PRC, principally to alleviate downstream customer perceptions as to security of supply risk. However, Western Australia is one of many options as an ex-PRC investment destination and other jurisdictions with lower cost structures, larger regional markets and more competitive policy frameworks will likely be preferred.

The immediate opportunity for Western Australia is to capitalise on its competitive advantage is grounded in the following attributes:

- The existence of an established and expanding high quality production base in key lithium-ion battery minerals, namely lithium, nickel and cobalt.
- An emerging battery chemicals processing sector that will produce high quality technical grade chemical products for the lithium-ion battery supply chain.
- Established and deep trade relationships with international jurisdictions that host the majority of the world's rapidly growing midstream and downstream lithium-ion battery production capacity.
- Strong industry regulation that is aligned with emerging customer behaviours with respect to environmentally and socially sustainable production.

The policy recommendations made by this study are designed to ensure Western Australia is optimally positioned to harvest maximum value from this competitive advantage, and that this positioning can be achieved within a time-bound window of opportunity.

Policy recommendations

This study has a specific mandate to restrict its policy recommendations to initiatives that are:

- Legal in that they do not require changes to the Australian Constitution or major renegotiation of international trade agreements to which Australia is party; and
- Consistent with Australia's rules based open economy and its general political and socio-economic norms and practices.

The reason for these limitations is so that the recommendations can be readily implemented. The window of opportunity for Western Australia to entrench its competitive position in the lithium-ion battery supply chain is time bounded, requiring a timely policy response.

Noting the analysis as to Australia's international competitiveness, the specific objectives of the policy recommendations are to:

- Ensure that Western Australia's competitive advantage as a supplier of relatively large volumes of high quality battery minerals to the global lithium-ion battery supply chain in entrenched and sustained;

- Ensure that the domestic lithium, nickel and possibly cobalt conversion plants that are the subject of domestic investment and FDI, as well as aspiring chemical conversion plants for these battery minerals and others, are given every opportunity to establish a sustainable competitive position in the lithium-ion battery supply chain; and

- Delineate a clear pathway for Western Australian industry and/or FDI in the establishment of cathode active material precursor chemical manufacture in Western Australia.

The specific recommendations are summarised in the following table.

SET THE RIGHT STRATEGY AND NARRATIVE	
1	The Western Australian Government and participants in the Western Australian lithium-ion battery supply chain should work together to establish a clear strategy designed to allow Western Australia and Western Australian industry to optimally capitalise on its competitive advantage in the global lithium-ion supply chain and sustain that competitive advantage.
2	Government and industry leadership should use an agreed narrative to promote Western Australia's prospects in the lithium-ion battery supply chain that is evidence-based, realistically achievable, clearly linked to the strategy, and very importantly recognises the importance of Western Australia's mining and emerging chemical processing industries as the fundamental source of Western Australia's competitive advantage in the lithium-ion battery supply chain, supporting their social licence to operate.
BUILD ON EXISTING TRADE RELATIONSHIPS	
3	Western Australian Trade Commissions, Austrade and the Commonwealth Department of Foreign Affairs and Trade should work with the various nations with which Western Australia and Australia already have extensive trade relationships and existing or prospective facilitative trade agreements, to optimise Western Australian supply of upstream products to the global lithium-ion battery supply chain and to attract FDI that builds upstream production capacity in Western Australia.
PROJECT INVESTMENT AND OPERATIONAL CERTAINTY	
4	The primary mechanisms for optimising project investment and operational certainty for the upstream lithium-ion battery industry in Western Australia should be in the form of specific improvements to the Strategic Industrial Area policy framework and the implementation of a time-bound machinery of government mechanism that facilitates all advanced lithium-ion battery supply chain projects under the existing Lead Agency framework.
NEW INDUSTRY DEVELOPMENT INCENTIVES	
5	To incentivise investment in conversion plants and upstream lithium-ion supply chain chemical manufacturing in Western Australia, the Western Australian Government should give consideration to the following: ▪ In accordance with the net-back principle that applies to the design of Western Australia's minerals royalty regime, operations that convert a mineral concentrate directly to a marketable chemical that has a higher primary constituent content should be charged a prescribed royalty rate that is between the current netback principle based mineral concentrate rate (5.0 percent) and the metal rate (2.5 percent), provided that the price differential between the two tax bases is such that the lower rate provides an incentive. ▪ Conduct further analysis and modelling to determine if there is an economic case for using the royalty regime to incentivise investment in Western Australian battery chemical precursor production capacity. ▪ As is always the case, consideration should be given to ensuring that Western Australia's overall taxation framework optimises the productivity of all Western Australian industry.
TARGETED RESEARCH AND DEVELOPMENT	
6	While there may be discrete areas of battery technology innovation where Australian science is at the cutting-edge, the proposed Future Battery Industries Cooperative Research Centre should carefully ensure that the vast majority of its resources are targeted at underpinning and expanding Australia's (primarily Western Australia's) competitive advantage in the lithium-ion battery supply chain, as articulated in this report.
7	The Commonwealth Government should give consideration to revoking the recently imposed $4 million cap on cash rebates for smaller businesses under the R&D Tax Incentive Program.

CONTENTS

1. Background and Purpose

1.1. Western Australia and the Lithium Battery Value Chain

1.1.1. There are reasons to be excited…

Lithium-ion battery technology has been used in a range of consumer and portable electronic devices for over two decades. In more recent times we have seen significant escalation in demand for modern lithium-ion battery technology that is derived primarily from global national policy frameworks designed to decarbonise the Planet, such as those that promote increased utility, commercial and residential renewable energy capacity, as well as increased adoption of electric vehicles.

This, in turn, has created heightened excitement among capital markets, industry, policy-makers, commentators and communities alike with respect to the potential for growth in Western Australian industry than could result from increased participation in the global supply chain that manufactures lithium-ion batteries.

Indeed Western Australia should be excited. For decades, Western Australia has produced and globally marketed a range of high quality minerals that are the raw material feedstock for the lithium-ion battery supply chain. Western Australia's competitive advantage in this market is a function of:

- Large, high quality *in situ* resources of many of the relevant minerals;
- Decades of private sector infrastructure investment designed to produce several of those minerals;
- World-class native geoscience and extractive metallurgy capability; and
- Very importantly, a relatively sound and stable resources industry policy framework that has generally had bipartisan support, and which have rendered Western Australia a highly competitive resources sector investment destination.

Further, in recent years several international companies that are producers of minerals used in the manufacture of lithium-ion batteries and/or operators of downstream processing infrastructure globally are investing in feasibility studies for, and in some cases have commenced construction of, processing plants in Western Australia that will convert some domestically produced mineral products to chemicals that are inputs to the manufacture of lithium-ion battery chemistries.

This downstream investment is a significant event that places Western Australia on a trajectory to become a major upstream player in the global lithium-ion battery supply chain.

1.1.2. There are reasons to be cautious…

These circumstances are indeed exciting for Western Australia, presenting new opportunities for primary production, an opportunity to pursue long-coveted value-adding to Western Australia's minerals resources and as a result, new jobs in an increasingly diversified economy. However, neither Western Australia's competitive advantage in the production of these minerals, nor the future competitiveness of the current and seemingly imminent investment in immediate downstream chemical production should be taken for granted.

The global lithium-ion battery supply chain is complex, dominated by large multinational chemical and manufacturing companies, exhibits ferocious low margin competition among these players at many stages of the supply chain, is primarily concentrated in low cost jurisdictions, and is strategically located to efficiently service large global markets. Furthermore, for both economic and geopolitical reasons, many nations are implementing very aggressive consumer market, industry development and Foreign Direct Investment (FDI) policy initiatives designed to attract elements of the lithium-ion battery supply chain to their jurisdiction.

Traditionally, and not surprisingly, Australian industry that does not possess comparative advantage in specific commercial activity has struggled (and typically failed) to compete with the industries of other nations that do possess comparative advantage, particularly when the competitiveness of the industries of other nations is further enhanced by relatively aggressive domestic industry policy.

While not quite 'comparing apples with apples', one only need to look to the Australian steel industry as reason for caution. Australia hosts expansive resources of some of the world's highest quality iron ore, substantial resources of coking coal, and a multitude of alloying mineral resources, all supported by globally competitive production systems. Additionally, through thermal coal and natural gas resources and infrastructure, Australia has at least theoretical access to competitive energy. Despite this, Australia has never hosted a globally competitive or indeed unprotected steel industry, and a similar narrative can be applied to a range of other downstream sectors, including in specialty metals and in the context of energy or petroleum manufacturing. This is discussed further in Appendix 1.

However, there are some notable differences between the downstream opportunity presented to Western Australia by the rapid expansion of the global lithium-ion battery industry and the context under which some previous attempts to create domestic resources industry value-adding sectors have proven unsuccessful. Generally speaking, the scale of capital investment is smaller - particularly regarding the more immediate downstream chemical manufacturing sectors - and opportunity exist to leverage from existing infrastructure and localised reagent by-products. While these attributes serve to mitigate some of the economic challenges that downstream sectors face in Western Australia, ignoring the underlying fundamentals and the State's history with respect to value-adding to its primary production would be unwise.

1.1.3. Nevertheless, there are definitely reasons to examine this opportunity closely and take action to optimise sustainable economic benefits from it…

The acceleration of global decarbonisation policy, combined with Western Australia's current competitive position in the upstream lithium-ion supply chain clearly presents opportunity to develop new industry and employment opportunities in Western Australia. This is happening now.

It is also an opportunity to learn from our past, adopt an evidence-based approach to understanding what are achievable outcomes for Western Australia in the globally competitive lithium-ion battery supply chain, and put in place a rational, world-class industry development policy framework that is consistent with Australian economic and policy norms and practices.

Understanding this and identifying appropriate policy is the fundamental purpose of this study.

1.2. The Purpose of this Study

The specific purpose of this study is to provide:

- A comprehensive, evidence-based commercial and economic assessment of the competitiveness of Western Australian industry and Western Australia as a Foreign Direct Investment (FDI) destination for discrete stages of the lithium-ion battery supply chain;

- Where the assessment has identified Western Australian industry and/or Western Australia to be currently or potentially *prima facie* competitive, make recommendations to the Commonwealth and Western Australian Governments as to policy initiatives that are designed to protect and optimise the competitiveness of Western Australian industry and Western Australia as a FDI destination for discrete stages of the lithium-ion battery value chain.

The study considers a wide range of policy instruments that are being deployed by other jurisdictions globally, as well as policy recommendations made by other studies focusing on the Western Australian battery minerals industry. However, with respect to its recommendations this study confines itself to policies that are:

- Legal, in the sense that they do not contravene the *Commonwealth of Australia Constitution Act 1901* or require major renegotiation of international trade agreements to which Australia is party; and

- Aligned with Australia's rules-based open economy, and the general Australian political philosophy and policy practice norms that are supported by the electorate.

While this approach could be reasonably criticised as being too constrained, it has a rational basis. Firstly, changes to the Australian constitution require referendum, which are expensive, unlikely to be pursued by an Australian Government in order to benefit a single industry and according to history, unlikely to be successful. Secondly, an Australian Government is unlikely to invest in renegotiating trade agreements to support a single nascent industry and in any event, counter-parties are unlikely to agree to any terms that increase international competition for their domestic lithium-ion battery industry. Thirdly, the adoption of policy that is non-conventional in the context of mainstream Australian political and economic philosophy and practice will invariably result in a protracted public policy debate before any changes to legislation are contemplated, let alone implemented. Finally, and arguably more importantly, the window of opportunity for Western Australia to capitalise on the opportunity presented to it is time bound, and changes to the Constitution, trade agreements or the adoption of un-conventional policy will likely take too long to implement for it to bear results.

1.3. Structure of this Report

In order to assist the reader in using this report for various purposes, the following Table 1 sets out the structure of the discussion.

Section	Description	Page Number
2. The Lithium-ion Battery Supply Chain: Derived Demand	This section describes the derived nature of demand along the lithium-ion battery supply chain and the three global megatrends from which that demand is derived – electric vehicles, energy storage systems and consumer and portable electronics. It also describes Australia's relative position in the market for these three product categories.	22
3. Key Trends in Lithium-ion Battery Chemistries	This section provides a 'layman' level overview of lithium-ion battery technology, its key components, the current and emerging trends in lithium-ion battery chemistries and implications for demand for various battery minerals.	43
4. Trends in Battery Minerals	This section discusses the nature of 'battery minerals', provides a detailed assessment of the global market and market trends in the key battery minerals and Western Australia's competitive position in terms of resources and production of those battery minerals. It also discusses the notion of 'critical' minerals and materials.	56
5. The Downstream Lithium-ion Battery Supply Chain	This section discusses the purpose of supply chains and why they are constituted, details the elements of the lithium-ion battery value chain downstream from primary production including chemical conversion, precursor, cathode, anode, electrolyte and separator, battery cell and battery pack manufacture. It also discusses the status, key trends and competitive dynamics of each of those discrete sectors of the lithium-ion battery supply chain. This section also briefly discusses recycling of lithium-ion batteries.	88
6. The International Policy Framework	This section discusses the large number of policy instruments that are used by various national and sub-national jurisdictions around the world to attract aspects of the lithium-ion battery supply chain to their economies.	123
7. Western Australia's Competitive Position in the Lithium-ion Battery Supply Chain	Based on the analysis in Sections 2 through 6, this Section details the nature of Western Australia's competitive position in the global lithium-ion battery supply chain, identifying areas in which Western Australia has competitive advantage, where it may be able to establish competitive advantage and areas where it is unlikely that Western Australia would be able to sustain a globally competitive industry. This section forms the basis for the policy recommendations discussed in Section 8.	141
8. Policy Recommendations	This section commences by providing a brief critique on general themes of policy recommendations made by other commentators and makes recommendations based on the scope and analysis of this report.	166

Table 1 – Structure of this Report

1.4. Acknowledgements

1.4.1. Project Principals and Resourcing

This report has been commissioned by the Chamber of Commerce and Industry Western Australia (CCIWA). The study was made possible by financial support from the following organisations:

- Chamber of Minerals and Energy of Western Australia
- BHP Nickel West
- Synergy
- City of Kwinana
- Neometals

1.4.2. Project Steering Group

The project scope and implementation was overseen by a steering group comprised of the individuals listed in Table 2 below.

Steering Group Member	Organisation
Ben Allen, Government Relations Specialist	BHP Nickel West
Justin Ashley, Manager – Policy	Chamber of Commerce and Industry Western Australia
Warwick Carter, Economic Development Specialist	City of Kwinana
Caroline Cherry, Manager - Economic Competitiveness	Chamber of Minerals and Energy of Western Australia
Steven Cole, Chairman	Neometals
Antonia Cornwell, Economist –Commercial	Synergy
Benjamin Hammer, Senior Policy Advisory - Commercial	Synergy
Chris Reed, Managing Director	Neometals

TABLE 2 – PROJECT STEERING GROUP

1.4.3. Interviewees

The study author, principals, funders and steering group extend their gratitude to the individuals and organisations listed in Table 3 below who kindly agreed to be interviewed as part of the study, and whose expertise and insights have a made a significant contribution to the analysis and findings of the study.

Name	Organisation
Joanne Abbiss, Chief Executive Officer	City of Kwinana
Carol Adams, Mayor	City of Kwinana
David Alexander, Principal Policy Advisor	Western Australian Minister for Mines and Petroleum; Commerce and Industrial Relations; Electoral Affairs; Asian Engagement
Kristin Berger, Deputy Director General	Western Australian Department of Mines, Industry Regulation and Safety
Ken Brinsden, Managing Director and Chief Executive Officer	Pilbara Minerals Limited
Warwick Carter, Economic Development Specialist	City of Kwinana

Name	Organisation
Jason Cooke, Advisor	Glencore Australia Holdings
Rachel Cooke, Consul General – Perth	United States Government
Antonia Cornwell, Economist -Commercial	Synergy
Gary Frampton, Head of Business Development	BHP Nickel West
Jason Froud, Manager, Policy - Commercial	Synergy
Christine Ginbey, Executive Director – Infrastructure and Panning	Western Australian Department of Jobs, Tourism, Science and Innovation Policy, Planning and Science
Phil Gorey, Acting Deputy Director General – Resources and Environment Regulation	Western Australian Department of Mines, Industry Regulation and Safety
Gary Gray, General Manager – External Affairs	Mineral Resources Limited
Robert Gray, Chief Commodities Strategist	Resource Capital Funds
Ella Herbert, Senior Project Officer – Infrastructure and Land Planning	Western Australian Department of Jobs, Tourism, Science and Innovation Policy, Planning and Science
Kim Horne, Non-executive Director	Synergy
Vincent Ledoux Pedailles – Vice President European Corporate Strategy and Business Development	Infinity Lithium
David Lake, Deputy Branch Manager, General Manager Business Development & Division Head – Iron Ore	Mitsubishi Development Australia
John Langoulant	
Ian Marcov, Director - Finance	Minara Resources
James McClements, Managing Director	Resource Capital Funds
Joe Ostojich, Deputy Director General	Western Australian Department of Jobs, Tourism, Science and Innovation Policy, Planning and Science
Chris Reed, Managing Director and Chief Executive	Neo Metals Limited
Chris Oughton, Director	Kwinana Industries Council
Ryan Parkin, General Manager – Corporate Development	Infinity Lithium Corporation
Michael Rodriguez, Chief Operating Officer	Poseidon Nickel
Tim Shanahan, Chair	Future Battery Industries CRC Bid
Anand Sheth, Sales and Marketing Executive	Pilbara Minerals Limited
Regina Soos, Economic Advisor – United States Consulate General Perth	United States Government

Name	Organisation
Trevor Taylor, Business Development Manager	Coogee Chemicals
Phil Thick, General Manager	Tianqi Lithium Australia
Chris Vernon, Program Director - Processing	CSIRO
Mark Woffendon, Chief Executive Officer	Minerals Research Institute of Western Australia

TABLE 3 - INTERVIEWEES

It should be noted that the analysis, observations and recommendations in this study do not necessarily represent the views and opinions of individual members of the steering group, individual interviewees or the organisations they represent.

2. Lithium Ion Battery Supply Chain: Demand Derived from Global Megatrends

This Section discusses the derived nature of demand along the lithium-ion battery value chain. Sub-section 2.1 discusses the ultimate drivers of demand for lithium-ion batteries. The following subsections discuss the global market megatrends that are the result of those drivers, namely electric vehicles (section 2.2), energy storage systems (section 2.3) and personal and portable electronic devices (section 2.4). Finally, sub-section 2.5 discusses the Australian domestic market in the context of each of these global market megatrends.

2.1. Demand Derived from Decarbonisation Policy

Demand for raw materials, intermediate products along the lithium-ion supply chain and lithium-ion batteries themselves is derived demand. That is, the demand along the supply chain is derived from the drivers of demand for the end product produced by the supply chain.

This is an obvious concept that applies to any supply chain. However, when assessing derived demand as it applies to the lithium-ion battery supply chain, it is important to consider the combined impact of the global proliferation of decarbonisation policy, such as that designed to incentivise the adoption of renewable energy platforms and electric vehicles (see Section 6), together with rapidly evolving mainstream consumer values and behaviour patterns, and business productivity demands that favour markets for products that are dependent on lithium-ion batteries. Combined, these factors create a 'perfect storm' for rapid demand growth in the form of three global demand megatrends that, through derived demand, are having a profound impact on demand for raw materials and intermediate products along the lithium-ion battery supply chain.

This relationship is illustrated conceptually Figure 1 below, with the individual global megatrends discussed in detail in the following subsections.

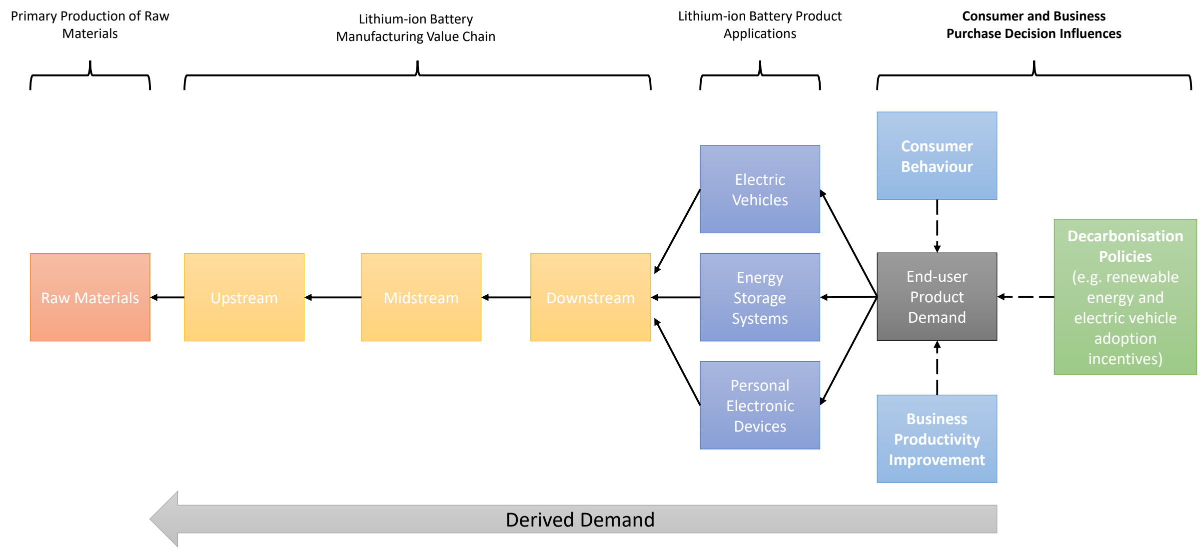

FIGURE 1 – DERIVED DEMAND AND THE LITHIUM-ION BATTERY VALUE CHAIN

2.2. Megatrend 1: Rapid Penetration of Electric Vehicles

Electric vehicles are currently available in three main technology platforms:

- **Pure Electric Vehicles (PEV)**
  Pure electric Vehicles (sometimes referred to as simply Electric Vehicles) do not involve any Internal Combustion Engine (ICE) technology, with the power train comprised entirely of a lithium-ion battery, electric motors and control systems. The battery in pure electric vehicles is primarily charged by connecting to an external charging device, and in some cases, secondarily by internal charging systems that source energy generated through the vehicle's braking system.

- **Hybrid Electric Vehicles (HEV)**
  Hybrid Electric Vehicles combine lithium-ion battery and electric motor technology with ICE technology, with the vehicle drive chain switching between the electric and ICE system depending on load and power requirements dictated by the driving phase, driver behaviour and driving conditions. The battery is primarily charged when the vehicle is being powered by the ICE, and in some cases secondarily by harvesting energy produced through the vehicle's braking system.

- **Plug-in Hybrid Electric Vehicles (PHEV)**
  Plug-in Hybrid Electric Vehicles are HEVs that have additional external charging capacity, allowing the vehicle to have a greater reliance on its battery and electric motor drive chain than its ICE drive train.

As discussed in this section, global demand for electric vehicles is rapidly emerging as a major global megatrend that is, in-turn, driving significant demand for lithium-ion batteries and therefore demand for raw materials and intermediate products along its supply chain.

2.2.1. Current Penetration and Expected Growth in Demand for Electric Vehicles

Being the anticipated main driver of demand for lithium-ion batteries, estimating the future demand for electric vehicles is 'good sport' for market analysts. As a result, there are forecasts from a large number of commentators across the contemporary literature. While they may vary according to factors such as the specific extent and timing of electric vehicle penetration, or the respective electric vehicle market shares of PEV, HEV and PHEV, all forecasts have one thing in common – they demonstrate exponential expected growth. This is illustrated by the sample of analyst forecasts summarised in the following Table 4.

Forecaster and Year of Forecast	Target Year	Total Vehicle Sales	Portion internal combustion (ICE)	Portion hybrid EV (HEV)	Portion plug-in HEV (PHEV)	Portion PEV
IHS Markit (2018)[1]	2029	115m	55%	32%	8%	5%
McKinsey[2] (Base Case)	2030	120m	77.5%	4.1%	5.0%	13.3%
McKinsey[3] (Aggressive Case)	2030	120m	70.0%	4.1%	5.0%	20.8%
Deutsche Bank (short term)[4]	2020	102m	90%	6.8%	0.7%	1.9%
Deutsche Bank (medium term)[5]	2025	112m	86%	8.0%	3.5%	2.6%

TABLE 4 – EXAMPLES OF ELECTRIC VEHICLE ADOPTION FORECASTS

2.2.2. Drivers of Rapid Penetration of Electric Vehicles

The rapid penetration of electric vehicles is being driven by both the decarbonisation policies of many jurisdictions across the globe and changing consumer value and behaviour patterns with respect to personal vehicle choices.

Penetration of Electric Vehicles and Government Policy

For many governments around the world that have a significant decarbonisation policy platform, the replacement of ICE vehicles with electric vehicles is a common policy objective that is frequently supported by incentives. Table 5[6] below summarises the electric vehicle adoption policy targets of a sample of countries (details of some specific policies are discussed in detail in Section 6).

[1] Ledoux-Pedailes, V (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment,* IHS Markit, Houston

[2] Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

[3] Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

[4] *Lithium 101,* Hocking, M et al, Deutsche Bank, published 9 May 2016

[5] *Lithium 101,* Hocking, M et al, Deutsche Bank, published 9 May 2016

[6] Leyland, A. (2018), 'Will we have enough lithium in 2025', Benchmark Mineral Intelligence AND Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

Country	Policy Target
Canada	30 percent penetration of electric vehicle sales by 2030
California	Nominal state level targets for size of EV fleet
Mexico	Target of 30 percent penetration of electric vehicle sales by 2030
Brazil	Target of 30 percent penetration of electric vehicle sales by 2030
United Kingdom	Proposal to end ICE vehicle sales by 2040
France	Proposal to end ICE vehicle sales by 2040
Italy	Target of 30 percent penetration of electric vehicle sales by 2030
Netherlands	Ban on all fossil fuel passenger car sales by 2025
Norway	Proposal to end ICE vehicle sales by 2025 Changes to tax and incentives to achieve only zero-emission vehicle sales by 2025
Germany	Proposal to end ICE vehicle sales by 2030 Changes to tax and incentives to achieve only zero-emission vehicle sales by 2030
India	Proposal to end ICE vehicle sales by 2030
Japan	Target of 30 percent penetration of electric vehicle sales by 2030
PRC	Target of 5 percent penetration of electric vehicle sales by 2020 and 20 percent by 2025. Existing subsidies will only apply to EVs with a range of greater than 150 kilometres, and vehicles with a range greater than 400 kilometres will receive additional subsidies.

TABLE 5 – ELECTRICAL VEHICLE ADOPTION POLICY TARGETS OF SELECTED JURISDICTIONS

Penetration of Electric Vehicles and Consumer Values and Behaviour

Electric vehicles are no longer only sought after by enthusiastic environmentalists and technology buffs. They are rapidly becoming a mainstream consumer product that is sought by a wider range of consumers seeking different price points, performance, styling and luxury vehicle attributes.

The rapid evolution of electric vehicles into the mainstream market can be illustrated firstly, by patterns in demand for high-end electric vehicles such as those manufactured by Tesla. As illustrated in Figure 2[7] below, customer pre-orders in the first 24 hours of Tesla model release grew from 300 in 2009 to 180,000 in 2016.

[7] Adapted from: Benchmark Minerals (2016), The Lithium Ion Supply Chain Reviewed, September Issue

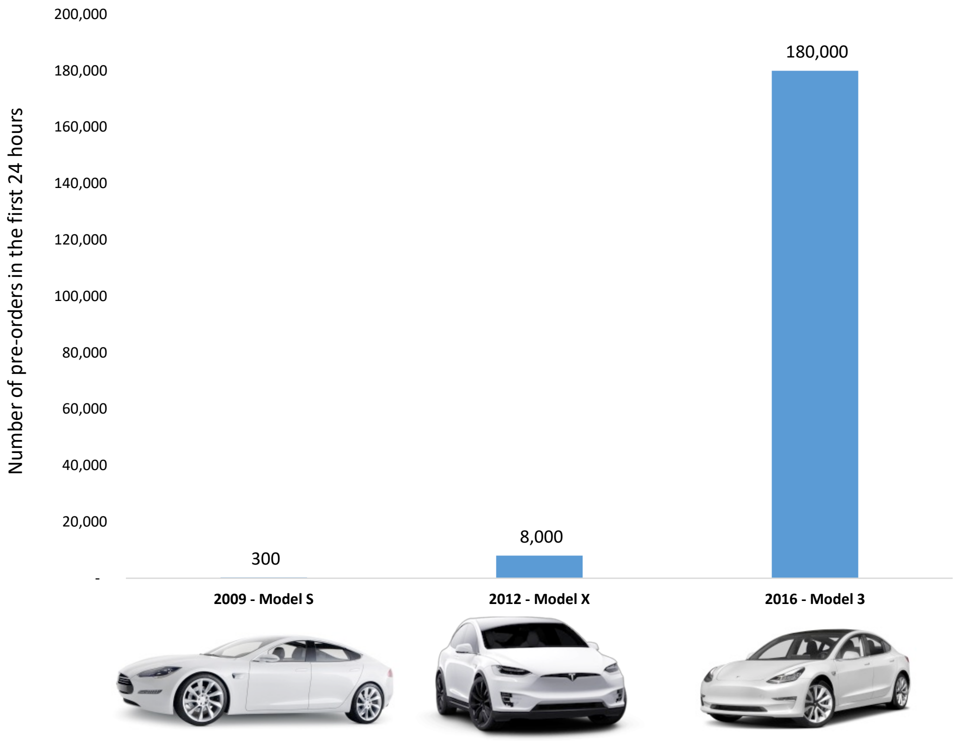

Figure 2 – Number of Customer Pre-orders for Tesla Models in the first 24 Hours of their Release

Secondly, and arguably more compelling evidence of the mainstream market penetration of electric vehicles, is the product development plans of major automobile manufacturers. As summarised in Table 6[8] below, most of the world's major automotive Original Equipment Manufacturers (OEMs) are planning to roll-out significant and diverse electric vehicle product lines over the coming decade.

[8] Ledoux-Pedailes, V. (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment,* IHS Markit, Houston AND Orocobre AND Leyland, A. (2018), 'Will we have enough lithium in 2025', Benchmark Mineral Intelligence

OEM	Electric Vehicle Product Development Plans
BMW	EVs to comprise 15 to 25 percent of total vehicle sales by 2025 12 pure EVs by 2025 25 electrified models, including 12 pure EVs by 2025
Mercedes	Electrification of entire portfolio by 2022 – 50 electric and hybrid models EVs to be 15 to 25 percent of total vehicle sales by 2025
Daimler	10 pure EVs by 2022
Volvo	All vehicles to be electric or hybrid by 2019 5 new pure electric vehicles by 2021
Volkswagen	30 new EV models to market by 2030
Honda	Target of 60 percent of vehicle sales by 2030 will be EV
BYD	All PRC sales to be EV by 2030
GM	At least 20 new EV models by 2023 1 million EV sales by 2025
Toyota	Over 10 EV and HEV models by the early 2020s Every Toyota and Lexus model to be electrified or have an electrified option by 2025 EV and HEV to comprise 50 percent of sales by 2030 (5.5 million vehicles with some form of electrification including 1 million pure EV)
Ford	Investing US$11 billion on EV development through to 2022 top create 40 EV models, including 16 pure EV models. 10 to 25 percent of total Ford sales by 2020
Renault Nissan Mitsubishi	Launching 12 EV models by 2022
Hyundai Kia Motors	Aiming to develop 8 EV models by 2025 and 30 by 2030
PSA	Aims to develop at least 40 EVs by 2025
PRC	JAC, Chery, SAIC, Great Wall, FAW, Geely, Dong Feng etc are all expected to comply with 20% EV penetration rate determination by 2025

Table 6 – Electric Vehicle Product Development Plans for Major Automotive Original Equipment Manufacturers

It is highly unlikely that the product development plans summarised in Table 6 above are exclusively a response to the policy targets and initiatives summarised in Table 5 (basing business strategy entirely on government policy usually results in sub-optimal outcomes). While policy has undoubtedly played a role, it is more likely that this aggressive investment in electric vehicle development by the automotive industry is a response to more fundamental market drivers, including:

- **Clear Consumer Behaviour Trends**
  As discussed above, electric vehicles are rapidly penetrating mainstream markets.

- **Rapid reduction in the Main Product Attribute Barriers to Adoption of Electric Vehicles**
  Market research indicates that the main reservation that consumers have with respect to electric vehicles is range anxiety, or the fear of the battery running out mid-journey or not being adequately charged for a planned journey. There is now an increasing number of new electric vehicle models on the market that have ranges of greater than 500 kilometres, and charge rates that can result in a full charge within 10 minutes. Furthermore, in many jurisdictions, there has been a rapid roll-out of charging infrastructure. For example, currently in the United States there are 115,000 petrol stations versus 17,000 electric vehicle charging stations.[9] Given that for most electric vehicle owners the primary charging point is the home garage, this represents significant public infrastructure.

- **Imminent ICE and Electric Vehicle Price Parity**
  The median price (pre-tax) for an ICE passenger vehicle is currently approximately US$30,000, whereas the median price of an electric passenger vehicle is US$40,000, with the battery accounting for approximately 40 percent of the value of the average electric vehicle. Current trends in the manufacture of lithium-ion batteries suggest that by around 2024 electric vehicles will become competitive on an unsubsidised basis, and achieve price parity with ICE vehicles by 2029.[10] This closing price differential is rendering electric vehicles an affordable choice for an increasingly larger sector of the market that would previously not consider electric vehicles as an option.

2.2.3. Disruption to the Automotive Industry Supply Chain

While not a focus of this study, it is worth noting the disruption to the ICE vehicle supply chain that is starting to take place. Electric vehicle manufacturers require reliable supplies of a range of new components for electric power trains other than cells and battery packs. This includes connectors, cables, controllers, converters and chargers, novel system integration, innovative thermal management solutions and new light materials for the chassis and vehicle body.

An adjustment in the vehicle manufacture supply chain is currently underway whereby electric vehicle manufacturers seek reliable and competitive sources for such components, and existing Tier 1 and Tier 2 automotive parts manufacturers seek to diversify into the electric vehicle supply chain. Traditional vehicle component suppliers include a large number of global companies such as Continental, Bosch, Denso, Magna, Hyundai Mobis, Johnson Controls, Aisin Seiki, Faurecia, TWR, Toyota Boshoku, Thyssen Krupp, Mahle, Sumitomo, Valeo, BASF, Delphi, Cummins and Shaeffler. How this disruption will impact many of these companies is currently unclear.

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[9] Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

[10] Bloombery New Energy Finance (2018), *Electric Vehicle Outlook 2018*, published Bloomberg NEF

2.3. Megatrend 2: Energy Storage Systems

Lithium-ion batteries are also used in Energy Storage Systems (ESS), which as the name suggests, are systems that story electricity for subsequent use. ESSs have application for both electricity grid operators and customers, and there are three primary stationary energy storage market segments – utility scale, behind-the-metre and remote ESS. These are discussed in the following subsections.

2.3.1. Utility Scale Energy Storage Systems

Utility scale ESS are battery systems installed on electricity transmission or distribution networks providing services to grid operators. The demand for utility scale ESS is derived from demand for increased renewable energy generation in the municipal electricity generation portfolio, whereby ESS facilitates smoothing of the variable output from the rapid ramping up and down of particularly solar and wind generation resources, and expands the scope for despatchability from renewable resources.

Table 7[11] below summarises the typical applications of utility scale ESS, together with critical capability requirements. It is important to note that in the case of utility-scale ESS, lithium-ion batteries are one of several potential energy storage technologies that can be used.

Application	Capacity Requirement	Classification	Discharge Cycles Per Annum
Peak pricing arbitrage	4 to 6 hours	Bulk storage	200 to 400
Generation capacity	2 to 6 hours	Bulk storage	200 to 600
Transmission and distribution asset capacity	2 to 4 hours	Bulk storage	200 to 600
Frequency regulation	1 to 15 minutes	Ancillary/power services	1,000 to 20,000
Volt/VAR support	1 to 15 minutes	Ancillary/power services	1,000 to 20,000
Renewable ramping/smoothing	1 to 15 minutes	Ancillary/power services	500 to 10,000

TABLE 7 – TYPICAL APPLICATIONS OF UTILITY SCALE ESS

As illustrated in Figure 3[12] below, the battery accounts for approximately 60 percent of the cost of an ESS.

[11] Eller, A., Gauntlett, D. (2017), 'Utility Scale Energy Storage Applications', *Energy Storage Trends and Opportunities in Emerging Markets,* International Finance Corporation and World Bank

[12] McLaren, J., Gagnon, P., Anderson, K., Elgqvist, E., Fu, R. and Remo, T. (2016), *Battery Energy Storage Market: Commercial Scale Lithium Ion Projects in the US*, National Renewable Energy Laboratory

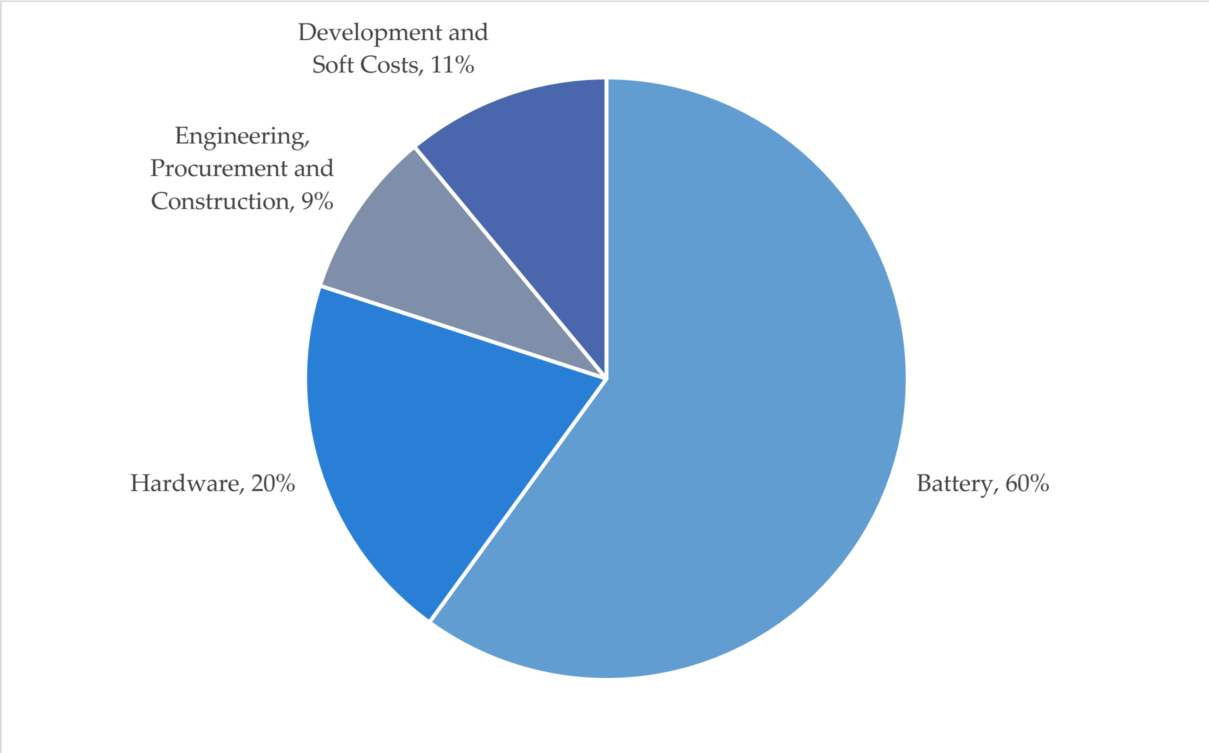

FIGURE 3 – APPROXIMATE COST STRUCTURE OF A UTILITY SCALE ENERGY STORAGE SYSTEM

There is a general trend toward municipal scale ESS projects becoming larger and being constructed more rapidly. For example, the recently commissioned 326MW Eliso Canyon ESS project in the United States was constructed in 8 months and the 129MW Hornsdale ESS project in South Australia was constructed in 3 months.

The three main drivers of demand for utility-scale ESS are:

- Increasingly aggressive jurisdictional decarbonisation policies that are characteristic of many of the world's electricity markets (i.e. ESS that facilitates optimal use of renewable generation);
- An increasing need to replace aging fossil fuel and nuclear electricity generation capacity and distribution infrastructure, which is creating opportunity for new renewable generation capital investment; and
- A recognised need by many electricity grid operators to improve the resilience of grids to natural disasters and extreme weather events.

2.3.2. Behind-the-Meter Energy Storage systems

Behind-the-metre (BTM) ESS are a major traditional ESS market. BTM ESSs are installed on the customer side of an electricity retailer or wholesaler meter, and are designed to reduce electricity costs and improve the resilience of electricity supply for commercial, industrial and residential electricity customers.

Demand for BTM ESS is derived from customer demand to reduce electricity costs and improve the resilience of electricity supply, as well as from electricity grid operators who promote the use of BTM ESS by their customers to reduce the load on the grid, thereby lowering network upgrade and infrastructure costs, and facilitate the optimal use of customer-side renewable generation.

From the customer's perspective BTM ESS provides three key benefits. They:

- Allow the customer to reduce overall dependency on the gird, reducing overall electricity costs;
- Allow the customer to reduce the amount of electricity drawn from the grid during periods of peak-demand, which in most electricity markets attract a higher pricing regime; and
- Where market mechanisms are in place, they allow excess customer-side renewable generation to be sold back into the grid.

BTM ESS can capture revenue from multiple value streams, including performing energy arbitrage, whereby ancillary services are sold to the grid, enabling participation in demand response programs, enabling distribution upgrades to be deferred and reducing demand charges or 'peak shaving'. They can also increase the energy resiliency of a site. Table 8[13] below summarises the main factors driving adoption of BTM ESS.

Market Drivers	Customer Applications	Description/Benefit
Rising electricity rates, increasing electric vehicle use and increasing energy management systems use	Demand charge reduction	Respond automatically to building load spikes – reduced electricity expenses
	Time-of-use energy bill management	Manage charging and discharging based on retail electricity rates (i.e. reduced electricity expense)
Increasing solar PV installations	Onsite generation self-consumption	Maximise consumption of onsite generation (primarily solar PV) to reduce electricity expense.
Need for resilience and power quality	Backup power and improved power quality	Protect sensitive equipment from power quality fluctuations and outages and ensure operability during grid outage
Grid stability concerns and capacity needs	Ancillary services	Provide frequency regulation, voltage support, electric supply reserve capacity and improve efficiency of centralised generation and smoother integration of variable generation
	Demand response	Manage charging and discharging based on retail electricity rates (i.e. reduced electricity expense)
New utility infrastructure needs	Transmission and distribution investment deferral	Limit investments in new infrastructure through reduced peak demand

TABLE 8 – MARKET DRIVERS FOR BEHIND-THE-METER ESS

Battery systems design and dispatch strategies differ depending on the use-case and the value streams that are being sought. While the kilowatt hour (kWh) dispatched may be the same in the cost of two different battery projects (or even by the same project at different times), the monetary value ($/kWh) gained from that dispatch may be very different. Depending on the market structure in a particular location, commercial scale (and in some

[13] Eller, A., Gauntlett, D. (2017), 'Behind-the-Meter Energy Storage Applications', *Energy Storage Trends and Opportunities in Emerging Markets,* International Finance Corporation and World Bank

cases residential scale) behind the metre battery projects may tap into one or more of the value streams listed in Table 9[14] below.

Value Stream	Reason for Dispatch	Value
Demand charge reduction	Reduce on-site load to shave peaks in usage	Lower retail electricity bill via lower demand charge
Time-of-use/energy arbitrage	Battery dispatched to meet on-site load during times of day when retail energy prices are high	Lower retail electricity bill via lower energy charge
Capacity/demand response	Dispatch power to grid in response to events defined by the utility or independent systems operator	Payment for capacity service
Frequency regulation	Battery injects/absorbs power to follow regulation signal	Payment for regulation services
Energy sales arbitrage	Dispatch power to grid during times that locational marginal prices are high	LMP price for energy
Resiliency	Battery dispatched to provide power to critical facilities during outages	Avoided cost of interruption

TABLE 9 – BATTERY USE-CASES AND VALUE STREAMS

It is important to emphasise that in addition to aligning with jurisdictional decarbonisation policy by encouraging increased adoption of customer-side renewable generation capacity, from an electricity supplier's perspective the main driver for promoting the use of ESS BTM to customers is to reduce demand on the grid during peak periods. This defers the need for additional generation, network upgrade and new infrastructure investment, and decreases the need for relatively expensive gas-fired fast response 'ramp-up' generators to meet peak demand.

2.3.3. Remote Power Systems

Remote power systems are stand-alone electricity generation systems that provide electricity to communities, townships and commercial operations that are not connected to the grid. In most instances, in order to provide dispatchability, they are based on fossil fuel generation capacity, typically diesel and/or natural gas, and are increasingly integrated with renewable capacity, typically in the form of wind or solar generation.

Remote power system ESS are used to optimise the use of the renewable generation capacity, or where climatic conditions and market requirements permit, to support dispatchability and load management for systems that use renewable generation exclusively.

[14] McLaren, J., Gagnon, P., Anderson, K., Elgqvist, E., Fu, R. and Remo, T. (2016), Battery Energy Storage Market: Commercial Scale Lithium Ion Projects in the US, National Renewable Energy Laboratory

2.3.4. ESS – market penetration and global developments

Not surprisingly, commercial scale lithium-ion battery ESS projects are typically located in areas characterised by higher commercial and industrial utility demand charges. By way of example, Figure 4 below compares the location of all commercial scale lithium-ion battery ESS projects listed on the United States Department of Energy's Energy Storage Database as at September 2016[15] with United States commercial and industrial utility demand charges in 2015[16].

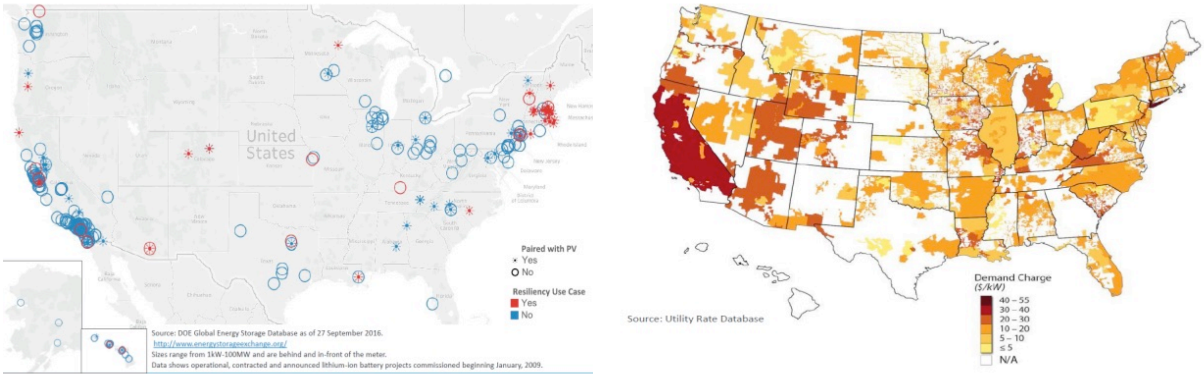

FIGURE 4 – UNITED STATES COMMERCIAL SCALE LITHIUM-ION ESS AND COMMERCIAL AND INDUSTRIAL UTILITY DEMAND CHARGES

The market for stationary ESS is estimated to grow to US$7 billion by 2022. [17] It is expected that the vast majority of this growth will be driven by demand from the Western Europe and Asia Pacific Regions. In the Asia Pacific Region, demand will be driven primarily by a need to provide grid support and reliability in areas where there are no or few sunk costs associated with legacy generation and distribution systems. Whereas demand in Western Europe will be driven primarily by the need to be able to provide dispatchability from increasing retrofit of renewable sources to existing distribution infrastructure.

The most rapid growth in demand for ESS is expected in less developed and regional markets world-wide, which are primarily concentrated in East Asia and the Pacific Region. This is illustrated in Figure 5[18] below.

[15] McLaren, J., Gagnon, P., Anderson, K., Elgqvist, E., Fu, R. and Remo, T. (2016), Battery Energy Storage Market: Commercial Scale Lithium Ion Projects in the US, National Renewable Energy Laboratory

[16] McLaren, J., Gagnon, P., Anderson, K., Elgqvist, E., Fu, R. and Remo, T. (2016), Battery Energy Storage Market: Commercial Scale Lithium Ion Projects in the US, National Renewable Energy Laboratory

[17] *The Lithium Ion Battery Market*, Jaffe, S, presented 28 January 2014, ARPA-E RANGE Conference, USA, published United States Advanced Research Projects Agency

[18] Eller, A., Gauntlett, D. (2017), 'Predicted Annual Stationary ESS', *Energy Storage Trends and Opportunities in Emerging Markets,* International Finance Corporation and World Bank

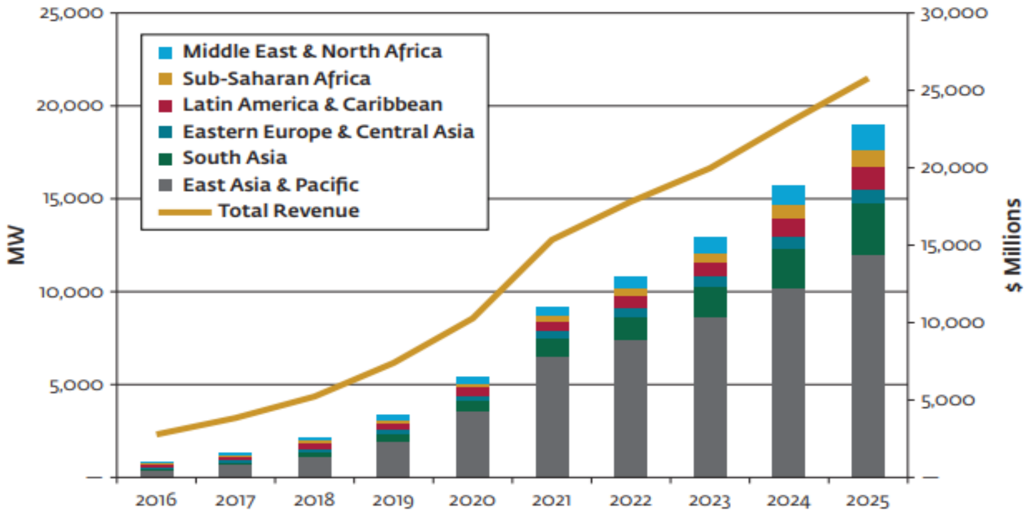

FIGURE 5 – REGIONAL GROWTH IN ESS (2021 TO 2022)

Global manufactures of ESS include some of the world's largest electronics and systems OEMs, domiciled primarily in Northern America, East Asia and Europe, with globally distributed supply chains. The main ESS OEMS are summarised in Table 10 below.

Company	Country	Market Capitalisation – US$ (2018)	Revenue – US$ (2017)
AES	United States	$9.1B	$11.0B
BYD Co	PRC	$18.8B	$20.4B
Duke Energy	United States	$56.5B	$23.5B
EDF SA	France	$54.10B (84.5% state-owned)	$15.8B
Enel	Italy	$53.1B	$86.1B
Exergonix Inc	United States	Unlisted	No reliable estimate
First Solar	United States	$5.3B	$2.9B
GE	United States	$100.1B	$122.1B
LG Chem	South Korea	$22.3B	$22.6B
Saft Groupe	France	$1.0B	$0.9B
Samsung	South Korea	$299.0B	$223.4B
Siemens	Germany	$110.4B	$4.6B
Sonnen-Batterie	France	$35.0M	$75.0B
Stem Inc	United States	Unlisted	$30-40M (est)
Tesla	United States	$51.2B	$11.8B
Vestas Wind Systems	Denmark	$13.76B	$11.5B

TABLE 10 – MAJOR GLOBAL MANUFACTURERS OF ESS BATTERY SYSTEMS

2.4. Megatrend 3: Personal and Portable Electronic Devices

Historically, the primary market for lithium-ion batteries has been consumer electronics and portable devices. In contrast to the larger and heavier lead-acid batteries that they replaced, lithium-ion batteries accelerated miniaturisation, by facilitating the design and commercial manufacture of progressively smaller, lighter and more powerful personal and portable electronic devices.

The rapid adoption of lithium-ion battery technology by personal and portable electronic device OEMs, combined with rapid escalation in demand for a wide range of personal and portable electronics in the decade that followed the commercialisation of the lithium-ion battery, led to a major increase in lithium-ion battery manufacturing capacity.

Personal and portable electronic devices accounted for the vast majority of demand for lithium-ion batteries up to 2014, and it is only since then that electric vehicle and ESS have collectively grown to account for slightly over 50 percent of lithium ion battery demand.[19] Indeed, since 2013, demand for lithium-ion batteries for personal and portable electronic devices has plateaued at approximately 30 gigawatt hours (GWh) per annum. This combined with increased competition, improvements in manufacturing processes and the removal of some constraints on raw materials, means the plateauing demand in GWh terms also resulted in a decline in total market value of the sector.[20]

With no other major process-mature competing battery chemistry predicted to reach their cost efficiency in the near future, the portable devices sector is likely to remain reliant upon lithium-ion battery technology over the short to medium term. Even though demand for personal and portable electronic devices is expected to continue to grow from a total of 8 billion devices in 2016 to approximately 11 billion in 2021[21] , as a result of growth in other sectors, the portion of total demand for lithium-ion batteries that is derived from personal and portable electronic devices is expected to decline.[22] Historical data, and predictions made in 2016 for derived lithium metal demand, are noted in the following Table 11[23], however consultation with industry experts during the preparation of this report suggests that recent growth trends place battery uptake at higher levels still.

Source of Demand	2015 (% of total demand)	2018 (Est. % of total demand)	2025 (% of total demand)
Non-battery demand	60	58	30
Traditional battery markets	25	21	12
Electric vehicles	14	18	38
E-bikes	1	2	14
Energy Storage	0	1	6

TABLE 11 – LITHIUM DEMAND BY APPLICATION

At face value this inverse relationship of plateauing battery demand paired with increased battery powered device sales may seem incongruous. It is explained, however, by the changing nature of powered devices. With every hardware refresh, designers and manufacturers aim to reduce power consumption for a given performance threshold, resulting in devices that either last longer, run faster, or both. As battery pack size is a major, if not the principal determinant of overall device size, manufacturers seeking to further miniaturise their product are also incentivised to reduce power requirements. This, paired with the economic

[19] *Main applications*, in *Lithium ion battery raw material supply and demand 2016-2025*, Pillot, C, Avicenne Energy, presented Advanced Automotive Battery Conference, 30 January 2017
[20] *Main applications*, in *Lithium ion battery raw material supply and demand 2016-2025*, Pillot, C, Avicenne Energy, presented Advanced Automotive Battery Conference, 30 January 2017
[21] Adapted from *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021 White Paper*, published Cisco Networking, 28 March 2017
[22] *Market Outlook – lithium,* published MetalsTech, July 2016
[23] *Market Outlook – lithium,* published MetalsTech, July 2016; Ledoux-Pedailes (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment,* IHS Markit, Houston

incentive to lower total input costs, results in a range of selection pressures keeping total battery demand relatively stable.[24]

Table 12 below lists some of the world's major consumer and portable electronic device OEMs, indicating the enormous scale of the sector.

Company	Country	Market Capitalisation – US$ (2018)	Revenue – US$ (2018)
PERSONAL ELECTRONIC DEVICES			
Alphabet Inc (Google)	USA	$827.1B	$110.9B
Apple	United States	$1.1T	$229.2B
Huawei Technologies Co	PRC	Unlisted	$87.9B
Panasonic	Japan	$29.6B	$64.2B
Samsung	South Korea	$299.0B	$223.4B
Sony	Japan	$73.7B	$71.9B
Xiaomi	PRC	$47.5B	$16.7B
POWER TOOLS			
Bosch	Germany	Unlisted	$90.0B
Fortive	USA	$29.9B	$6.7B
Hilti Corporation	Liechtenstein	Unlisted	$0.5B
Makita	Japan	$13.8B	$32.9B
Stanley Black & Decker	USA	$23.1B	$12.7B
Techtronic Industries	PRC (Hong Kong)	$11.3B	$6.1B

TABLE 12 – MAJOR MANUFACTURERS OF PERSONAL AND PORTABLE ELECTRONIC DEVICES

2.5. Australia and the Megatrends

Supply chains are established for the fundamental purpose of producing a product that meets the attribute and value expectations of a market of end-user customers (see Section 5.1). While geographic proximity is not the sole determinant of key elements of a supply chain, the optimisation of logistics costs with respect to sourcing manufacturing inputs and servicing the end-user market is an important economic consideration. Therefore, understanding the Australian market with respect to these megatrends is an important aspect to understanding

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[24] *Consumer Electronics Market to hit $1,500bn by 2024*, Global Market Insights, published 29 January 2018; *Technology, Media and Telecommunication Predictions 2018*, Deloitte Access Economics, published January 2018; *The Lithium Ion Battery Market*, Jaffe, S, presented 28 January 2014, ARPA-E RANGE Conference, USA, published United States Advanced Research Projects Agency

Western Australia's competitiveness in the global lithium-ion battery supply chain that services these megatrends.

Generally speaking, with respect to the three megatrends discussed in the previous sections, Australia is a relatively small market. This is discussed in the following subsections.

2.5.1. Australia and the Electric Vehicle Market

Australia is currently not a large market for electric vehicles. For example, of the 1.1 million pure electric, hybrid and plug-in hybrid electric vehicles sold globally in 2015, only 1,100 were sold in Australia, representing 0.1 percent of the global market.[25]

A number of factors contribute to the low level of market penetration of electric vehicles in Australia:

- Even-though Australia has a high per capita rate of motor vehicle ownership, Australia's relatively small population means that total vehicle demand in Australia is comparatively small;
- Absence of domestic policy in Australia that motivates or incentivises adoption of electric vehicles;
- Relatively limited breadth of options with respect to electric vehicles readily available through domestic automotive OEM distributors (Appendix 2 provides a list of electric vehicle models available in Australia in 2016); and
- Exacerbated consumer range anxiety that is a function of relatively large segments of the domestic market that have long range driving requirements and limited public use charging infrastructure.

Nevertheless, as is the case for the rest of the world, penetration of electric vehicles is expected to increase in Australia. As adoption of electric vehicles increases in Australia, grid operators will be required to give consideration to how best to manage the additional load that results from charging demand. Table 13[26] below summarises the basic power requirements for batteries with different ranges.

Range	Charging Requirements
200 kilometres plus	30 to 40 kW
350 to 470 kilometres	50 to 65 kW
400 to 500 kilometres	75 to 100 kW
Ultra-fast chargers	350 kW

TABLE 13 – ELECTRIC VEHICLE CHARGING REQUIREMENTS

Most people will seek to charge their vehicles in the evening during periods that are typically characterised by peak load, such as early evenings when they return from work. Grid operators, governments and private sector service providers will increasingly be required to give consideration to how best to roll-out ex-home and work charging networks. As

[25] Federal Chamber of Automotive Industries IN: Lewis, H (2016), *Lithium-ion Battery Consultation Report*, Department of the Environment

[26] Kane, M. (2018), 'Charging infrastructure planning for electric vehicles', *Economic Development Queensland*, Queensland Government

summarised in Table 14[27] below, charging infrastructure has to accommodate a range of charging and location needs.

Charging location	Fast to slow charge	What?	Where?	Enabling
Inter-regional	Dedicated fast or ultra-fast chargers	50kW+ DC fast chargers	Convenient locations	Long distance travel
Destination	Mix of fast to slow chargers	Destination AC chargers	Variety of destinations	Widespread charging and EV tourism
Workplace	Mix of slow to fast chargers	Basic AC chargers	Park-n-rides and workplaces	Commuting and fleets
Home	Basic AC chargers and occasional use charging			

Table 14 – Electric Vehicle Charging Infrastructure Categories and Needs

Regardless of future trends in Australian consumer behaviour and electric vehicle infrastructure, Australia's relatively small population and geographical isolation will render it a relatively small market for electric vehicles for the foreseeable future.

2.5.2. Australia and the Energy Storage Systems Market

Australian municipal grids will see an increasing reliance on ESS to support increased deployment of renewable generation capacity by utilities and on the client side. Australia also has an atypical number of remote generation systems supporting regional and remote townships, communities, agricultural and industry enterprise that for emission reduction and cost reasons, will become increasingly reliant on ESS. By way of example, the following Figure 6[28] illustrates growth in rooftop solar PV in Australia and related growth in storage capacity.

[27] Kane, M. (2018), 'Charging infrastructure planning for electric vehicles', *Economic Development Queensland*, Queensland Government

[28] *Operational and Market Challenges to Reliability and Security in the NEM* (2018), published Australian Energy Market Operator, March 2018

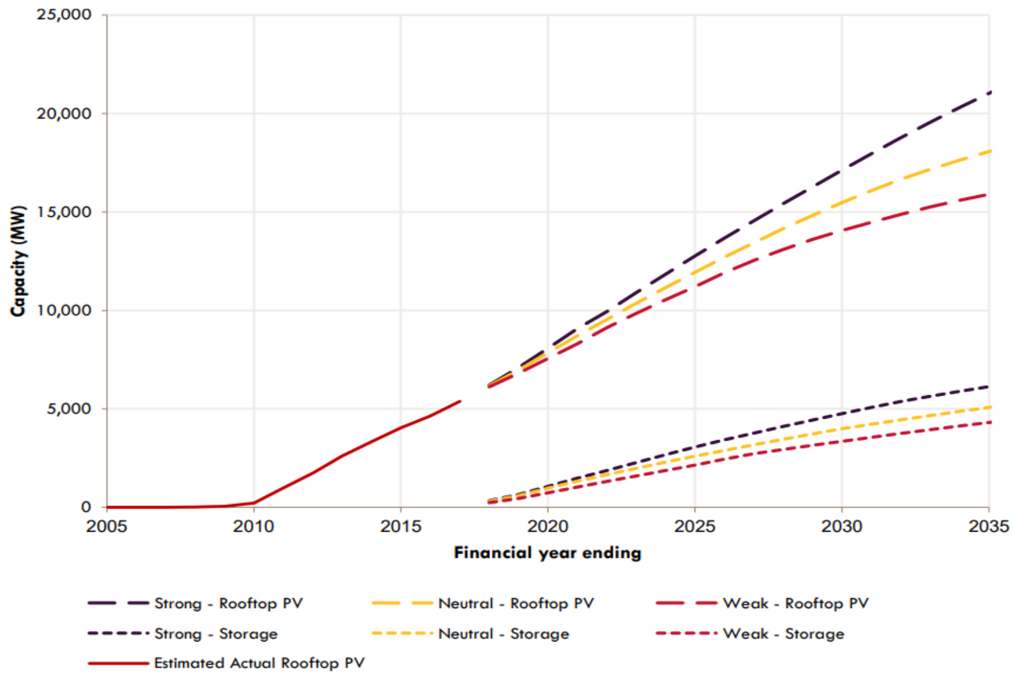

FIGURE 6 – ESTIMATED GROWTH IN ROOFTOP SOLAR PV AND STORAGE CAPACITY IN AUSTRALIA

However, compared to the large electricity generation and distribution systems of Europe, Asia and North America, the Australian market is relatively small. As shown in Figure 7[29] below, as of 2017, analysis commissioned by the Australian Energy Market Operator (AEMO) predicted total installed battery storage capacity of non-utility scale systems in the Australian market to track at approximately 6GWh by 2025, significantly below other jurisdictions.

[29] *Projections of uptake of small-scale systems*, Gerardi, W, O'Connor, D, published Australian Energy Market Operator, 9 June 2017

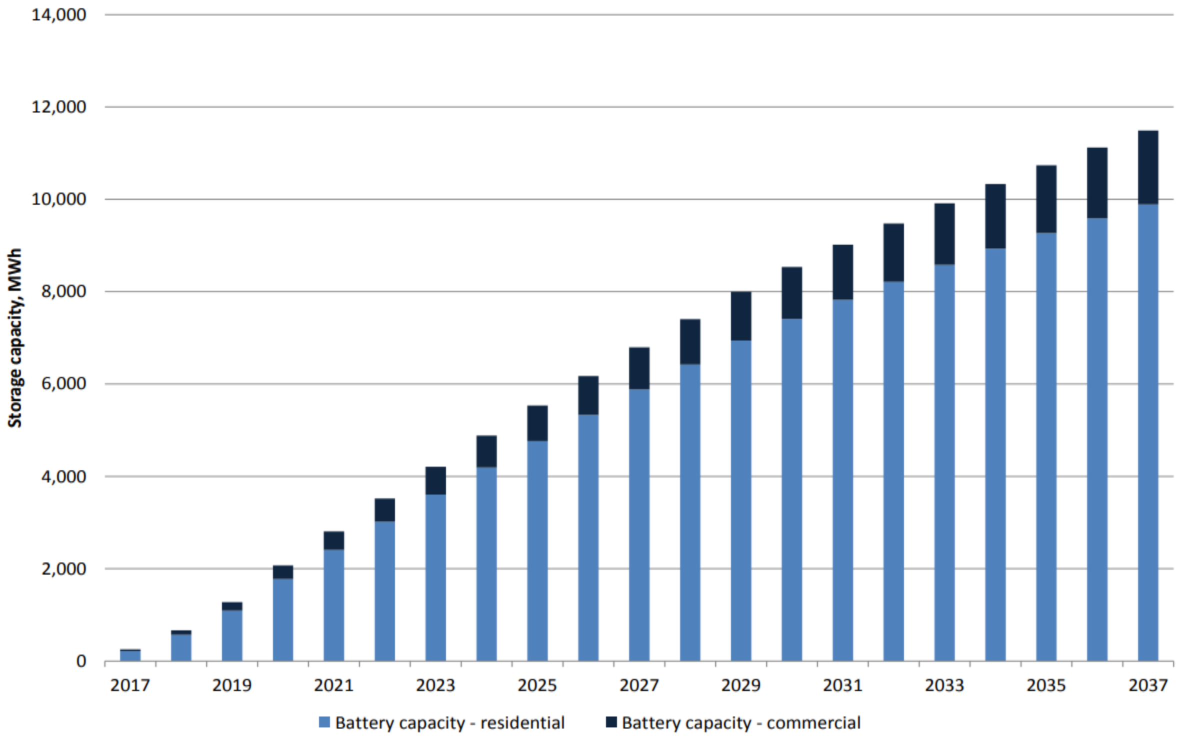

FIGURE 7 – ESTIMATED TOTAL INSTALLED CAPACITY OF SMALL SCALE BTM BATTERIES IN AUSTRALIA

Given the significant policy and regulatory uncertainty surrounding electricity provision in Australia, however, there is a high degree of uncertainty surrounding projections for future use in Australia. In particular, lower retail electricity prices will result in a less favourable payback period for non-utility scale end users contemplating the installation of battery storage systems. As such, the increasing adoption of grid-scale battery installations will result in lower growth and demand for BTM ESS systems.

This is illustrated in the August 2018 revision of AEMO predictions, shown in Figure 8[30] below, which decreases BTM predictions to less than half previous assumptions, predicated on lower dispatchable power prices from renewable installations backed by grid-scale storage systems.

[30] *Electricity Statement of Opportunities* (2018), published Australian Energy Market Operator, August 2018

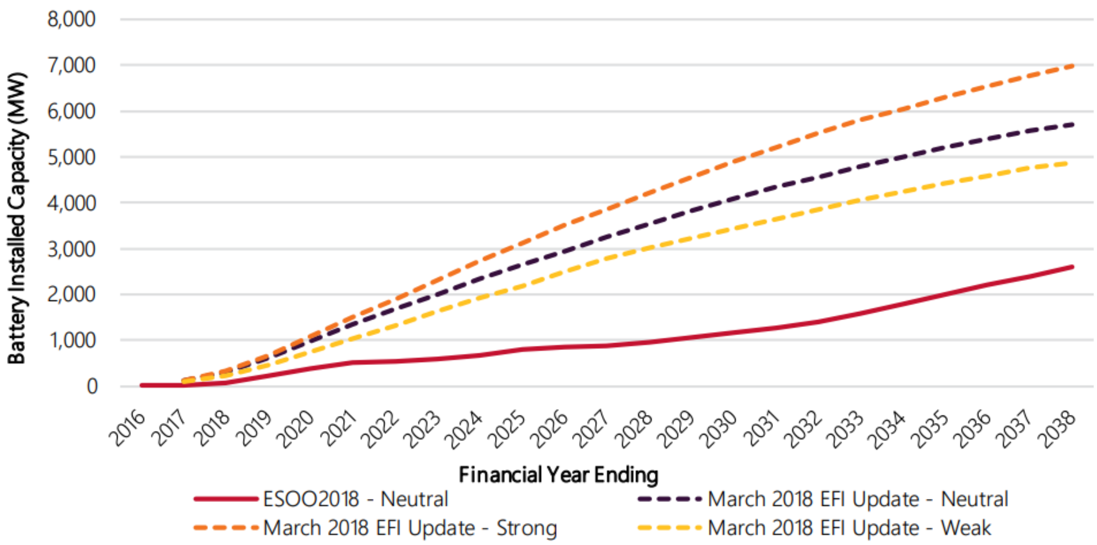

FIGURE 8 – TOTAL INSTALLED CAPACITY SMALL SCALE BTM BATTERIES IN AUSTRALIA

Given the recent announcement that the Commonwealth Government will not proceed with the proposed National Energy Guarantee, it is not clear what the future policy, business and investment climate will be for ESS in Australia, and hence it is difficult to make future predictions as to the impact of Australian ESS demand on the battery industry.

2.5.3. Australia and the Portable and Personal Electronic Device Market

Australians are enthusiastic adopters of personal electronic devices, with a literate population and generally access to disposable income. Approximately 88 percent of Australians own a smartphone, above comparable jurisdictions like the United Kingdom, United States and Canada, with the vast majority of these devices new purchases and little second-hand resale market.[31]

Further data on Australian market demand and adoption of battery-powered portable electronic devices is generally difficult to find. However in 2010 consumption was estimated at approximately 350 million batteries annually, of which 98% were less than 1kg in weight, and therefore intended for portable electronic devices.[32] Given the industry developments since, this proportion is unlikely to still stand in either relative or absolute terms. However there is no evidence to suggest the consumption patterns of Australians have altered drastically since that time.

At the most basic level, with a population of 24 million people (50th largest national in the world), Australia is a relatively small consumer market for personal electronic devices such as mobile phones, tablets and portable personal computers, and is unlikely to have a significant impact or unique or novel relationship with global portable electronics-driven demand impact on battery industries.

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[31] *Device Landscape* in *Mobile Consumer Survey 2017*, published Deloitte Access Economics, 2017

[32] *Analysis of Battery Consumption, Recycling and Disposal in Australia* (2010), published Warnken ISE Consulting/Australian Battery Recycling Initiative, November 2010

3. Trends in Lithium-ion Battery Chemistries

This Section provides an overview of current status and trends in the key technology platforms that underpin the performance of lithium-ion batteries.

Sub-section 3.1 below compares lithium-ion battery technology to other rechargeable battery technologies, provides a brief history of the development of lithium-ion battery technology, describes the basic components and structure of a lithium-ion battery and discusses the various cathode chemistries on which currently available and soon to be commercialised lithium-ion batteries are based. The remaining sub-sections describe the current status and trends in technology that underpins the key components of a lithium-ion battery, namely cathode active material (section 3.2), anode active material (section 3.3), electrolytes (section 3.4), separators (section 3.5) and current collectors (section 3.6).

3.1. Lithium-ion Battery Technology: A Brief Overview

3.1.1. Lithium-ion and Other Rechargeable Battery Technologies

Battery Technologies Compared

Lithium-ion batteries are one of several rechargeable battery technologies that are currently commercially available. Other rechargeable battery technologies include nickel cadmium (NiCd), nickel metal hydride (NiMH), lead acid and lithium-ion polymer batteries. The following Table 15[33] summarises typical characteristics of the main alternative rechargeable battery technologies.

[33] Blomgren, G. (2017), 'The development and future of lithium ion batteries', *Journal of the Electrochemical Society,* Vol. 164, Issue 1

	NiCd	NiMH	Lead Acid	Reusable Alkaline	Lithium-ion	Lithium-ion Polymer
Used commercially since	1950	1990	1970	1992	**1991**	**1999**
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	80	**110-160**	**100-130**
Internal Resistance (mΩ)	100 to 200 (6V pack)	200 to 300 (6V pack)	<100 (12V pack)	200 to 2000 (6V pack)	**150 to 250 (7.2V pack)**	**200 to 300 (7.2V pack)**
Cycle Life	1500	300 to 500	200 to 300	50	**500 to 1000**	**300 to 500**
Fast Charge Time	1 hr	2-4hr	8-16hr	2-3hr	**2-4hr**	**2-4hr**
Overcharge Tolerance	Mod	Low	High	Mod	**Very Low**	**Low**
Self-discharge/Month	20%	30%	5%	0.3%	**10%**	**10%**
Cell voltage	1.25	1.25	2	1.5	**3.6**	**3.6**
Operating Temperature (°C)	-40-60	-20-60	-20-60	0-60	**-20-60**	**0-60**

TABLE 15 - CHARACTERISTICS OF THE MOST COMMONLY USED RECHARGEABLE BATTERY TECHNOLOGIES

Competitive Advantage of Lithium-ion Batteries

Primarily by virtue of their light weight and high energy density, lithium-ion batteries are the preferred technology for many products for which there are existing and rapidly growing global markets such as portable electronic devices, power and gardening tools, medical devices and electric vehicles (see Section 2). While weight and energy density are arguably less compelling features for stationary energy storage systems, the proliferation of lithium-ion battery manufacturing capacity combined with other beneficial characteristics such as charge rates is likely to result in them being a higher value solution for energy storage systems as well (see Section 2).

Indeed, for the following reasons[34], most analysts concur that lithium-ion batteries will remain the dominant rechargeable battery technology for the foreseeable future.

- **Product developer familiarity -** developers of rechargeable consumer and industrial products have almost 30 years of experience in working with lithium-ion batteries, meaning the technology is a relatively known quantity that presents limited product development risk.
- **Market familiarity -** similarly, because they have been used in a wide range of products over the past several decades, consumers are relatively comfortable with the performance and safety aspects of lithium-ion battery technology.

[34] Benchmark Minerals (2016), *The Lithium Ion Supply Chain Reviewed*, September Issue

- **Rapid rates of product improvement -** as a result of focused commercial research and development, the performance of lithium-ion batteries is continuously improving, with the energy density of lithium ion batteries increasing at an average of five percent per annum since commercialisation of the technology in the early 1990s.

- **Rapidly decreasing cost -** as a result of both research and development and economies of scale in production, the cost of lithium-ion batteries is continually decreasing, from approximately US$2,500 per kWh in the early 2000s to around US$180 per kWh today.

- **Switching costs –** there is 30 years of legacy lithium-ion battery manufacturing capacity in place, as well as significant contemporary roll-out of new capacity. 'Retooling' this supply chain to produce an alternative technology at scale represents significant economic cost.

- **Payback requirement from current investments –** the significant investment in manufacturing capacity along the lithium-ion battery supply chain that is currently taking place globally will require a significant payback period, adding to the economic cost of switching to the production of a new battery technology.

- **High risk associated with launching a competing technology platform -** in light of the entrenched position of lithium-ion battery technical development and commercialisation, promotion of a substantially different technology platform represents significant expense and risk, particularly if that alternative technology only offers incremental benefits over lithium-ion battery technology.

3.1.2. A Brief History of the Development of Lithium-ion Batteries

The potential benefits that can be derived from lithium's low atomic weight compared to other positive electrode material in battery chemistries seeking high specific energy and energy density characteristics has been understood by battery technology developers for a long time. However, lithium-ion battery chemistries only became a significant focus of the battery industry during the late 1980s and early 1990s, when several mobile phone OEMs were forced to recall products as a result of the propensity of the molybdenum disulphide and other battery chemistries used in early model mobile phones to combust.[35]

In 1991, Sony Corporation commercialised the first lithium-ion rechargeable battery.

3.1.3. Basic Structure of a Lithium-ion Battery

A lithium-ion battery is comprised of five main components:

- **Cathode (or positive electrode) -** typical comprised of a lithium metal oxide.
- **Anode (or negative electrode) -** typically comprised of a porous carbon based compound.
- **Electrolyte -** which is a mixture of lithium salt and an organic solvent.
- **Separator -** which is a permeable polymeric membrane placed between the battery's anode and cathode.
- **Binders -** which are a typically a solvent that binds the cathode materials.

35 Julien, C., Mauger, A. , Vijh, A. and Zaghib, K. (2015), *Lithium Batteries: Science and Technology,* Springer, New York.

During discharge, the ions flow from the anode to the cathode through the electrolyte and separator. Charging reverses the direction and the ions flow from the cathode to the anode. This is illustrated in Figure 9[36] below.

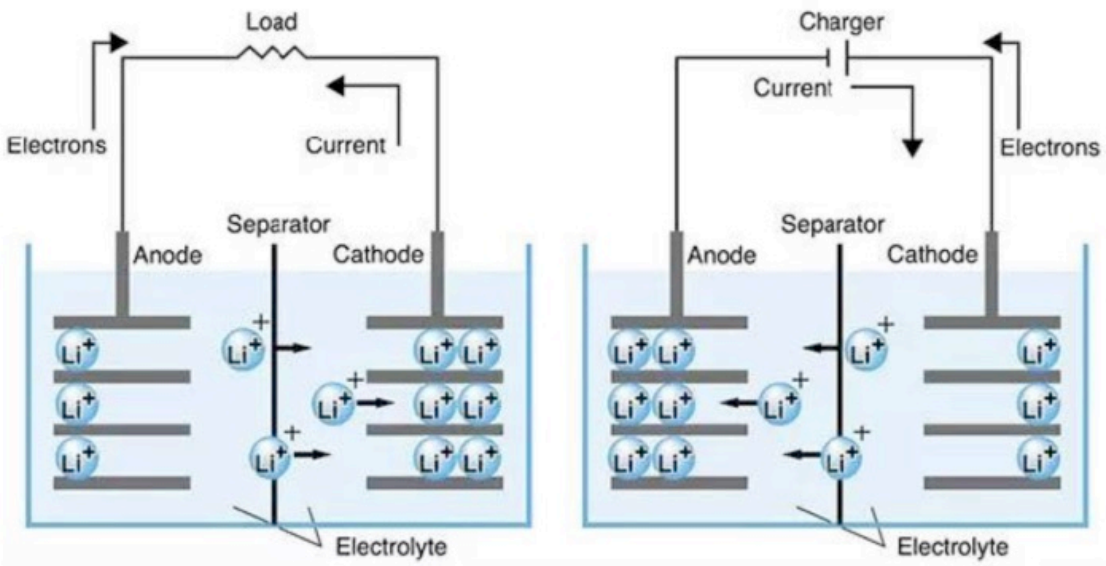

Figure 9 – Rechargeable Lithium Ion Battery Cell

3.1.4. Current and Emerging Lithium-ion Battery Chemistries

The various dimensions of performance of a lithium-ion battery are determined primarily by its cathode chemistry.

Since its market release in the early 1990s, several different lithium-ion battery cathode chemistries have been commercialised, including lithium-cobalt-oxide (LCO), lithium-manganese-oxide (LMO), nickel-cobalt-aluminium (NCA), lithium-ion-phosphate (LFP) and nickel-manganese-cobalt (NMC). Additionally, there are a number of emerging lithium-ion battery chemistries that are yet to be commercialised. The various existing and emerging lithium-ion battery chemistries, their characteristics, main applications and approximate market share are summarised in Table 16 below.

[36] Evanczuk, S. IN: CleanTeq (2016), *Lithium Ion Batteries Whitepaper*

Battery Chemistry	Formula	Characteristics	Product Applications	2016 demand (tpa)	2016 Market Share
		Current Lithium-ion Battery Chemistries			
LCO (lithium-cobalt-oxide)		High energy density but incurs longer charge time and shelf life of 1 to 3 years.	Mobile phones and laptop computers	41,000	39%
LMO (lithium-manganese-oxide)	LiMn2O4	Fast recharge and high current discharge, by 1/3 of LCO's energy density low cost as the result of the absence of cobalt	Power tools and medical instruments	20,000	19%
NCA (nickel-cobalt-aluminium)	NliNoCoAlO2	Extremely high energy density and long lifespace	Electric Vehicle, powertrains, energy storage	12,000	11%
LFP (lithium-iron-phosphate)	LiFePO4	Reasonable energy density, low power. Low raw material cost is offset by poor conductivity and high manufacturing cost	Electric Vehicle, powertrains and e-bikes	9,000	9%
NMC (nickel-manganese-cobalt)	LiNiMnCoO2	Can be tailored to high energy or power density.	Electric Vehicle, powertrain, power tools	23,000	22%
		Emerging Lithium-ion Battery Chemistries			
LTO (lithium titanate)	Li4Ti5O12		Power tools, e-bikes, electric vehicles, medical devices		
LiS (lithium sulphur)	LiS	Emerging technology			
Lithium Polymer		Polymer electrolyte	Soft pouch batteries		

TABLE 16 – CURRENT AND EMERGING LITHIUM-ION BATTERY CATHODE CHEMISTRIES

Generally speaking, the different lithium-ion battery chemistries summarised in Table 16 above have different product applications. LCO is the dominant lithium-ion battery chemistry for portable devices. This is unsurprising given its 'default' status as the most widely manufactured lithium-ion battery chemistry globally. Traditionally, electric vehicle manufacturers have favoured LFP and LMO lithium-ion battery chemistries. However, as a result of their higher energy density, increased lifecycle and ability to provide longer vehicle range, NCA and particularly NMC are increasingly becoming the industry standard for electric vehicles.

While it is likely that LCO chemistries will remain the mainstay of portable electronic devices, the growing preference for NCA and NMC battery chemistries in electric vehicle manufacture is likely to drive significant growth in demand for these chemistries. Demand for LFP chemistries will be very much dependent on future preferences of the People's Republic of China (PRC) electric vehicle manufacturers.[37] However, as discussed in Section 6, recent PRC policy incentives that are designed to encourage consumers to purchase domestically manufactured vehicles with higher intensity batteries, suggests that an increasing shift away from LFP battery chemistries may emerge in the PRC automotive manufacturing industry.

3.2. Status and Trends in Cathode Active Material

The performance of a lithium-ion battery in terms of attributes such as energy density, charge rate, lifecycle and safety are determined primarily by the chemical composition of its cathode, and are as such a constant focus of commercial research and development. The composition of the cathode also has a significant impact on the safety of the battery.

Stability in battery performance and safety is of paramount concern to battery OEMs, as product recalls of major consumer products or vehicles that can result from battery failure are typically very expensive exercises. Of particular concern is thermal runaway, a mechanism of chain reactions during which the decomposition reaction of the battery component materials occurs one after the other.[38] In lithium-ion batteries, thermal runaway can be caused by thermal, mechanical or electrical abuse, with the amount of energy released dependent on parameters such as cell chemistry, design, state of charge and ambient temperature. The quality of sulphates and precursor chemicals used in the manufacture of cathode active material is critical to controlling thermal runaway.

Cathode active material for lithium-ion batteries are comprised of the complex transition metal oxides and phosphates listed in Table 16 above. The following Figure 10[39] summarises demand forecasts for the main lithium-ion battery cathode active materials.

[37] Benchmark Minerals (2016), The Lithium Ion Supply Chain Reviewed, September Issue

[38] Feng, X., Ouyang, M., Liu, X., Lu, L., Xia, Y. and He, X. (2018), 'Thermal runaway mechanisms of lithium ion battery for electric vehicles: a review', *Energy Storage Materials,* January, pp.246-267

[39] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission; "Avicenne in Neometals: An Insider's View of the Lithium Industry"

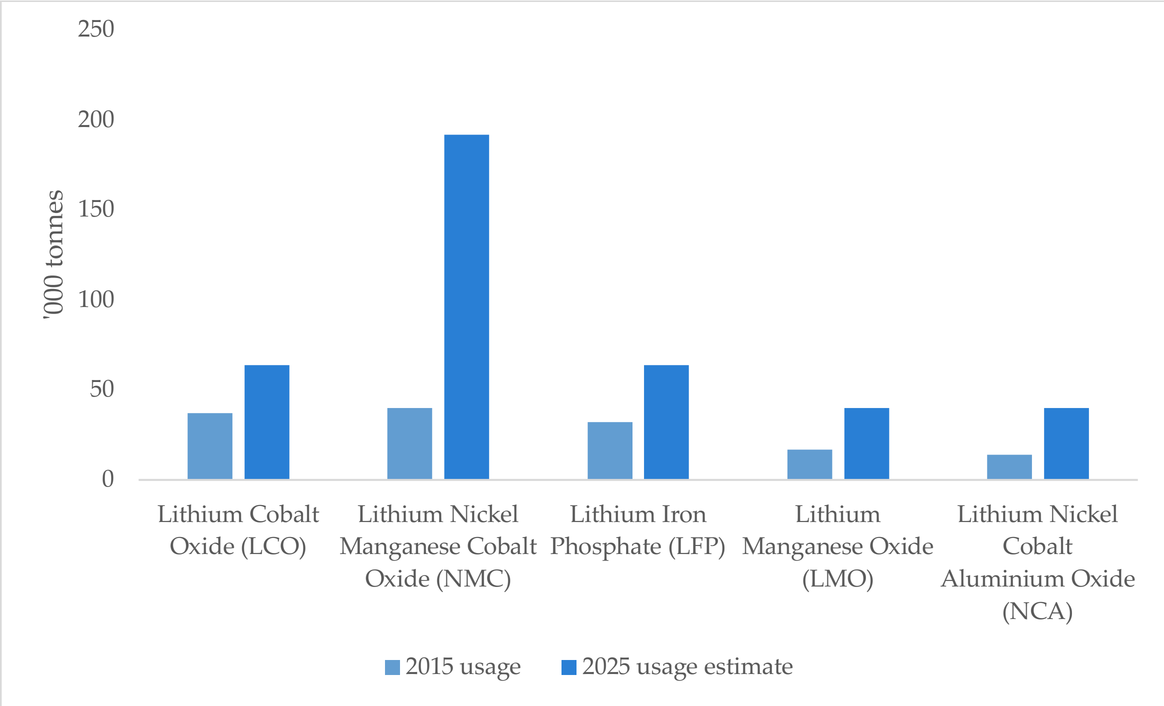

FIGURE 10 – DEMAND FORECASTS FOR LITHIUM-ION BATTERY CATHODE ACTIVE MATERIALS

The main metals that comprise the various lithium-ion battery cathode active materials are lithium, cobalt, nickel, manganese and iron. The approximate composition of these metals in each of the chemistries is illustrated in Figure 11 below.

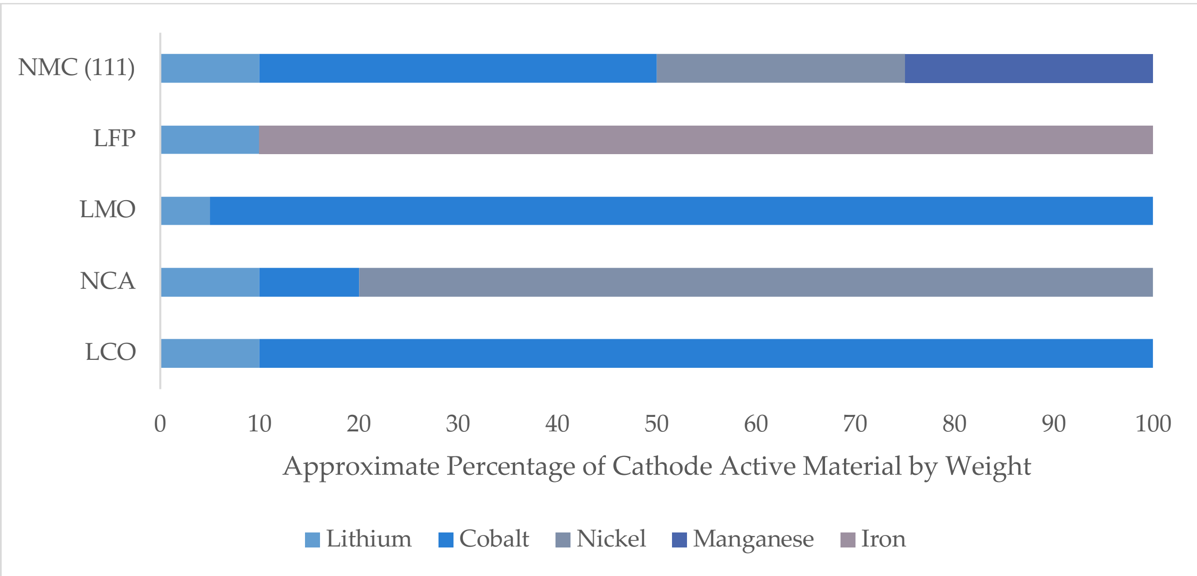

FIGURE 11 - APPROXIMATE METAL COMPOSITION OF LITHIUM-ION BATTERY CATHODE ACTIVE MATERIAL CHEMISTRIES

As a result of the emerging dominance of NMC cathode active material in the electric vehicle market, there is significant focus on optimising the performance of NMC chemistries and to substitute its cobalt composition for additional nickel (see Section 4.2).[40] In addition to the current NMC 111 chemistry, there are number of new NMC chemistries that are expected to

[40] RMC IN: Neometals (2018), An Insiders View of the Lithium Industry, Goldman Sachs

be commercialised progressively out to 2030.[41] The metal composition and expected commercialisation of emerging NMC battery chemistries is summarised in Figure 12 below. It is understood that additional chemistries under development are reducing cobalt content to as low as 2.5 to 4.0 percent, replacing it with nickel.

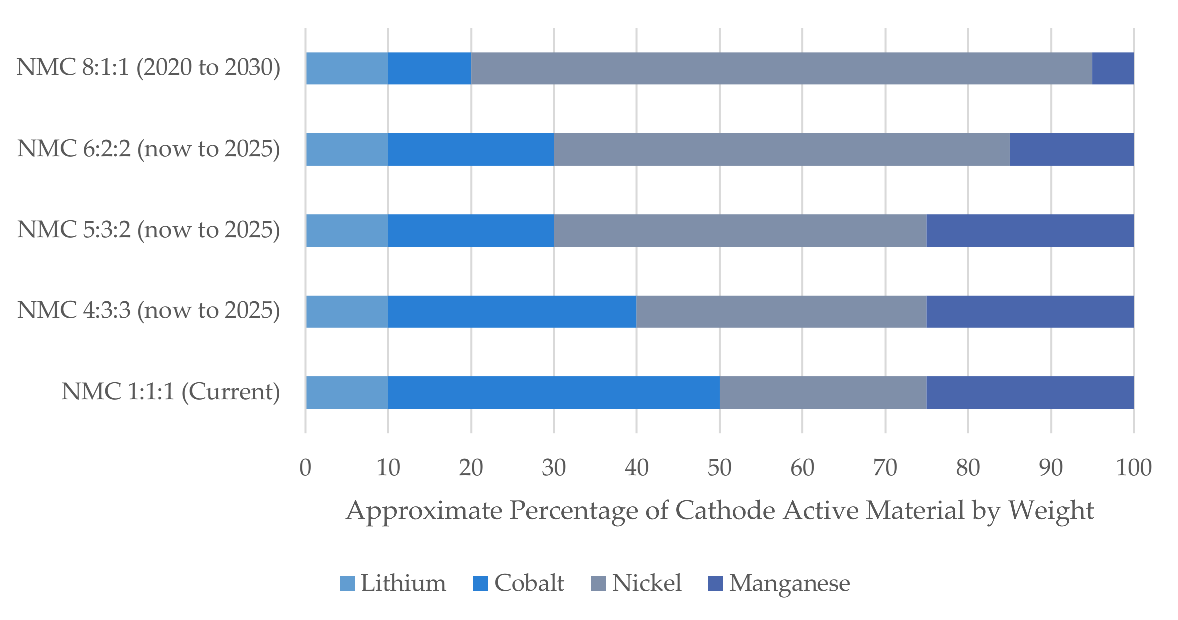

FIGURE 12 – METAL COMPOSITION OF EMERGING LITHIUM-ION BATTERY NMC CATHODE ACTIVE MATERIAL CHEMISTRIES

As a consequence of the mounting primacy of nickel-rich battery chemistries is a shift in lithium conversion (see Section 5.3.1). As a result of process requirements, nickel-rich cathodes require lithium hydroxide as an input rather than the currently more prevalent lithium carbonate. Together with its purity and other advantages discussed in Section 5.3.1, lithium hydroxide is expected to dominate battery-grade lithium demand by the mid-2020s.[42]

3.3. Status and Trends in Anode Active Material

Compared to the cathode, the anode of a lithium-ion battery is relatively simple. Various carbonaceous materials are used as the active material for the battery's anode including natural graphite, artificial graphite, meso-phase carbon and amorphous phase carbon, with materials such as tin, silicon oxides and alloys and lithium titanium oxide demonstrating potential as future anode active material.

However, currently graphite in both natural and artificial forms accounts for approximately 90 percent of the anode active material market.[43] As illustrated in Figure 13[44] below, it is expected that artificial graphite will be increasingly substituted for natural graphite out to 2025.

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[41] Auslaf der Technologie jeweils unbekant IN: Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission

[42] Roskill (2018) IN: Infinity Lithium (2018), *The Supply Side Reacts to the Hydroxide Trend*

[43] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission

[44] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission

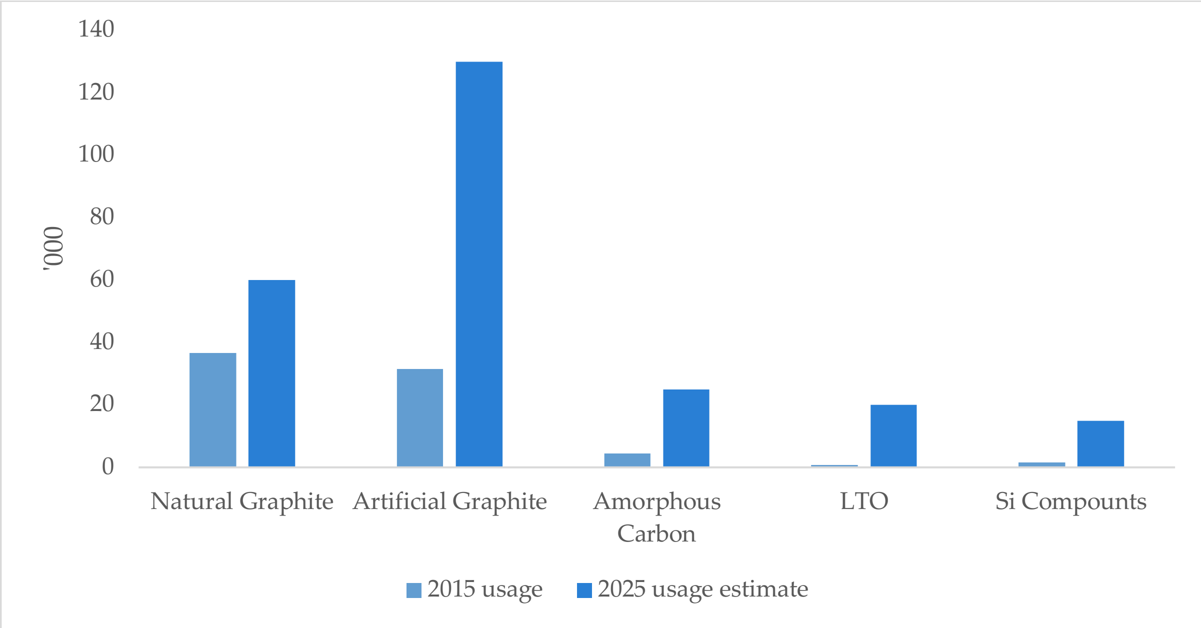

FIGURE 13 – DEMAND FORECASTS FOR LITHIUM-ION BATTERY ANODE ACTIVE MATERIAL

3.4. Status and Trends in Electrolytes

The electrolyte acts as a carrier agent to complete the internal circuit of the battery. It allows movement of lithium ions between the positive and negative electrodes, which are kept apart by the separator (see Section 3.5) during charging and discharging of the battery.

During the charging cycle, positively charged lithium ions are carried via the electrolyte solution from the cathode, through the separator, to the anode. During discharge, the positively-charged ions move from the anode to the cathode, while the electrons move through the external load. In the vast majority of commercial lithium-ion batteries available today, the electrolyte consists of lithium fluoride salts in solution of an organic solvent.

The critical technical characteristics sought in an electrolyte are:

- **Conductivity -** or the speed and ease with which lithium ions can move the through the electrolyte, and particularly conductivity at room temperature.
- **Stability -** or the resistance of the electrolyte to permanent electro-chemical changes which reduce its ability to carry a charge over time.
- **Safety** - as noted above, most electrolyte solutions involve organic solvents. While specific chemistries carry greater or lesser risks, in general organic solvents are toxic to humans and have inherent environmental risks. Most certainly battery manufacturers have made concerted efforts to move away from earlier, higher risk solvents such as thionyl chloride (caustic and carcinogenic) and acetonitrile (source of cyanide poisoning) to carbonate based chemistries, albeit if mishandled some risk to human health remains with these newer chemistries.[45] Indeed public health warnings attached to lithium-ion batteries tend to include (among other events such as choking), the risk of damage to the battery cell resulting in the leakage of hazardous electrolyte solution. Additionally, lithium metal (and its salts)

[45] *Toxicity of Materials used in the Manufacture of Lithium Batteries*, Archuleta, M.M, (1995), *Journal of Power Sources*, 54:1, pp 137 (March 1995)

is highly reactive and most electrolyte solutions are flammable and a major source of thermal runaway risk.

In an issue stemming from both electrolyte and separator design, and discussed further below, liquid or gel electrolytes can allow the formation of dendritic tendril growth, which are essentially, spurs or outcroppings of deposited lithium metal that gradually lengthen over time and result in a bridge across the carefully engineered gap between cathode and anode. This is illustrated in Figure 14[46] below. Once the gap is bridged, a short-circuit results, usually leading to thermal runaway and resulting in combustion or, in poorly engineered cells, explosion.

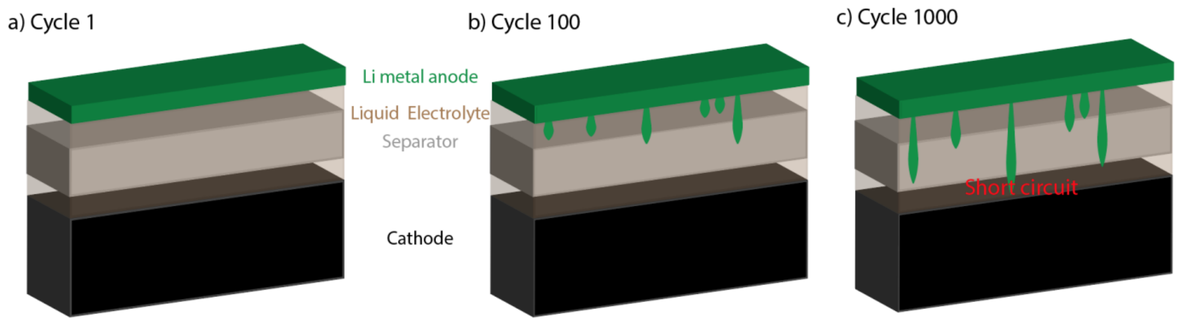

FIGURE 14 – LITHIUM DENDRITE GROWTH IN LIQUID OR GEL ELECTROLYTE SOLUTION

Despite significant development of improved and novel chemistries for battery electrodes (and particularly cathodes) as a driver for improved performance, reliability and safety over the past ten years, battery electrolytes have not seen significant change. Most, if not all modern electrolyte solutions rely on lithium hexafluorophosphate (LiPF6) in solution with a cyclic carbonate (ethylene carbonate, propylene carbonate, etc.), a liner carbonate, and a variety of additives. It is in this last area that significant innovation and product competition has emerged over recent years, with battery manufacturers offering proprietary electrolyte solution blends that can comprise up to fifteen often exotic compounds.[47]

In refining the additive mixture in their solution, manufacturers are principally trying to achieve one or more of four outcomes:

- Increasing the lithium salt concentration, allowing higher capacity anodes and increased energy capacity;
- Refining the electrochemical pathways to improve the same;
- Reducing the total cost through substitution or dilution of expensive ingredients; and/or
- Increasing safety and stability by inhibiting dendrite growth, reducing flammability or reactivity or replacing toxic and/or caustic ingredients.[48]

Potential future developments also include a move to solid-state electrolytes, usually ceramic doped or admixed with lithium metal. While some initial promising work has been undertaken

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[46] *Schematic of Li dendrite formation due to repeated charge and discharge cycles that could lead to a short circuit and ignite the flammable electrolyte*, in *A Brief Review of Current Lithium Ion Battery Technology and Potential Solid State Battery Alternatives* (2018), Ulvestad, A, published Applied Physics, arXiv.org, 12 March 2018

[47] *Trends in Lithium Electrolytes*, Clemens, K/Jaffe, S, published Design News Magazine, 27 August 2018.

[48] *Ibid*

in this area[49], with the solid nature of the electrolyte acting as a physical barrier against dendrite formation and therefore permitting higher energy cathode and anode chemistries, as well as generally superior performance at room temperature, issues include cost, stability and limited cycle life.[50] Commercial scale production is not expected within the medium term outside niche applications.

3.5. Status and Trends in Separators

The function of the separator is to isolate and prevent the anode and cathode from coming into contact with each other and causing the circuit to short (see Figure 14), while allowing the flow of ions between the two to complete the circuit. This is illustrated in Figure 15[51] below.

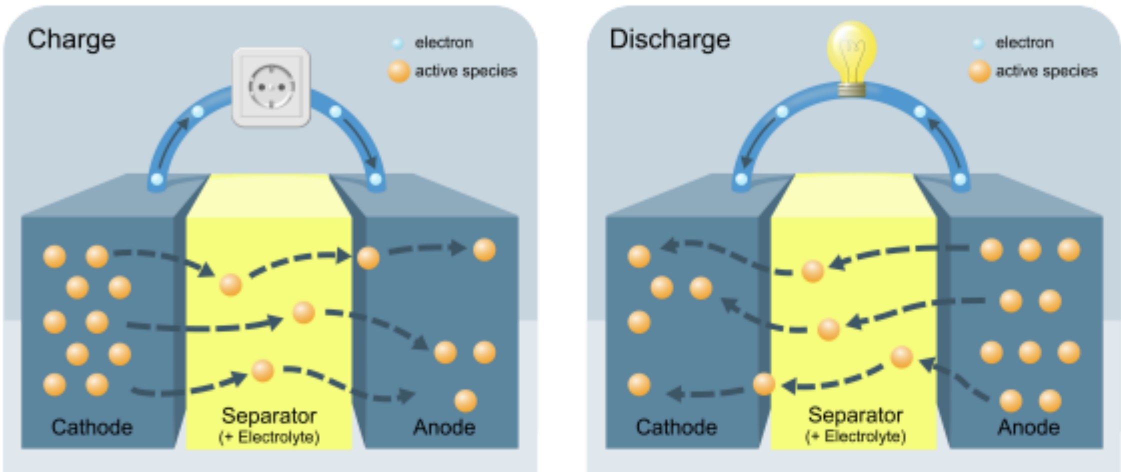

Figure 15 – Role of the Separator in Battery Function

Design of the separator is a trade-off between mechanical robustness, which provides the internal rigidity of the battery ensuring the anode and cathode remain separated, with electromechanical porosity and permeability (transportability) properties, which allow low-resistance passage of ions.

Separators are thin membranes (in the range of 12 to 20 microns in thickness) and may be classified as:

- **Ion-conducting separators** - which are comprised of a solid such as ceramic or glass and which allow the transfer of ions from one electrode to the other; or
- **Ion-permeable separators –** in which a separate liquid or gel electrolyte 'wets' the separator, fills the gap in its structure and performs the ion-conductive function.

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[49] Eg. *Demonstration of high current densities and extended cycling in the garnet Li7La3Zr2O12 solid electrolyte* (2018), Talor, N.J et al, published *Journal of Power Sources* 396 pp314 (August 2018)

[50] *A Brief Review of Current Lithium Ion Battery Technology and Potential Solid State Battery Alternatives* (2018), Ulvestad, A, published Applied Physics, arXiv.org, 12 March 2018; *Trends in Lithium Electrolytes*, Clemens, K/Jaffe, S, published Design News Magazine, 27 August 2018.

[51] *Separators - Technology review: Ceramic based separators for secondary batteries* (2014), Nestler, T et al, published American Institute of Physics Conference Proceedings 1597:155 (2014)

The separator also performs a key safety function for batteries. To prevent an internal circuit forming between the electrodes, separators must exhibit low electrical conductivity. A variety of materials can be used to ensure different levels of performance of this characteristic and different price points depending on market requirements. Characteristics of separator materials that determine their application include:

- Electrical insulation ability;
- Minimal ionic resistance;
- Physical strength, including mechanical and dimensional stability which impacts on durability and ease of handling;
- Chemical resistance to degradation by electrolyte impurities and electrode reactants and products;
- Effectiveness in preventing undesired migration of material between the two electrodes; and
- Uniformity of thickness impacting usability and process line.[52]

Most commercial batteries utilise separators made from polyolefins such as polyethylene or polypropylene, as they are relatively cheap to manufacture, durable and as a result of maturity of their manufacturing process, demonstrate high uniformity. However, they also demonstrate a relatively low melting temperature of approximately 150° C and are therefore unsuitable for many high-performing battery chemistries that operate in higher temperature environments.[53]

Increasingly, manufacturers are moving toward ceramics and high-purity aluminium (HPA) as the basis for separators. These offer superior mechanical integrity and durability, particularly in high internal heat operating environments that are typical of high performance batteries used in electric vehicles and other high performance applications. Generally, ceramic separators are ion-conducting solids and therefore obviate the need to separate liquid or gel electrolyte, while HPA separators are a more traditional web or mesh design, wetted by a conventional electrolyte fluid.

3.6. Status and Trends in Current Collectors

The current collectors serve as the interface between the battery internals and the external circuit. The collectors receive and transmit electrons through the external circuit (passing through the load as they do so to provide power), balancing the internal flow of lithium ions from one electrode to the other.

Current collectors must be electrochemically stable when in contact with the cell internals during the potential operation voltages of each electrode as any reactivity between the current collector and the electrode material, or between the current collector and the electrolyte, will lead to corrosion, pitting, oxidisation or deposition of unwanted material. In most benign form, this will lead to a gradual decline in battery performance over time as electron transfer is inhibited, or the electrode is forced away from the current collector. In more drastic failure, leaking of electrolyte or decay may occur.

Current collectors are therefore selected specifically for their passivity at the working potential of the electrode that they are in contact with. For a typical lithium-ion battery cell, the anode is between 0.5 and 2.5 volts, and the cathode ranges between 3 and 5 volts. At potentials

[52] *Battery Separators* (2004), Arora, P, Zhang, Z, published *Chemical Reviews* 104(10) pp4419 (October 2014)
[53] *State of Lithium Ion Battery Research* (2018), Wood, V, published ETH Zurich, 2 May 2018

above approximately 4 volts, most metals will strongly oxidise, and as such materials which form an inert protective oxidised layer are required.[54] The precise electrochemical reaction pathways relating to the interplay between electrode, electrolyte/separator (and additives to the same) and current collector are beyond the scope of this paper. However, for a variety of reasons (principally cost and ease of process), in virtually all commercial batteries copper foil is used as an anode collector, while aluminium is used as the cathode collector.[55]

Copper and aluminium foil are sufficient as current collectors for most battery types. However, they may present limitations with respect to novel, higher power density (instantaneous discharge potential) or faster-charging battery technologies. An increase in voltage (usually at the cathode) will result in an increase in working potential and therefore endanger the electrochemical stability of the current collector. Future developments in this area will rely on the formation of protective passive films on the metal surface to ensure battery performance and safety.[56]

[54] *Revisiting the Corrosion of the Aluminum Current Collector in Lithium-Ion Batteries*, Ma, T et al, published *The Journal of Physical Chemistry Letters*, 2017 8(5), 16 February 2017; *Passivation behaviour of aluminium current collector in ionic liquid alkyl carbonate (hybrid) electrolytes* (2018), Theivaprakasam,S et al, published *npj Materials Degradation* 2, 13(2018), March 2018

[55] *Electrochemical behavior and passivation of current collectors in lithium-ion batteries*, Myung, S-T et al, published *Journal of Materials Chemistry* 27(2011)

[56] *Ibid*

4. Status and Trends in the Battery Minerals

This Section describes global dynamics pertaining to the production and consumption of battery minerals. Sub-section 4.1 describes the nature of what have become termed 'battery minerals', as well as 'critical' battery minerals. The remaining sub-sections describe current and projected global demand, reserves and production, as well as Western Australia's competitive position as a producer or prospective producer of some key 'battery minerals', namely lithium (section 4.3), nickel (section 4.4), cobalt (section 4.5), graphite (section 4.6) and some other current and emerging battery minerals (section 4.7).

4.1. What are Battery Minerals

4.1.1. The Battery Minerals

The manufacture of the various cathode active material, anode active material and other key battery materials discussed in Section 3, requires the input of a range of high-purity chemicals, the raw materials for which are a number of key mineral products. These include lithium (Li), nickel (Ni), cobalt (Co), manganese (Mn), aluminium (Al), copper (Cu), silicon (Si), tin (Sn), titanium (Ti) and carbon (C). While all of these minerals are used (in most cases predominately) in the manufacture of a wide range of non-battery products, in the context of their application in the manufacture of lithium-ion batteries, they have become collectively referred to as the 'battery minerals'.

Generally speaking, battery minerals have a number of typically common characteristics, namely:

- **Mining operations are often small** – compared to many other sectors, mines for many of the battery minerals are relatively small, reflecting the relatively small volumes of material that are required as inputs to the chemical manufacturing sector that supplies the battery supply chain. For example, the world's largest graphite mine produces approximately 50,000 tonnes per annum and no lithium mine currently produces more than 65,000 tonnes per annum of lithium carbonate equivalent (LCE). The exception to this are operations producing the battery minerals that have much larger industrial applications such as bauxite (alumina and aluminium), copper and nickel.

- **Different value-adding pathways** – minerals destined for the lithium-ion battery supply chain are sold into the high purity chemical industry, which compared to processes such as the manufacture of stainless steel or copper wire are complex, often revolving around proprietary intellectual property that produces relatively small volumes of tightly specified products designed to meet a particular downstream customer's requirements. In other words, they are less commoditised. These supply chains are also relatively long, with significant competition at most stages (see Section 5).

- **Opaque and immature markets** – because the battery minerals market is relatively young and involves relatively small volumes, terms are often the subject of commercial confidentiality and not widely publicised. Unlike many widely used metals in today's conventional vehicles such as copper, aluminium and steel, lithium and cobalt come from different market environments. Both lithium and cobalt have been categorised in the past as minor metals and do not have high transparency and liquidity in their pricing. In the PRC the spot price is used predominately for speculation and is rarely used to hedge as is the case with most metals, with lithium contract prices often being at substantial discounts to the spot price.[57]

- **Pricing divergence** – as a result of the above characteristics, markets for battery minerals are often not affected by the same macro factors that impact commodity mineral markets, and are driven primarily by events that are specific to the particular supply chain they are sold into.

4.1.2. Demand Forecasts for Battery Minerals

For many battery minerals, the majority of production is consumed by other industrial processes. Figure 16[58] below summarises a demand forecast for key battery minerals that is expected to be derived from future demand from all of the lithium-ion battery chemistries discussed in Section 3 made in 2016. The current dynamic nature of markets for lithium-ion batteries, together with constant technology development means that demand projections for lithium in particular change frequently, with more recent demand forecasts expecting demand for lithium (LCE) to be in the range of 0.8 and 1.0 million tonnes by 2025.[59]

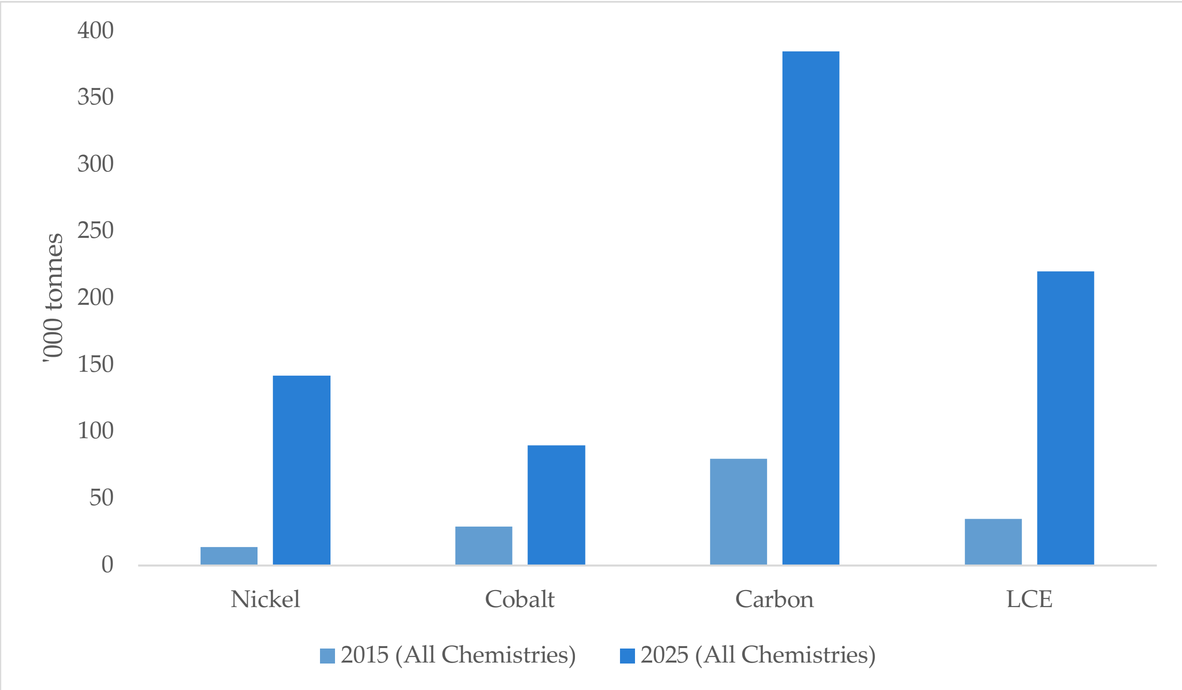

FIGURE 16 – EXPECTED FUTURE DEMAND FROM ALL LITHIUM-ION BATTERY CHEMISTRIES FOR KEY BATTERY MINERALS

4.2. What are the 'Critical' Battery Minerals

A subset of the battery minerals are sometimes described as 'critical'. The designated criticality of these minerals is a function of the perceived market supply risk, rate of recycling and extent to which the particular mineral can be substituted in the battery chemistry. In formal lists of

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57 Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

58 Avicenne Energy Analysis IN: CleanTeq (2016), Lithium Ion Batteries

59 Adapted from: 2018 forecasts published by Albemarle, SQM, Roskill, IHS Markit and Cannacord.

critical materials or minerals, battery minerals form a subset of a much larger list of feedstock to various industrial processes. The raw materials and minerals designated as 'critical' by the European Union and United States and their intersection with the lithium-ion battery industry are discussed in the following subsections.

4.2.1. European Union Critical Materials List

The European Union has an official list of 'Critical Materials', which are raw materials that are important inputs to the European Union's wider domestic manufacturing sector and which exhibit supply risk, low levels of recycling and limited substitutability in the product that is being manufactured. The full list of European Union Critical Materials List is comprised of the 27 materials listed in Table 17 below.

European Union Critical Materials List 2017

Antimony	Fluorspar	Light Rare Earths	Phosphorous
Baryte	Gallium	Magnesium	Scandium
Beryllium	Germanium	Natural Graphite	Silicon Metal
Bismuth	Hafnium	Natural Rubber	Tantalum
Borate	Helium	Niobium	Tungsten
Cobalt	Heavy Rare Earths	Platinum Group Metals	Vanadium
Coking Coal	Indium	Phosphorous Rock	

Table 17 – European Union Critical Raw Materials List

Included in the European Union's Critical Raw Materials List are three battery minerals, namely cobalt, natural graphite and silicon metal. The basis for the inclusion of these battery minerals in the European Union Critical Raw Materials List is summarised in Table 18[60] below.

[60] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission

EU Critical Raw Material	Supply risk	Substitutability Index[61]	End-of-life Recycling Input Rate[62]
Cobalt	Production is concentrated (51%) in the Democratic Republic of Congo	0.71 (0.8 in batteries)	16%
Natural graphite	Supply is concentrated (66%) in PRC	0.72 (0.3 in batteries)	0%
Silicon Metal	Supply is concentrated (68%) in PRC	0.81	0%

TABLE 18 – EUROPEAN UNION BATTERY CRITICAL RAW MATERIALS

Australia is not identified by the European Union as a major global supplier of any of the materials listed in Table 17 and Table 18 above. This is partly because while Australia might be a primary producer of relevant mineral products such as light and heavy rare earths, the specific material identified by the European Union is a downstream product that is produced by processing in other jurisdictions. It is also because Australia is currently not a major supplier of mineral products directly to the European Union, with most European supplied by production from North America, Central Europe, East Asia and to a lesser extent Africa.

4.2.2. United States Presidential Executive Order on Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals

In recognition of the United States' reliance on imports of certain mineral products that are critical inputs to the United States' manufacturing economy, and by virtue of the importance of some of those minerals to defence manufacturing, the Nation's national security, the President of the United States issued a Presidential Executive Order in December 2017, summarised as follows:

- The United States Government will publish a list of 'Critical Minerals', whereby a 'Critical Mineral' is a non-fuel or mineral material essential to the economic and national security of the United States, the supply chain of which is vulnerable to disruption, and which serves an essential function in the manufacturing of a product, the absence of which would have significant consequences for the economy or national security of the United States.
- It will be a policy of the United States Government to reduce the United States' vulnerability to disruptions in the supply of 'Critical Minerals'.

The main mechanisms through which this policy will be enacted are, not surprisingly, internally focused, such as:

- Identifying new domestic sources of 'Critical Minerals';
- Increasing domestic activity at all levels of the supply chain for 'Critical Minerals';

[61] Substitutability Index is a measure of the difficulty in substituting the material, scored and weighted across all applications. Values are between 0 and 1, with 1 being the least substitutable.
[62] End of Life Recycling Rate measures the proportion of metal and metal products that are produced from end of life scrap and other metal-bearing low grade residues in end of life scrap worldwide.

- Streamlining domestic leasing and permitting processes to expedite exploration, production, processing, reprocessing, recycling and domestic refining of 'Critical Minerals';
- Develop a strategy to reduce domestic industry reliance on 'Critical Minerals';
- Assess progress toward developing 'Critical Minerals' recycling and reprocessing technologies and technological alternatives to 'Critical Minerals';
- Develop a plan to improve topographic, geological and geophysical mapping of the United States and make the resulting data and metadata electronically accessible; and
- Recommendations to streamline domestic permitting and review processes related to developing leases

Importantly for this study, the Presidential Order also makes reference to identifying options for accessing and developing critical minerals through investment and trade with allies and partners of the United States, which through mechanisms such as the Australia, New Zealand, United States Security (ANZUS) Treaty (1951), Australia is formally a long-standing candidate to benefit from such a relationship.

The following Table 19 lists the 35 Critical Minerals that have been identified by the United States Department of Interior pursuant to the Presidential Order, several of which are Battery Minerals including aluminium, cobalt, graphite, lithium and vanadium.

United States Critical Minerals (2018)

Aluminium (bauxite)	Fluorspar	Manganese	Tantalum
Antimony	Gallium	Niobium	Tellurium
Arsenic	Germanium	Platinum Group Metals	Tin
Barite	Graphite (natural)	Potash	Titanium
Beryllium	Hafnium	Rare Earths	Tungsten
Bismuth	Helium	Rhenium	Uranium
Caesium	Indium	Rubidium	Vanadium
Chromium	Lithium	Scandium	Zirconium
Cobalt	Magnesium	Strontium	

TABLE 19 – UNITED STATES CRITICAL MINERALS

4.3. Lithium

Lithium is the least dense (or lightest) elemental metal, and with an average abundance in the Earth's crust of 17ppm, it is the world's 27th most abundant mineral. Currently, battery manufacture accounts for approximately 35 percent of demand for lithium, with the balance derived from a range of industrial applications including steel making, aluminium smelting, ceramics, glass, grease and polymer production.

Lithium is supplied to the market in a number of different chemical forms. The approximate market share of these different lithium products is summarised in Table 20.[63]

[63] Benchmark Minerals (2016), The Lithium Ion Supply Chain Reviewed, September Issue

Lithium Chemical Product	Approximate Market Share
Lithium carbonate	53%
Lithium hydroxide	25%
Lithium metal	6%
Butyl lithium	5%
Lithium chloride	5%
Other	6%

TABLE 20 – GLOBAL LITHIUM SUPPLY BY PRODUCT TYPE

As illustrated in Figure 17[64] below, compared to other global chemical industries, the lithium industry is relatively small.

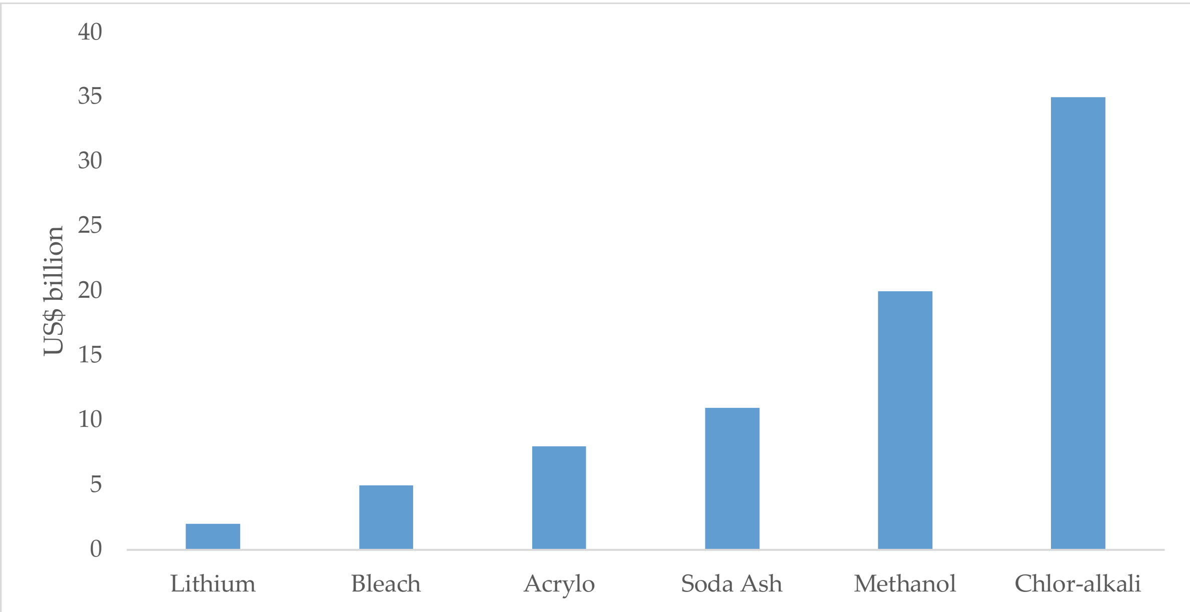

FIGURE 17 – GLOBAL CHEMICAL INDUSTRY SECTORS BY REVENUES (2017)

The vast majority of lithium is produced from the mining of hard-rock mineralisations, or the evaporation of naturally occurring brines that contain lithium, with very small volumes also produced from lithium containing clays. The vast majority of brine primary production occurs in Latin America (Argentina and Chile) and the vast majority of hard rock primary production occurs in Australia from the mining and processing of spodumene mineralisation. The PRC produces lithium from both domestic hard-rock (lepiodite) and brine sources, albeit it's domestic primary production is relatively small in both cases, with its downstream processing sector heavily reliant on imported feedstock.

During the 1990s, as a result of comparatively low production costs, brines were the preferred source of lithium feedstock. However, partly as a result of limited expansion investment by

64 Ledoux-Pedailes (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment,* IHS Markit, Houston

existing brine producers and partly as a result of increased demand for lithium hydroxide which can be produced cost competitively from hard-rock sources (see Section 5.3.1), hard rock lithium's share of supply has increased in recent years.

4.3.1. Demand for Lithium

As illustrated in Table 20 above, the vast majority of lithium is sold as lithium carbonate or lithium hydroxide. Lithium carbonate has a lithium content of approximately 19 percent, whereas lithium hydroxide has a lithium content of approximately 29 percent. Because lithium carbonate has traditionally accounted for the majority of marketed lithium, lithium demand and production is often described in terms of a lithium carbonate equivalent (LCE) irrespective of its specific form.

Current total demand for lithium is estimated at 218,000 tonnes per annum of LCE and is expected to grow to between 0.8 and 1.0 million tonnes per annum of LCE by 2025.[65] Table 21[66] below summarises various sources of demand for lithium currently.

Source of demand	Tonnes per Annum (LCE)	Market Share
E-mobility batteries	43,600	20%
Consumer and personal device batteries	45,780	21%
Energy Storage System Batteries	2,180	1%
Total Battery Demand for Lithium	**91,560**	**42%**
Other Demand for Lithium	126,440	58%
Total Lithium Demand	**218,000**	**100%**

TABLE 21 – ESTIMATED CURRENT DEMAND FOR LITHIUM

The increase in demand for lithium is derived almost exclusively from demand for batteries, with batteries expected to account for between 65 to 75 percent of lithium demand by 2025.[67] The extent to which demand for lithium grows is very much dependent on trends in demand for electric vehicles. For example, one forecast suggests that at an electric vehicle penetration rate of 4 percent of global vehicle sales by 2025 will result in total demand of approximately 605,000 tonnes per annum LCE. However, if electrical vehicles achieve a global vehicle market penetration rate of 8 percent by 2025, total demand for lithium will be 820,000 tonnes per annum LCE.[68]

[65] Adapted from various reports sourced: Albemarle (2018), SQM (2018), Roskill (2018), IHS Markit (2018) and Canacord (2018)
[66] Ledoux-Pedailes, V. (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment,* IHS Markit, Houston
[67] Neometals: An Insider's View of the Lithium Industry
[68] Ledoux-Pedailes, V. (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment,* IHS Markit, Houston
[68] Neometals (2018) *An Insider's View of the Lithium Industry*

4.3.2. Global Lithium Resources

Global estimates of lithium reserves and mineral production vary, primarily as a consequence of limited reporting in many countries of production (particularly some Latin American nations) and a general reluctance to disclose commercial-in-confidence data by an overall small number of producers. Combined with the current environment of rapid project development whereby exploration, ore reserve development work and new production is constantly changing the resource base and output from the sector, expert estimates can differ dramatically.

According to the United States Geological Survey, current total global resources are estimated at approximately 249 million tonnes LCE. Latin America accounts for approximately 70 percent of resources, PRC 15 percent, United States 15 percent and Australia 11 percent. The geographical distribution of this resource is illustrated in Figure 18[69] below. Estimates of the proportion of this total mineral resource that are economically recoverable vary.

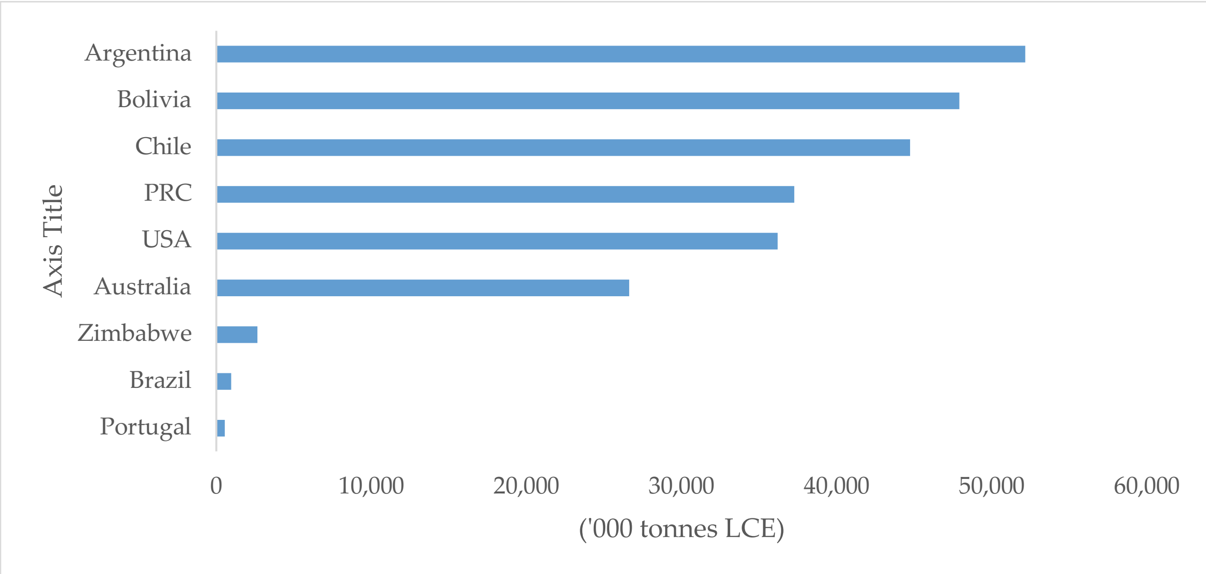

FIGURE 18 – NATIONAL RESOURCES OF LITHIUM (2017)[70]

4.3.3. Global Lithium Production

While global lithium resources are geographically dispersed, production is not - approximately 95 percent of global supply stems from four countries: Chile, Argentina, Australia and the PRC. Traditionally, Chile has been by far the largest supplier of lithium, accounting for approximately 47 percent of global supply, with Australia and Argentina each accounting for approximately 18 percent of global supply. The geographical distribution of lithium production in 2017 is illustrated in Figure 19[71] below

[69] "US Geological Survey IN: Neo Metals: Lithium Insider's View"

[70] Note that as the result of recent exploration and ore reserve development activities across the globe, the resource estimates in Figure 18 should be viewed as indicative only

[71] United State Geological Survey (United States production estimates sourced from the British Geological Survey, with no United States estimate available for 2017).

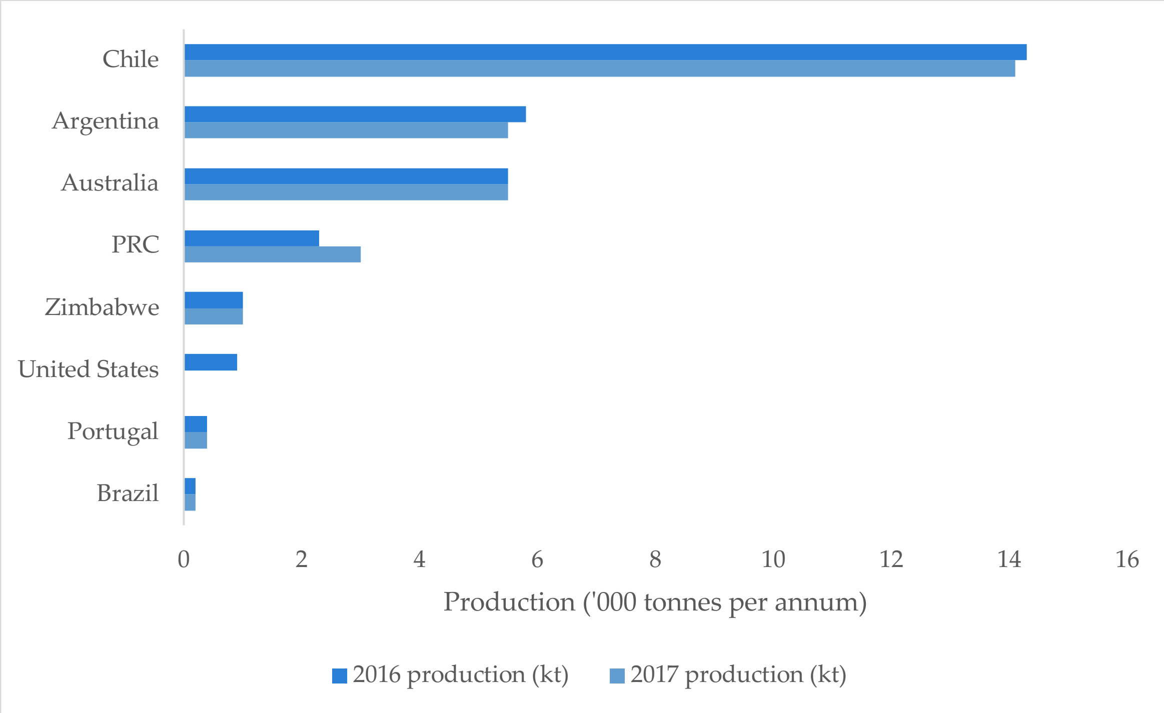

FIGURE 19 – GLOBAL LITHIUM PRODUCTION

Significant commissioning of new production in Western Australia over the past 12 months has seen Western Australian spodumene and spodumene concentrate production increase to a level where Western Australian production currently accounts for close to 50 percent of global supply. Further increases in production in Western Australia (see Table 23 below), as well as other jurisdictions (see following subsections) will likely see the supply balance shift again in the near future.

From a mine ownership perspective supply is similarly concentrated, with the globally distributed production assets of Talison, Sociedad Quimica y Minera (SQM), Albemarle and FMC Lithium accounting for the majority of supply.

Trends in Latin American Brine Production

Bolivia's Salar de Uyuni is the world's largest resource of lithium. However, its high lithium to magnesium ratio has continually presented challenges as has the Bolivian Government's position on foreign investment.

Chile's dominance as a producer of lithium is a function of SQM and Albemarle's significant continental brine operations in the Atacama Desert. Potash and magnesium are also extracted from these resources.

In Argentina, FMC is the major producer, with new entrant Orocobre beginning to scale-up production. Additionally, the relatively new Argentinian government is actively courting FDI, with a number of potential new entrants such as Lithium Americas, Lithium X Energy and Galaxy Resources identified as potential future brine producers in Argentina.

Imminent expansion of Latin American brine production is summarised in Table 22[72] below.

[72] NeoMetals: Insider's View of Lithium

Company	Estimated Additional Production (LCE)	Estimated Timing
Albemarle	40,000t	2020-21
FMC Lithium	20,000t	2019
Lithium Americas Corp	25,000t	2020
Orocobre	25,000t	2019-20
SQM	50,000t	2019-20
TOTAL	**160,000t**	

TABLE 22 – EXPECTED IMMEDIATE EXPANSION OF LATIN AMERICAN BRINE PRODUCTION

Trends in the People's Republic of China Production

Despite hosting significant resources of lithium (see Figure 18), the PRC produces only small volumes of raw material from domestic brine and lepiodite resources. However, the Qinghai Salt Lakes in the PRC's west have long been identified as a potential significant source of lithium, albeit it's chemistry is less favourable than the Latin American brines.

North and Central America

While not a large producer of lithium on the global scale, significant interests in expanding domestic production exists in United States, Canada and Mexico.

Of particular note is Clayton Valley, an area of approximately 100 square kilometres in south-west Nevada, close to the Californian border. A topographical nadir, the valley has a playa[73] floor and a drainage catchment of approximately 1,300 square kilometres, resulting in an expanse of lithium-rich brines and clays. A large number of mineral claims have been made over areas of the valley floor, including from Advantage Lithium, Cypress Development, Lithium X, Nevada Energy Metals, Nevada Sunrise Gold, Noram Ventures, Pure Energy Minerals (which signed an offtake agreement with Tesla Motors in 2015), Red Mountain Mining, Sienna Resources and Supreme Metals. The area is also home to the only producing lithium mine in North America, Albemarle's Silver Peak brine project, with an annual production of approximately 3,500 tonnes of lithium carbonate.

The geology of northern Mexico is also prospective for lithium clay deposits. Located approximately 200km north-east of Hermosillo, the Sonora Lithium project, majority owned by Bacanora Minerals with JV partner Rare Earth Minerals, is estimated to have a total reserve of 4.5 million tonnes of LCE and aims to produce 35,000 tonnes per annum of LCE at 99.5 percent battery grade purity.[74] With a pilot plant completed and an offtake agreement signed with 10 percent equity holder Hanwa Corporation of Japan, production was scheduled to commence in 2018. However, a similar offtake and equity deal with PRC-based Nextview, worth approximately US$37 million, collapsed in February with Nextview failing to make placing

[73] Also known as an alkali flat – a desert basin with no outlet which periodically fills with water.

[74] *Sonora Lithium Project*, published Bacanora Lithium, available www.bacanoralithium.com, accessed 01/09/2018

payments. Bacanora is understood to be seeking alternate finance to meet a total capital cost of approximately US$180 million.[75]

Canada, particularly northern Canada and the Quebec province, has also seen significant exploration and early stage project activity. As distinct from the United States and Mexico, Canadian lithium deposits are in similar form to Australia, found in hard rock pegmatite and spodumene. Most advanced are Critical Elements Corporation's Rose Lithium-Tantalum Project, having recently completed a positive bankable feasibility study for an estimated 186,000 tonnes of lithium concentrate, Nemaska Lithium's Whabouchi mine and Shawinigan pilot hydroxide plant, seeking funding to scale to production of 27600 tonnes per annum nameplate capacity[76], and a number of projects at or nearing completion of feasibility studies, including Galaxy Resources' James Bay Pegmatite, Sayona Mining's Authier project, and Pioneer Resources Mavis and Raleigh projects.

4.3.4. Trends in Western Australian Lithium Concentrate Production

All current and aspiring lithium concentrate production in Western Australia is produced from hard-rock (primarily spodumene) sources. The lithium concentrate produced from these sources has a lithium content in the range of 6.0 to 7.0 percent. Associated with the existing and potential lithium hard rock mining operations is one lithium hydroxide conversion plant under construction and several others at various stages of the development pipeline. These are discussed in detail in Section 5.3.1.

As summarised in Table 23 below, six current lithium mining operations in Western Australia collectively are expected to produce approximately 2.1 million tonnes per annum of spodumene (lithium) concentrate in 2018. If all of the more advanced pre-production projects identified in this study come on stream, Western Australian spodumene (lithium) concentrate production will double to approximately 4.4 million tonnes per annum. As discussed further in Section 5.3.1, the extent to which this production will be converted to lithium hydroxide through domestic processing capacity or exported to conversion plants in Asia will be a function of the extent to which the planned domestic conversion capacity materialises, as well as individual company decisions with respect to the best strategy for optimising shareholder returns.

[75] *Bacanora Minerals confident over financing for Sonora lithium mine*, Whiterow, S, published *Proactive Investor*, 2 March 2018

[76] Nemaska has recently concluded an offtake agreement with LG Chem for 7ktpa hydroxide - *Lithium is exploding but Canada's distance from China has miners at a disadvantage*, Friedman, G, published *The Financial Post*, 6 July 2018

Project	Proponents	Resource/Reserve	Region	Production (tonnes per annum)	Status
CURRENT SPODUMENE (LITHIUM) CONCENTRATE PRODUCTION					
Bald Hill	Tawana Resource & Alliance Minerals	11.3mt@1.01% (Reserve)	Coolgardie	220,000 (est.)	First shipment May 2018
Greenbushes	Tianqi Lithium & Albermarle	31.4mt@3.1% (Reserve)	Greenbushes	750,000	Long-standing producer
Mt Cattlin	Galaxy Resources & Traka Resources	7.6mt@1.1% (Reserve)	Ravensthorpe	156,000	First shipment 2017
Mt Marion	Neometals & Jianxi Ganfeng	77.8mt@1.4% (Resource)	Coolgardie	435,000	First shipment 2017
Pilgangoora	Pilbara Minerals	80.3mt@1.3% (Reserve)	East Pilbara	330,000 (est.)	First Shipment Oct 2018
Pilgangoora	Altura Mining & Atlas Iron	30.1mt@1.0% (Reserve)	East Pilbara	230,000 (est.)	First Shipment Oct 2018
Total Current Spodumene (Lithium) Concentrate Production				**2,121,000**	
ASPIRING SPODUMENE (LITHIUM) CONCENTRATE PRODUCTION					
Cowan	Tawana Resources	60.5mt@1.4% (Resource)	Coolgardie	n.a.	Feasibility
Greenbushes Expansion	Tianqi Lithium & Albermarle	31.4mt@3.1% (Reserve)	Greenbushes	1,200,000	Under construction
Lynas Find	Pilbara Minerals	7.3mt@1.25% (Resource)	East Pilbara	n.a.	Feasibility
Mt Holland	Kidman Resources, SQM & Western Areas	128mt@1.4% (Resource)	Yilgarn	300,000	Feasibility
Wodgina	Mineral Resources	233mt@1.2%	Port Hedland	750,000	Under Construction
Total Aspiring Spodumene (Lithium) Concentrate Production				**2,250,000**	
Total Potential Spodumene (Lithium) Concentrate Production				**4,371,000**	

Table 23 – Total Current and Likely Short Term Western Australian Production of Spodumene (Lithium) Concentrate

The key Western Australian lithium production projects are detailed in the following subsections.

Bald Hill

Located near Kambalda in the Goldfields Region, the Bald Hill project is a 50:50 joint venture between Tawana Resources and Alliance Mineral Assets, with a proposal to consolidate these entities into a single asset holding entity progressing.[77] The operation is an open-cut lithium and tantalum ore mining operation. The mineral resource on which the greenfields operation is based is yet to be fully delineated, with a recent drilling program resulting in an estimated 105 percent increase in the JORC compliant reserve.[78]

All concentrate production from Bald Hill is currently shipped to the PRC in accordance with an offtake agreement with Hong Kong SAR domiciled Burwill Commodity Limited that extends to 2023[79] as a key component of the project's financing package.

Greenbushes

Located immediately adjacent to the town of Greenbushes in Western Australia's southwest, the Greenbushes spodumene mine is the single largest hard-rock lithium resource in the world. The open-cut operation has been producing spodumene and tantalum from this resource for decades.[80]

The mining operation has changed ownership several times over the past three decades, and is currently the subject of a 51:49 joint venture between Tianqi Lithium Corporation and Albemarle Corporation, with the vast majority of spodumene concentrate production from Greenbushes used as feedstock for the respective supply chains of its joint venture partners.

Spodumene ore is processed at the Greenbushes mine site to produce a 6.0 percent lithium oxide concentrate. Currently this concentrate product is transported by rail to Bunbury Port where it is shipped to Tianqi and Albemarle conversion plants in the PRC. As discussed in Section 5.3.1, Tianqi and Albemarle are separately progressing the construction of lithium hydroxide conversion plants in Kwinana and Kemerton respectively.

The Greenbushes joint venture partners are also investing approximately A$840 million in a significant expansion at the Greenbushes mine.[81] Subject to regulatory approvals, this will see spodumene ore throughput increase from 4.7 million tonnes per annum currently to 9.5 million tonnes per annum, initially producing 1.05 million tonnes per annum of lithium concentrate expanding to 1.95 million tonnes per annum, with a nameplate capacity of up to 2.3 million tonnes per annum.[82]

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[77] *Tawana and Alliance a step closer to $446m merger*, Hosie, E, published Australian Mining, 12 June 2018

[78] *Lithium ore reserve increase of 105% at Bald Hill*, published Tawana Resources, Alliance Mineral Assets, 6 June 2018

[79] *Tawana Resources ships first batch of Bald Hill lithium concentrate to China*, George, T, published 3 May 2018

[80] *Greenbushes mine (Greenbushes pegmatite)*, Mindat.org, accessed 01/08/18

[81] *Ibid*

[82] *Greenbushes mine expansion – EPBCA 1999 Referral*, April 2018, published Department of Environment

Mt Cattlin

Mt Cattlin is Western Australia's second largest lithium mine and a globally significant source of raw material for the lithium chemical industry. Located near Ravensthorpe in the Great Southern Region, Mt Cattlin is an open pit lithium tantalum operation mining a relatively flat ore body. Like the Greenbushes operation, the ownership of Mt Cattlin has changed hands several times over its long history, which as an exploration project dates back to the 1960s.

Current owners, Galaxy Resources, operated the mine from 2009-2012, before placing it in care-and-maintenance in 2013 and sourcing supply from the Greenbushes project, citing a high Australian dollar and increased low-cost supply from Latin American brine operations as factors rendering Mt Cattlin production non-competitive at the time.[83]

Following additional capital works designed to upgrade the processing plant and double throughput to 1.6 million tonnes per annum[84], the Mt Cattlin mine was recommissioned in 2016, with first the concentrate production shipped through Esperance Port in early 2017. The project is underpinned by five separate offtake agreements that cover 100 percent of planned production with conversion plants across Asia[85] (understood to be predominately with PRC converters[86]), that extend out to 2023 and which were brokered by Mitsubishi Corporation.

With some concerns raised in 2018 regarding rising process costs and falling ore feed grades, Galaxy Resources has stated an intention to invest in plant and process upgrades for the Mt Cattlin facilities.[87] In a potential value-add, unconventional lithium producer Lepidico has secured access rights to the Mt Cattlin tailings, and has announced test work production of 99.8 percent pure lithium carbonate utilising a proprietary recovery process.[88]

Mt Marion

The Mt Marion mine is located south-west of the town of Kalgoorlie in the Eastern Goldfields region and is based on the world's second largest known high-grade spodumene resource. While the Mt Marion resource has been the subject of exploration since the 1950s[89], production has only recently commenced under the current owners, Jiangxi Ganfeng Lithium (43.1 percent), Mineral Resources (43.1 percent) and Neometals (13.8 percent).

Offtake from the Mt Marion project is secured through a life-of-project binding offtake agreement with Jiangxi Ganfeng Lithium for 100 percent of production for so long as the mine is operating, with Neometals and Mineral Resources having an option to purchase 51 percent

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83 *Lithium mine shut down in blow to Ravensthorpe,* Kagi, J, published ABC News Online, 20 March 2013

84 *Galaxy Resources waves off first lithium shipment from Mt Cattlin mine*, Lucas, J, published ABC Rural News, 3 January 2017

85 *Galaxy signs binding long-term offtake agreements for Mt Cattlin*, published Galaxy Resources, 29 November 2017

86 *Galaxy Resources Limited shares storm higher on massive offtake agreement*, Mickleboro, J, published The Motley Fool, 29 November 2017

87 *Galaxy Depends Heavily On Mt Cattlin Upgrade*, Brocklehurst, E, published FN Arena, 24 April 2018

88 *Lepidico uses L-Max technology to create 99.8% pure battery grade lithium from Galaxy's Mt Cattlin tailings*, Nicholas, L, published SmallCaps, 1 March 2018

89 *Mount Marion pegmatites*, published Mindat.org, accessed 01/08/2018

of production from the fourth year of production onwards if a price premium over the price specified in the Jiangxi Ganfeng Lithium offtake agreement can be secured.[90]

Production from Mt Marion for the first partial year of operation in 2017 reached 170,000 tonnes, with maturing processes expected to deliver nameplate capacity of approximately 435,000 tonnes in 2018. Minority shareholder Neometals has conducted process testing to produce lithium hydroxide from Mt Marion-sourced spodumene, and is in the process of an engineering design study for a 10,000 tonne per annum hydroxide plant to be operational by 2021.[91] If commissioned, Neometals will use its offtake option to provide feedstock for the proposed conversion plant.

The Pilgangoora (Pilbara Minerals and Altura Mining) Projects

The Pilgangoora province is characterised by extensive pegmatite mineralisation located approximately 140 kilometres south of Port Hedland and is currently the subject of several exploration and development projects. The most advanced of these projects are adjacent open-pit developments operated by Pilbara Minerals and Altura Mining, both of which very recently commissioned, producing lithium and tantalum.

Pilbara Minerals first shipped direct shipping ore (DSO) under a DSO agreement with Atlas Iron from Port Hedland in June 2018[92], with first lithium concentrate exports on 1 October 2018[93]. The Pilbara Minerals project will have an initial nameplate capacity of approximately 350,000 tonnes per annum of spodumene (lithium) concentrate, the vast majority of which is the subject of offtake agreements with General Lithium Corporation, Ganfeng Lithium, Great Wall Motors and POSCO.[94] Pilbara Minerals is currently planning a second stage expansion, that if implemented will see production increase to approximately 800,000 tonnes per annum.[95]

On 9 October 2017, Altura Mining made its first shipment of concentrate from Port Hedland to its offtake partner LionEnergy in the PRC.[96] At nameplate capacity, Altura will produce 220,000 tonnes of spodumene (lithium) concentrate, 90 percent of which is the subject of offtake agreements with PRC based battery chemical producers Lionenergy Limited and Shaanxi J&R Optimum Energy Co for the first five years of production.[97] While still the subject of a definitive

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[90] *Reed Industrial Minerals signs offtake and funding deal with lithium producer Jiangxi*, Venna, S, published Mining Technology; *Neometals sends maiden shipment to "lithium giant" Ganfeng,* published InvestorIntel, 9 February 2017

[91] *Outstanding vendor test results for lithium hydroxide produced from Mt Marion concentrates*, published Neometals, 10 April 2018

[92] Creagh, B. (2018), 'Atlas ships first lithium DSO from Pilbara Minerals' Pilgangoora', *Australian Mining*, June Edition

[93] Zhou, V. (2018), 'Pilbara Minerals' first shipment from Pilgangoora to set sail', *Australian Mining,* October Edition

[94] Creagh, B. (2018), 'Pilbara Minerals a step closer to production at Pilgangoora', *Australian Mining*, May Edition; McKinnon, S. (2018), 'Pilbara Minerals calm on fears of global lithium glut', *Diggers and Dealers*; AND Pilbara Minerals (2018), 'Development and offtake in Pilgangoora Lithium-tantalum Project.

[95] Pilbara Minerals (2018), 'Development and offtake in Pilgangoora Lithium-tantalum Project.

[96] Australian Mining (2018), 'Alutura's first lithium shipment leaves the Pilbara', *Australian Mining*, October Edition

[97] Karinja, F. (2017), 'Altura scores two lithium offtake agreements in China', *Small Caps*, July edition

feasibility study, expansion plans for Altura's Pilgangoora Project would see production increase to 440,000 tonnes per annum of spodumene (lithium) concentrate by 2020.[98]

Wodgina

Located in close proximity to Pilgangoora, south of Port Hedland, Wodgina has historically been mined extensively for iron ore and tantalum, but has only recently become the focus of lithium recovery. The project is 100 percent owned by Mineral Resources, who since April 2017 has been undertaking pre-stripping operations to expose the lithium ore body. To date, the pre-striping operations have produced 3.25 million tonnes of tonnes lithium DSO for PRC-based processors.[99]

With reduced profitability from DSO and a reported slowing of demand from the PRC[100], Mineral Resources has commenced construction of a 750,000 tonnes per annum lithium concentrate operation that is expected to be commissioned by March 2019.[101]

4.3.5. Cost of Production

Figure 20[102] below illustrates the lithium production cost curve. It is expected that new Western Australian production will be slightly more costly, but broadly equivalent to the Greenbushes operation. However, several new brine operations will likely see the cheapest producers operating below US$2,000 per tonne.[103]

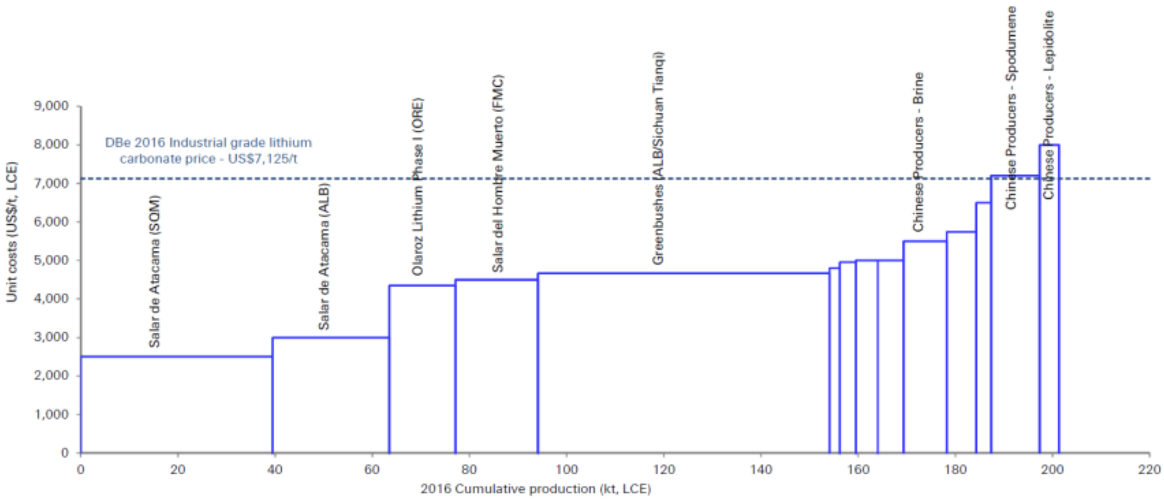

FIGURE 20 – LITHIUM PRODUCTION COST CURVE (2016)

In 2017, the marginal cost of production was estimated to be US$6,500 of LCE[104], however this is routinely changing. Brine operations are more cost competitive than hard rock operations,

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[98] Altura Mining (2018), *Investor Update: New significant supply to the battery market,* (June)
[99] *ASX Announcement: Wodgina Update*, published Mineral Resources, 15 June 2018
[100] *Chris Ellison's lithium fantasy exposed at Mineral Resources*, Aston, J, published 18 June 2018
[101] *ASX Announcement: Wodgina Update*, published Mineral Resources, 15 June 2018
[102] Hocking, M., Kan, J., Young, P., Terry, C. and Begleiter, D. (2016), *Lithium 101,* Deutsche Bank Markets Research
[103] Hocking, M., Kan, J., Young, P., Terry, C. and Begleiter, D. (2016), *Lithium 101,* Deutsche Bank Markets Research
[104] Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

with SQM and Albemarle being the most cost competitive. Talison is the most cost competitive hard rock producer, with the PRC players positioned in the middle and top position on the cost curve.

Brine producers have production costs of approximately US$2,500 to US$3,000 per tonne of LCE and with the exception of the outliers at the high end, the hard rock production cost curve is relatively flat at around US$5,000 per tonne of LCE.[105]

This picture changes slightly when viewed from the lithium hydroxide perspective which is important given its preference for use in NCM 811 and NMC 955. The conversion of lithium carbonate that is produced from brines into lithium hydroxide is more expensive compared to production from carbonate by about US$500 per tonne[106]. However, this changes frequently, primarily as a function of the price of spodumene concentrate.

The economics of lithium production and conversion is discussed in greater detail in Section 7.8.4.

4.4. Nickel

Of all the key battery minerals, the wider global market for nickel is arguably the most mature, with nickel having been an important industry mineral for many decades. The nickel industry is characterised by multiple sources of primary and recycled production of various nickel products, an established and relatively liquid London Metals Exchange market, and an active intermediary sector.

However, the specific nickel product that is required for the purposes of producing battery grade chemicals is less developed.

4.4.1. Global Demand for Nickel

Nickel's light weight and corrosion resistant properties have resulted in numerous industrial manufacturing applications for the metal.

The majority (approximately 65 percent) of all nickel production is consumed by austenitic stainless steel production. A further 12 percent of nickel production is used to manufacture highly refined 'superalloys' such as Inconel 600 or nonferrous alloys such as cupronickel. These alloys are typically used to manufacture componentry that operates in harsh industrial or environmental conditions such electricity generation turbines, or jet engine turbine blades and discs.[107]

The remaining 23 percent of nickel production is used by a range of industrial applications such as coinage, foundry products, plating, catalysts, chemical products and rechargeable battery chemistries.[108]

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[105] Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

[106] Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

[107] *Nickel – Statistics and Information* (2018), United States Geological Survey

[108] *Nickel – Statistics and Information* (2018), United States Geological Survey

4.4.2. Global Nickel Reserves

The United States Geological Survey estimates global nickel resources total 130.2 million tonnes, with reserves at 74.0 million tonnes. Twelve nations have nickel reserves greater than 1.0 million tonnes. Together, Australia, Brazil, Russian Federation, Cuba, Philippines and Indonesia account for 70 percent of global nickel reserves. The geographical distribution of global nickel reserves is illustrated in Figure 21[109] below.

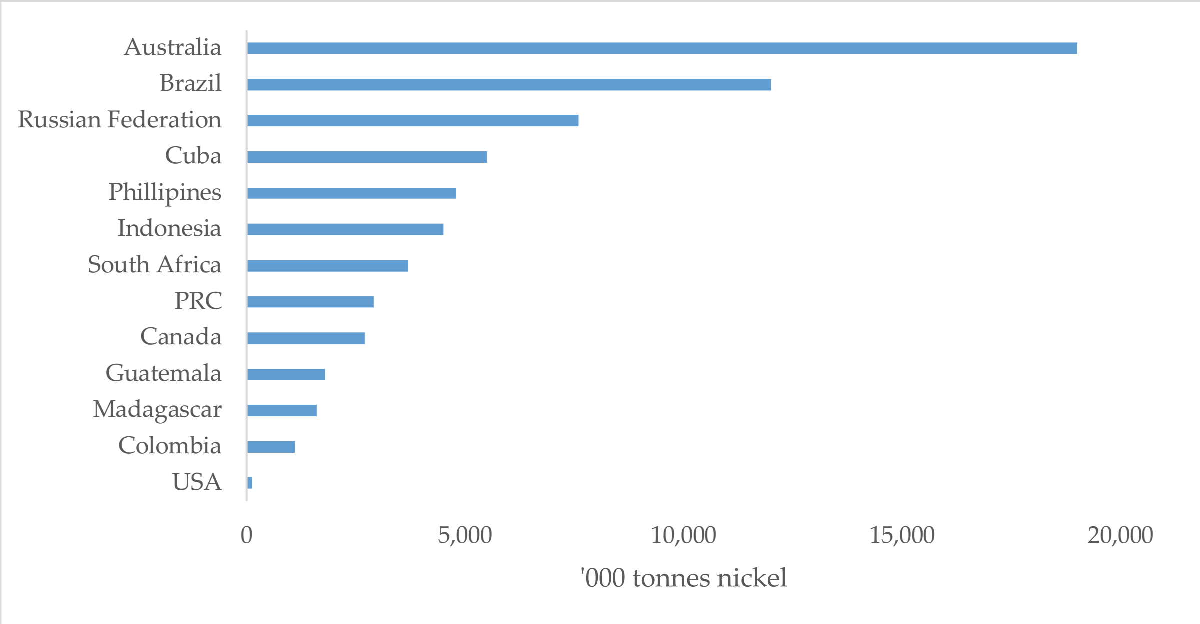

Figure 21 – Global Nickel Reserves

4.4.3. Global Nickel Production

According to the United States Geological Survey, global nickel production currently stands at approximately 2.1 million tonnes per annum. Nickel is produced from mining operations across the globe, with Indonesia, Philippines, France (New Caledonia), Canada, Australia, Russian Federation, Brazil and the PRC accounting for approximately 80 percent of global production. The geographical distribution of global nickel production is illustrated in Figure 22[110] below.

[109] United States Geological Survey
[110] United States Geological Survey

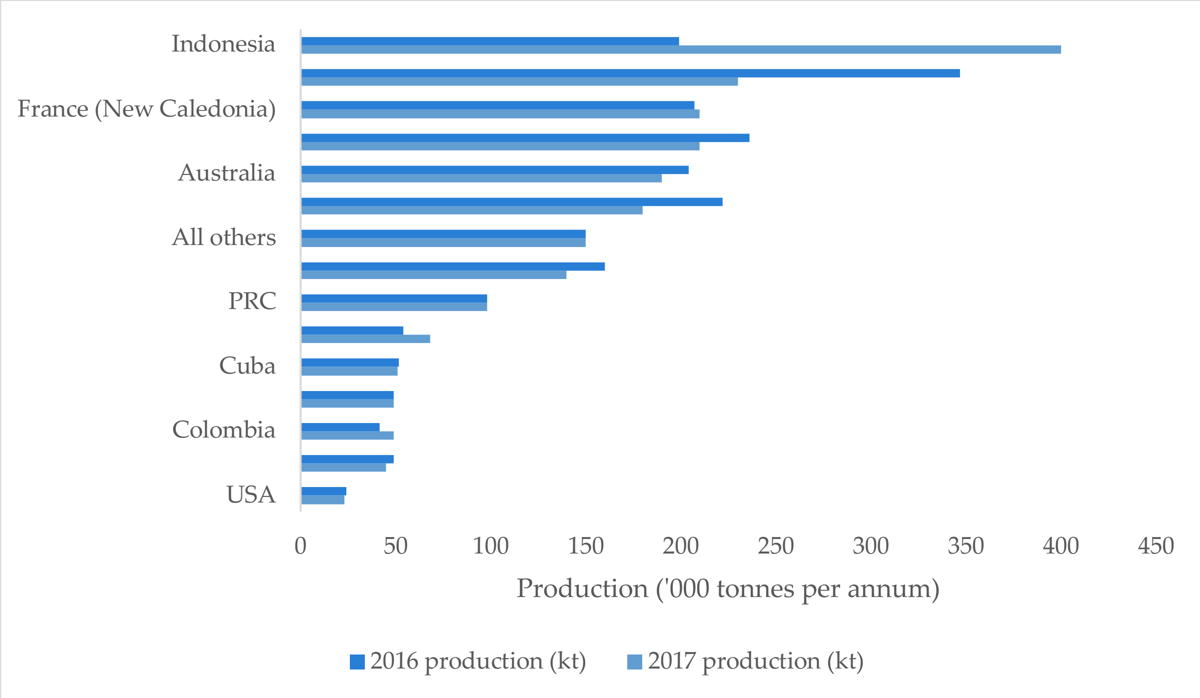

FIGURE 22 – GEOGRAPHICAL DISTRIBUTION OF GLOBAL NICKEL PRODUCTION

The evident recent dramatic decrease in production from the Philippines is a function of approximately 50 percent of Philippine mining operations suspended for failing to meet regulated environmental conditions. The dramatic increase in production from Indonesia is the result of lifting of export bans by Indonesian authorities following pledges from Indonesian nickel miners that they will invest in domestic downstream processing.

4.4.4. Nickel Products and the Lithium-ion Battery Supply Chain

The production of stainless steel can use both Class 1 nickel product (nickel purity of 99.8 percent or higher) and class 2 nickel product (nickel purity of less than 99.8 percent). Class 2 nickel products are primarily produced from a nickel pig iron process and are a less expensive input to the manufacture of stainless than class 1 products. Over the past decade demand for Class 2 nickel products has risen dramatically as stainless steel producers seek to lower costs. The resulting increase in supply of nickel pig iron has resulted in a significant overhang of supply in markets and has kept downward pressure on prices.[111]

Of total global supply, only approximately 230,000 tonnes is in the form of class 1 nickel powder and briquettes. It is this product that is used to produce nickel based precursors for cathode manufacturing. In 2017, approximately 65,000 to 75,000 tonnes of class 1 nickel product was converted to nickel sulphate for this purpose.[112] While Class 2 nickel product can theoretically be used to manufacture technical grade nickel sulphate, the extra purification steps required currently render it sub-economic.

[111] Campagnol, N., Hoffman, K., Lala, A. and Ramsbottom, O. (2017), The Future of Nickel: A Class Act, McKinsey & Company
[112] Campagnol, N., Hoffman, K., Lala, A. and Ramsbottom, O. (2017), The Future of Nickel: A Class Act, McKinsey & Company

Principle production from the Nickel West and Murrin Murrin downstream operations is a Class 1 nickel product.

4.4.5. Western Australian Nickel Production

Western Australia hosts significant sulphide and lateritic nickel mineralisation and has been the nation's sole primary producer of nickel in recent times.

High-grade komatiite-associated nickel sulphide deposits were first discovered in Western Australia in 1966 by Western Mining Corporation (WMC). The development of these resources and their commercialisation, which was the result of significant investment in downstream concentrating, smelting and refining capacity by WMC over the period 1966 to 1971, resulted in what is now referred to in the Western Australian capital market annals as Western Australia's 'nickel boom'. By 1980, WMC had identified 24 nickel sulphide deposits in the Kambalda area, of which 15 were being mined, delivering WMC virtual control over nickel production in Western Australia.

During the mid-1990s the Western Australian nickel industry underwent considerable structural change, driven by the following key events[113]:

- **Development of Laterite Resources**
  The introduction of High Pressure Acid Leaching (HPAL) technology demonstrated the potential to render a number of laterite hosted nickel resources in Western Australia viable. While significant investment was directed toward developing these resources, and in some cases implementing HPAL circuits, there is only one nickel laterite operation currently producing in Western Australia, Murrin Murrin, which currently accounts for approximately 30 percent of Western Australia's nickel output and the vast majority of the State's cobalt output as a co-product (see Section 4.5.4).

- **New Entrants in Nickel Sulphide Production**
  A series of additional high-grade komatiite-associated nickel sulphide deposits were discovered by companies other than WMC. These new sulphide deposits include Emily Ann, Flying Fox Deeps, Cosmos, Silver Swan, Waterloo/Amorac and Mt Goode. Some of these sold ore into WMC's downstream infrastructure, while others developed their own downstream capacity.

- **WMC Partial Divestment of Nickel Assets**
  In 2000, WMC sold its Kambalda-Widgiemooltha mining assets to independent operators under conditions which provided WMC with an ore offtake agreement, maintaining feedstock for its concentrator, smelter and refining infrastructure. The main WMC developed mines and infrastructure are now owned and operated by BHP Nickel West.

During the period 2000 to 2007, the value of Western Australian nickel production grew from approximately A$2 billion to A$8 billion, supported by higher global nickel prices (which reached a peak of approximately A$35,000 per tonne in 2006-07). Primarily as a result of this dramatic expansion phase, Western Australia has at least 30 individual delineated nickel resources, some of which have been the subject of historical production, including production in recent history. These are summarised in Appendix 3.

However, as a result of a sustained depressed nickel price that is primarily the result of pig nickel substitution in many nickel applications, currently only three Western Australian nickel projects

[113] Elias, M. and Donaghy, T. (2015), 'Focus on nickel in Western Australia', *Mining Journal*

are producing. These are summarised in Table 24 below and described in detail in the following subsections.

Project	Proponent	Resource	Region	Production (nickel metal equivalent)	Downstream
Forestania	Western Areas & Great Western Exploration	25.91Mt @ 1.7% (Resource)	Kondinin	23,050 tonnes per annum	Forestania
Nickel West	BHP	958Mt @ 0.64%	Goldfields & Kwinana	90,600 tonnes per annum	Nickel West
Murrin Murrin	Minara Resources (Glencore)	268Mt @ 1.01% (Resource)	Laverton	41,900 tonnes per annum	HPAL
TOTAL				155,550 tonnes per annum	

TABLE 24 – WESTERN AUSTRALIAN NICKEL PRODUCTION

Nickel West

Nickel West is a 100 percent owned subsidiary of BHP Billiton and is comprised of a portfolio of upstream and downstream nickel assets acquired from the former WMC. This includes mining operations at Mount Keith, Leinster and Cliffs; nickel concentrator circuits at Mouth Keith, Leinster and Kambalda; a nickel smelter at Kalgoorlie; and a nickel refinery at Kwinana. These operations produce approximately 50 percent of all Western Australian nickel production and in terms of nickel concentrate production, Nickel West is the third largest in the world.[114] In 2017-18, NickelWest operations produced 90,600 tonnes of nickel metal equivalent.[115]

In addition to ore from Nickel West mines, the Nickel West Kambalda concentrator also sources sulphide nickel ore from a number of other smaller mines in the region, historically accounting for around 30 percent of the feedstock for that concentrator.[116] However, softer nickel prices have seen much of this third-party feedstock evaporate.

Nickel West has recently undertaken significant investment to expand production at its Mount Keith mine, with production at the Yakabindie satellite deposit expected to commence in 2019, together with a study into the feasibility of increasing the Mount Keith concentrator capacity to 50,000 tonnes per annum, and restart the upgrade of pits at the Leinster operations with an aspirational target of 40,000 tonnes per annum.[117]

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[114] *Minerals Statistics Digests* (1990-91 to 2015-16), Department of Mines, Industry Regulation and Safety

[115] *BHP Operational Review for the year ended 30 June 2018*, published BHP Billiton, 30 June 2018

[116] *Third party supply to Kalgoorlie Smelter* in *Nickel West: Think Big – A view to the future*, published BHP Billiton, 6 August 2018

[117] *Nickel West: Think Big – A view to the future*, published BHP Billiton, 6 August 2018

Important to the subject of this study, Nickel West is also investing in downstream capacity at its Kwinana Refinery to produce nickel sulphate, a chemical product that is used to manufacture battery precursor chemicals. This is discussed in detail in Section 5.3.2.

Forrestania Nickel

Located approximately 100 kilometres east of Hyden in the Wheatbelt Region, the Forrestania Nickel project is comprised of two mines, Flying Fox and Spotted Quoll and an associated concentrator plant. The operations is 100 percent owned and operated by Western Areas.

In 2017 the Forrestania project produced 23,050 tonnes of nickel concentrate[118], from a nameplate production capacity of 25,000 tonnes per annum. The vast majority of this production is sold via an offtake agreement with BHP Nickel West for 12,000 tonnes per annum and with the PRC based Tsinghan Group from 10,000 tonnes per annum.

The Forrestania project is the subject of further exploration, with definitive feasibility studies currently underway for the Cosmos and Odysseus prospects.[119] Additionally, Western Areas is currently undertaking a Mill Recovery Enhancement Project, which utilises a proprietary biological tailings treatment process to recover a nickel concentrate with nickel content of approximately 45 to 50 percent, compared to the 14 percent nickel product produced by contemporary milling practices. Commissioned in March 2018, the initial production from the Mill Recovery Enhancement Project is being blended with existing concentrate sold under the offtake agreements presently in place, but Western Areas plans to separately sell the high-grade production into a new offtake agreement with an electric vehicle battery precursor supplier.[120]

Murrin Murrin

The Murrin Murrin project is a lateritic nickel project using High Pressure Acid Leaching (HPAL) technology to recover nickel and cobalt. The project is located between Leonora and Laverton in the north-east Goldfields region and has been operating under different ownership since 1999. Primarily as a result of low mining costs, the Murrin Murrin project is one of the lowest cost nickel operations in the world.[121]

The project is currently owned and operated by Minara Resources, a wholly owned subsidiary of Glencore. In 2017, the Murrin Murrin operation produced 41,900 tonnes of nickel sulphide and 3,000 tonnes of cobalt sulphide. All production is marketed through Glencore's operations and is the subject of offtake agreements.[122]

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118 *Annual Report 2017*, published Western Areas,

119 *Ibid; Activity Report for the Quarter ending 31 March 2018,* published Western Areas, April 2018

120 *Ibid*

121 *Anaconda Nickel Ltd Nickel and Cobalt Mine*, published Mining Technology, accessed 01/08/2018

122 *Amended and Restated Offtake Agreement* in *Notice of Annual General Meeting and Explanatory Memorandum*, published Minara Resources, April 211

4.4.6. Production Cost Curve

With respect to the production of nickel metal equivalent, Western Australian nickel production costs are in the higher-third quartile, lower fourth quartile of global production costs.[123] However, with respect to the Class 1 nickel product, Australia's production costs are understood to be at least globally competitive. Furthermore, if price premiums for value-added nickel products such as nickel sulphate (see Section 5.3.2) are subtracted from operating costs in the same way as by-products often are, then the production of these value-added products may have a material impact on cost-curve positioning.

4.5. Cobalt

Cobalt is a chemical element that is generally found only in a chemically combined form, albeit it can be smelted into a metal. It is one of the world's few metals that is consumed at industrial scale that does not have a source of primary production, as all of the world's cobalt is produced as a co-product from other mining operations, particularly nickel, copper and gold operations.

4.5.1. Global Cobalt Demand

Cobalt is used in a range of industrial applications such as superalloys, hardened materials (carbides and diamond cutting tools), pigments, catalysts and magnets. However, its application in batteries accounts for approximately 37 percent of cobalt demand.[124] There are two main downstream pathways from cobalt primary production. Traditional cobalt metal manufacturers produce superalloys, binder and catalysts for mature industrial markets. Whereas cobalt chemical manufacturers supply the battery supply chain with battery grade cobalt chemicals. Battery grade consumption of cobalt has increased three-fold over the past five years.[125]

Demand for cobalt that is derived from NCA, NMC and LCO battery chemistries (see Section 3.1.4) has been the main driver of cobalt markets in recent times. Cobalt plays a critically important role in these battery chemistries, acting as a binder for the lithium ions, allowing ions to move from the cathode to the anode during discharge.

Demand for cobalt is expected to increase from 136,000 tonne today, to 222,000 tonnes by 2025.[126]

4.5.2. Global Cobalt Reserves

According to the United States Geological Survey, the Democratic Republic of Congo accounts for approximately 50 percent of the world's reserves of 7 million tonnes of cobalt, with Australia (primarily Western Australia) a further 17 percent. No other country hosts reserves

[123] AME (2017), Nickel: The Battle to Regain Lost Ground, AME (http://www.amegroup.com/Website/FeatureArticleDetail.aspx?faId=353)

[124] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission

[125] Benchmark Minerals (2016), The Lithium Ion Supply Chain Reviewed, September Issue

[126] Ledoux-Pedailes, V. (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment,* IHS Markit, Houston

that are more than 8 percent of the world's existing known reserves of cobalt. The geographical distribution of the world's cobalt reserves is illustrated in Figure 23[127] below.

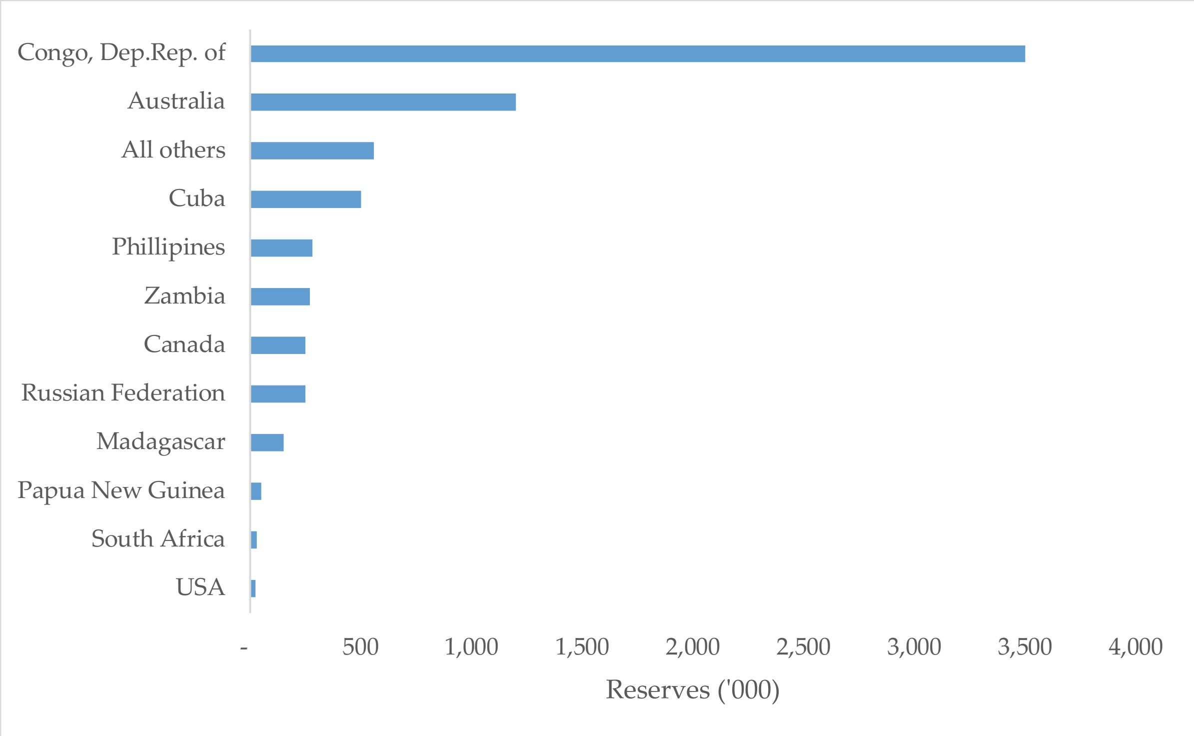

FIGURE 23 – GLOBAL RESERVES OF COBALT

4.5.3. Global Cobalt Production

As with cobalt reserves, the Democratic Republic of Congo also dominates global production. Indeed, the Democratic Republic of Congo accounted for almost 60 percent of the 108,000 tonnes of cobalt produced in 2017, which was produced primarily as a by-product from copper mines. This is illustrated in Figure 24[128] below.

[127] United States Geological Survey (2018)
[128] United States Geological Survey (2018)

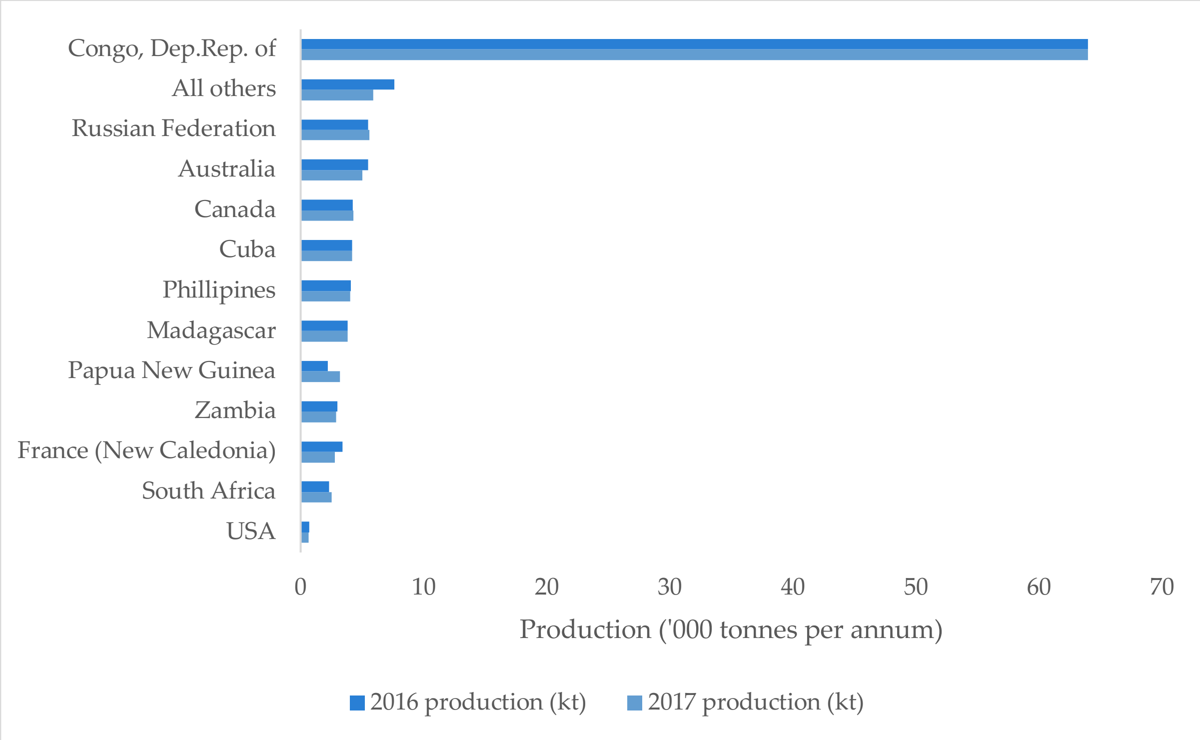

FIGURE 24 – GLOBAL COBALT PRODUCTION

As discussed in Section 4.2, the concentration of global cobalt supply in the Democratic Republic of Congo is a significant strategic concern for the lithium-ion battery industry and other technology sectors that are reliant on cobalt as a raw material. Not only is supply concentrated in the Democratic Republic of Congo, but a significant portion of cobalt production in the Democratic Republic of Congo is produced from artisanal mining operations that have been exposed by Amnesty International for using child labour in hazardous mining conditions. While cobalt is not listed as a 'conflict mineral', this predicament is becoming increasingly problematic for the lithium-ion battery industry as discerning consumers are demanding ethical production practices and traceability of product. The absence of transparency in cobalt trade out of the Democratic Republic of Congo renders supply audits difficult, threatening to exacerbate this issue.

Approximately 40,000 to 45,000 tonnes of cobalt mine capacity expansions by 2025 are expected to come from three projects, all of which are located in the Democratic Republic of Congo, namely Glencore's Katanga Mining, Gecamine's joint venture project and the Eurasian Resources Group's Metalkol Roan Tailings Reclamation project.

Across its operations, Glencore produces 22 percent of the world's cobalt with Gecamine, a Democratic Republic of Congo state owned enterprise, accounting for a further 9 percent of global production and China Molybdenum 7 percent. The dominance of the Democratic Republic of Congo and Glencore and Gecamine in cobalt supply is expected to be further enhanced with Democratic Republic of Congo based expansions from both of these producers, together with the Eurasian Resources Group Metalkol Roan Tailings Reclamation Project expecting to deliver an additional 40,000 to 45,000 tonne of production in the near future.

Approximately 50 to 60 percent of global cobalt refining capacity is located in the PRC, with some capacity in Finland and Japan.

4.5.4. Western Australian Cobalt Production

A significant number of Australian mineral resources that support gold and nickel mining operations host some cobalt mineralisation. Increased demand for cobalt that is derived from battery manufacture has driven a significant escalation of interest in developing cobalt oriented projects in Western Australia and across the nation. Appendix 4 provides a summary of these projects.

Currently, the main source of cobalt production in Western Australia is the Murrin Murrin nickel laterite project, together with some by-product production from Nickel West operations and emerging by-product production from the Nova-Bollinger project. These are summarised in the following subsections.

Nickel West

As noted above, Nickel West is predominantly and primarily a nickel operation, which has historically not targeted cobalt for extraction. As part of a pivot to targeting battery minerals, however, Nickel West has reported that it is in the early stages of developing a cobalt circuit at its Kwinana refinery and increasing cobalt recovery at the Kalgoorlie smelter, as well as potentially sourcing cobalt ore or concentrate from third-party suppliers, as it presently does for some nickel ore.[129]

Murrin Murrin

The Murrin Murrin project produces relatively large volumes of cobalt from its HPAL process as a co-product.

Glencore markets cobalt to a range of customers, and has recently signed a three-year offtake deal with PRC-based GEM Co, equivalent to approximately 30 percent of its worldwide production.[130]

Nova-Bollinger

The Nova-Bollinger project is an operating mafic nickel-copper-cobalt open-stope underground mine, targeting predominantly nickel and copper recovery but producing cobalt as a by-product. 100 percent owned by Independence Group, acquired from Sirius Resources in 2015, first shipments of ore from the project commenced in 2017 with 2018 expected to be the first year of commercial-scale production at nameplate capacity of 1.5million tonnes per annum of ore throughput.[131] On past estimates, this would result in an estimated cobalt production for the year of approximately 850 tonnes.[132] An expansion of the project to increase throughput to1.8 million tonnes per annum is presently under way, due to be completed in 2019-2020[133].

Both nickel and copper production from the project is secured with three-year offtake agreements, namely nickel to BHP Nickel West and Glencore and copper to Singaporean

[129] *BHP Billiton to produce nickel sulphate next year, eyeing cobalt on battery boom*, Daly, T, published Reuters Commodities News, 18 April 2018
[130] *Glencore signs massive cobalt sale deal with China's GEM*, published Reuters Business News, 15 March 2018
[131] *Nova Site Visit*, published Independence Group, 4 August 2018
[132] *Definitive feasibility study indicates Nova is a goer*, published Sirius Resources, 14 July 2014
[133] *Nova Site Visit*, published Independence Group, 4 August 2018

entity Trafigura Group.[134] However there appears to be no publicly reported offtake agreement securing cobalt production.

With approximately 11.7 million tonnes of ore reserves, and increasing production rates, there are obvious issues relating to the life of the project. Discovery of the nearby 'Silver Knight' deposit 25km from the Nova-Bollinger ore body by Mark Creasy, a 16 percent owner of Independence Group, has led to speculation regarding a partnership or sale agreement to extend the mine life.[135]

4.5.5. Cost of Production

Because cobalt is produced as a co-product from nickel production, its production costs are incremental.

4.6. Graphite

Graphite is produced in both a natural and synthetic form. Natural graphite is a mineral that forms when carbon is subjected to heat and pressure in the Earth's crust and upper mantle. Synthetic graphite is produced using a feedstock of petroleum coke and coal tar pitch, which are both by-products of oil and coking coal production respectively. These carbon raw materials are mixed with a binder, usually coal tar pitch and baked at temperatures exceeding 2,500°C.

4.6.1. Global Demand for Graphite

Natural graphite is also known as flake graphite and there is a physical and chemical process that converts flake graphite into spherical graphite. Only 4 percent of natural graphite is used in battery manufacture, with the balance used in a number of industrial applications including refractory products, lubricants, foundries and electrodes.

Synthetic graphite's primary product is steel electrodes, which are large rods used to melt scrap. To produce these rods graphitised raw material is extruded in rods, an energy intensive process that can take up to three weeks to produce, with the majority of this time required to cool the rods.

Graphite is the largest raw material input by volume in a lithium-ion battery cell and comprises the majority of the anode. Battery grade, or anode graphite, can be sourced either from naturally mined and processed graphite, or synthetic graphite. It takes approximately two tonnes of flake graphite to produce one tonne of spherical graphite, with new technology presenting a potential yield of 70 percent compared to today's 40 percent.[136] The spheres are then sold to an anode manufacturer or trading company and made battery ready by coating them with a carbon film, which adds stability and conductivity to the spheres.

Advances in thermal technology and acid-leaching techniques that enable the production of higher purity graphite powders are likely to see the development of new applications for graphite in a range of high technology fields.

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134 *First nickel concentrate shipment from Nova project*, published Independence Group, 12 December 2016

135 *Official figures show Creasy's WA nickel-copper find could provide needed feed for hungry Independence*, Fitzgerald, B, published Resources Rising Stars, 2 August 2018

136 Benchmark Minerals (2016), The Lithium Ion Supply Chain Reviewed, September Issue

4.6.2. Global Natural Graphite Reserves

The following Figure 25[137] illustrates the estimated geographical distribution of known natural graphite resources. Estimates of mineral reserves are not available for several exporters due to unreliable or incomplete data, or data that is withheld due to commercial sensitivity.

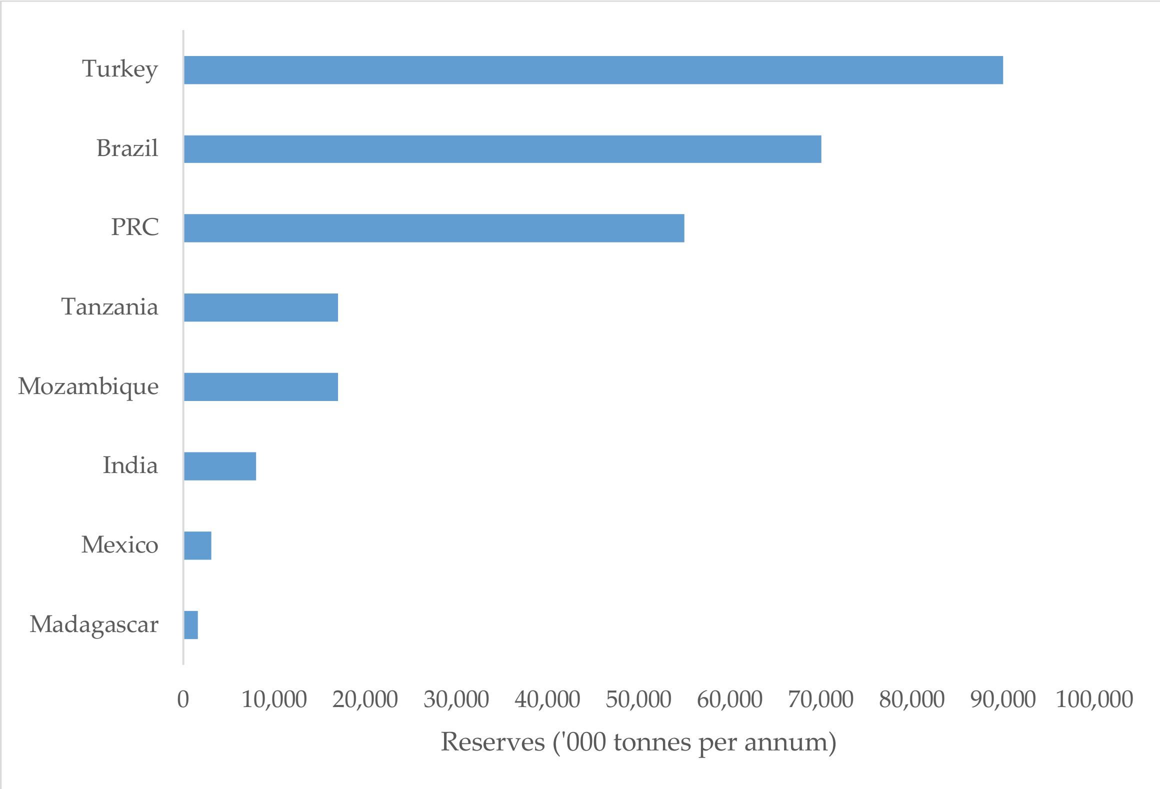

FIGURE 25 – KNOWN RESERVES OF GRAPHITE

4.6.3. Natural Graphite Production

As illustrated in Figure 26[138] below, production of natural graphite is concentrated in Sri Lanka, the PRC, Russian Federation, India and Brazil.

[137] *Graphite (Natural) – Statistics and Information* (2018), United States Geological Survey
[138] *Graphite (Natural) – Statistics and Information* (2018), United States Geological Survey

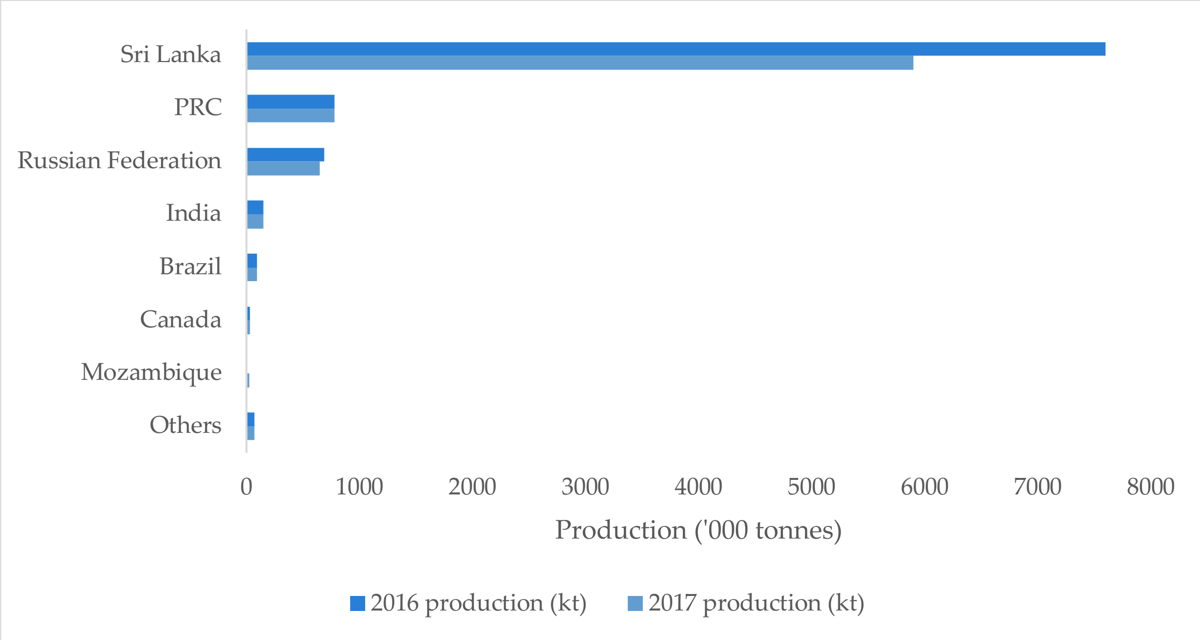

FIGURE 26 – GEOGRAPHICAL DISTRIBUTION OF NATURAL GRAPHITE PRODUCTION

The PRC accounts for 100 percent of uncoated spherical graphite production and 65 percent of the anode market. The PRC is a low cost source of flake graphite feedstock, producing 66 percent of the world's flake graphite output. Major producers are Aoyu Graphite Group, BTR New Energy Minerals, Qingdao Black Dragon.

Brazil produces a further 25 percent of the world's flake graphite, with Nacional de Grafite being the main domestic producer.

Syrah Resources (Mozambique) is building the world's largest graphite mine with a capacity of 380,000 tonne per annum and a focus on producing 30,000 to 50,000 tonnes per annum of spherical graphite for the lithium ion battery market from a plant in Louisiana, United States.

4.6.4. Global Synthetic Graphite Production

The cost of production for synthetic graphite of is more than double that of producing spherical graphite, the equivalent competing product. Japan, the PRC and the United States are the major producers of battery grade synthetic graphite.

4.6.5. Western Australian Graphite Projects

Although home to a number of large deposits, Western Australia does not currently produce graphite. There are however, several exploration projects seeking to develop graphite production facilities. There are also a number of projects at similar stages of development in other Australian states. These are discussed in Appendix 5.

4.7. Other Battery Minerals

4.7.1. Commodity Products

Other minerals that are used in battery production such as copper, manganese and aluminium are produced in Western Australia. However, the form in which they are used in the manufacture of batteries is largely as commodity products that are competitively available from multiple chemical and material suppliers globally.

4.7.2. Emerging Battery Minerals

There are number of other minerals that have potential in the evolution of lithium-ion battery chemistries (see Section 3.1.4). Western Australia hosts resources of these minerals and a number of projects are seeking to commercialise those resources. These are discussed in the following subsections.

High Purity Aluminium

Briefly discussed earlier in this report (see Section 3.5), high purity aluminium (HPA) is another emerging growth sector in battery manufacture.

HPA is a high-grade form of non-metallurgical alumina, with a purity level of 99.99 percent or above. Like most forms of aluminium, it is chemically inert in most environments, has a very high melting point, has high hardness, is electrically non-conductive, but has high thermal conductivity. The majority of global demand (55 percent in 2015) stems from its use in manufacturing light-emitting diodes (LEDs), followed by applications in the semiconductor industry (22% of global demand).[139] Demand for HPA is currently estimated at approximately 30,000 tonnes per annum[140], but is expected to grow at a CAGR of around 20 percent through to 2025[141], derived from continually growing demand for computers, consumer electronics and LED lighting.

Despite currently low relative demand (estimated at 1,000 tonnes per annum in 2016[142]), the battery sector is expected to increase consumption dramatically over the medium-term, as manufacturers chase the benefits to be gained from adopting HPA separators, discussed in section 3.5). Estimates for likely final demand from the battery sector range between 23,000 tonnes per annum and 43,000 tonnes per annum by 2025, from a total global demand of around 90,000 tonnes per annum.[143]

Global production of HPA is fragmented, and concentrated in the PRC, Japan and to a lesser extent France and South Africa. The material is not widely traded on commodities markets, and pricing is opaque.[144] Production of HPA is further likely to see significant disruption over the medium term, with conventional manufacture reliant on hydrolysis of already-processed aluminium feedstock. This reliance on expensive input material adds significantly to process

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[139] *Global High Purity Alumina Market 2016-2020*, Technavio Research, July 2016
[140] *High Purity Alumina stocks on the ASX*, Nicholas, L, published *SmallCaps*, 6 September 2018
[141] *Global High Purity Alumina Market, op cit; Global HPA demand to reach 86,831 tpa growing at 17% CAGR by 2024*, Gupta, D, published Alumina Circle, 6 October 2017
[142] *Lithium-Ion Battery Grade 4N HPA*, in *2017 Annual Report*, published Altech Chemicals, 27 September 2017
[143] *Ibid; Forecast Surge in HPA Demand Drive by Lithium-Ion Battery Sector*, media release published Altech Chemicals 8 June 2018
[144] *High Purity Alumina stocks on the ASX, op cit*

costs and leads to inefficiencies. As a result, a number of manufacturers are exploring novel process technologies to capitalise on the expanding HPA market, including in Australia Collerina Cobalt, based in New South Wales, and Andromeda Metals, in South Australia, both of which are understood to be in the process of completing feasibility studies.

In Western Australia, Altech Chemicals commenced construction of its new 4.5 tonne per annum HPA plant in Malaysia in July 2018, sourcing feedstock from its 100 percent owned kaolin deposit at Meckering, Western Australia, while FYI Resources is undertaking a feasibility study on developing its Cadoux kaolin project.

Vanadium

While not strictly a lithium-ion battery mineral, vanadium is worthy of mention.

Global demand for vanadium is currently limited, at approximately 80,000 tonnes per annum. The vast majority (92 percent) of vanadium production is used as an additive in the manufacture of high-strength steel, whereby as little as 0.15 percent of vanadium additive can double the strength of the resulting alloy.[145] However, the rise in demand in energy storage applications has prompted renewed interest in an alternate usage for the metal, in vanadium redox flow batteries.

Vanadium redox flow batteries (VRB) generate power via a reduction-oxidation reaction. Unlike in a lithium-ion battery, the reaction occurs between two electrolytes (catholyte and anolyte) rather than between an electrolyte and an electrode. During discharge, electrons are removed from the anolyte via reduction and transferred through the external circuit to the catholyte by oxidisation. This flow is reversed during charge.[146]

While a number of different redox flow chemistries have been explored, including zinc bromine, polysulfide bromide and cerium zinc, pure vanadium (exploiting the ability of vanadium to exist in four different oxidisation states) is likely to be the dominant technology moving forwards, due to low cost, simplicity of design and chemistry, and lack of any toxic process chemicals, requiring only vanadium salts and water.[147]

As a result of very different electrochemistry, VRB have markedly different performance profiles to lithium batteries. Due to the different reaction pathway, VRBs do not degrade over time to the same extent as lithium chemistries, with an estimated lifespan in excess of 10,000 full cycles and a capacity retention of 90 percent over 20 years. This compares favourably with conventional lithium-ion batteries, whose capacity in some instances can decline by 50 percent after only 1,000 cycles. VRBs are also far safer than lithium cells, with no risk of thermal runaway and non-hazardous components, and are highly suited to long discharge cycles (6-8 hours), with very high energy density, ease of upgrade and a lower unit cost at scale.[148]

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[145] *Why vanadium may be the next lithium or cobalt*, Yeo, M, published *Stockhead Australia*, 14 November 2017; *From buildings to batteries: is the time right for Vanadium?*, Davies, R, published *Mining Technology*, 10 January 2018

[146] *Schematics of a Vanadium Redox Flow Batter*, from *Chapter 18: Understanding the Vanadium Redox Flow Batteries* (Blanc, C, Rufer, A) in *Paths to Sustainable Energy* (2010), ed. Ng, A, published IntechOpen

[147] *Ibid*

[148] *Ibid; Lithium-based vs. Vanadium Redox Flow Batteries – A Comparison for Home Storage Systems* (2016), Uhrig, M et al, published Energy Procedia 99 pp35 (November 2016)

However, there are also significant drawbacks to VRB technology. Unlike lithium-ion batteries, VRBs have low round-trip efficiency, outputting only about 75 percent of the energy used to charge them. They are also ‘low and slow’, meaning they have significantly lower peak power output, making them unsuitable for applications such as grid frequency support, and would rely on a co-installation of lithium or lead-acid batteries, gas or diesel co-gen, supercapacitors or flywheels to meet peak loads.[149] In order to supply a ‘peaky’ load with dips and troughs, significant overprovision would be required, of which most would sit idle during non-peak times. Finally, VRBs have a large and bulky physical footprint, making them unsuitable for many high-end use scenarios.

The underlying economics of VRBs are also questionable. Unlike in lithium cells, with a mix of inputs, approximately 40 percent of the total battery cost is the vanadium, exposing them to price volatility. Also unlike lithium cells, very large amounts of vanadium material is required to produce significant capacity (approximately 5,000 tonnes of vanadium would be required to produce one gigawatt-hour of output, compared to approximately 80 tonnes of lithium metal). In the context of the approximately 80,000 tonnes of vanadium produced annually, over 90 percent of which is used in the steel-making industry, difficulties in securing sufficient product would likely arise. As a result, the cost per kWh is also high, with VRBs estimated to have a cost of between $300-500 per kWh compared to around $250 for conventional lithium cells[150].

Presently, the majority of vanadium produced worldwide is sourced from the PRC, South Africa and Russia, mostly as a by-product of steel smelter slag, but also found in carbonaceous shale and magnetite deposits and alongside titanium.

In Western Australia, two vanadium projects are at a reasonably advanced stage. Australian Vanadium’s Gabanintha Vanadium Project, south of Meekatharra, with a JORC-compliant resource of 175.5Mt vanadium oxide @ 0.77%; and King River Copper’s Central, Red Hill and Buckman claims south of Wyndham, with a JORC-compliant resource of 4,700Mt @ 0.3%. Both projects are understood to be at the pre-feasibility stage, with no offtake agreements or project timeframes yet published.

149 *Vanadium-lithium hybrid systems would be ‘optimal’ for power and energy applications*, Colthorpe A, published *Energy Storage News*, 1 June 2017

150 *From buildings to batteries: is the time right for Vanadium?*, Davies, R, published Mining Technology, 10 January 2018

5. The Downstream Lithium-ion Battery Supply Chain

5.1. What is a Supply Chain?

The term 'supply chain' refers to a relationship between two or more otherwise independent organisations that, through commercial arrangements, contribute their specific capabilities to the development and delivery of a final product or service to an end-user customer.

The fundamental economic principle that underpins supply chain formation is that of comparative advantage. That is, supply chains exist because different organisations are able to contribute a product attribute that is valued by a customer at a lower opportunity cost than another organisation, resulting in the more economically efficient production and delivery of a product whose attributes are valued by an end-user customer. The benefit of the economic efficiency that is achieved is appropriated in the form of improved customer value (and therefore greater market share) and/or supply chain surplus (i.e. supply chain participant profitability).

Sequential participants in a supply chain are counterparties in commercial transactions that are typically the subject of longer-term supply and offtake contractual arrangements between organisations, sometimes supported by spot markets for key inputs along the supply chain. The most effective supply chains are typically characterised by a high level of collaboration and coordination between the organisations that comprise the supply chain, with the purpose of ensuring that the supply chain continues to deliver a compelling and competitive product to the end-user, and that the organisations that participate in that supply chain are adequately commercially motivated to continue to deliver on their contribution to the product or service attributes that are valued by those end-customers.

Notwithstanding the benefits of a strategic approach to managing a supply chain, at the end of the day, supply chains exists for purposes of economic efficiency. As such, *ceteris paribus*, cost structures along the supply chain are a critically important factor and a major focus of the relationship between supply chain participants. Other important factors include reliability of supply, managing supply risk and producing quality that meets customer expectations (see Section 5.2.2).

5.2. Overview of the Lithium-ion Battery Supply Chain

5.2.1. Basic Elements of the Lithium-ion Battery Supply Chain

Figure 27 below depicts a high-level illustration of the lithium-ion battery supply chain revolving, in this case, around technical grade lithium hydroxide production.

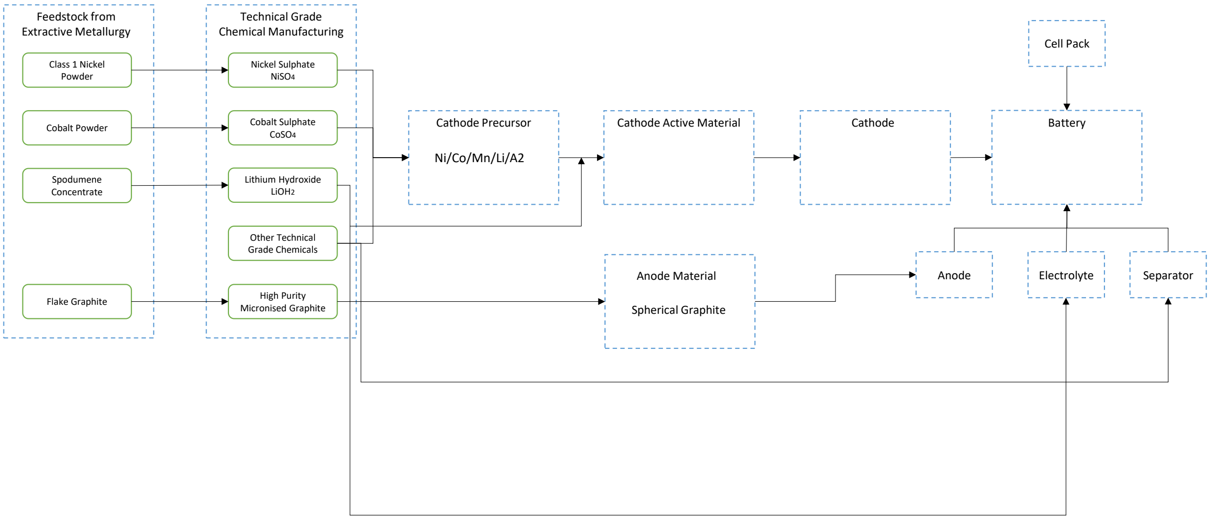

FIGURE 27 – LITHIUM-ION BATTERY SUPPLY CHAIN

Process Overview

To arrive at a final finished product, lithium-ion batteries are typically manufactured in sets of electrodes, then assembled into individual cells. These individual cells are combined in the size and number required to meet a final end use scenario, together with control and charging circuitry, which manages charge and discharge of the collected cells to optimise battery life and prevent catastrophic failure.

Cathode Supply Track

Chemical manufacturing operations acquire raw material feedstock from downstream minerals production facilities for nickel, cobalt and, in this case, spodumene concentrate, as well as a range of other chemicals such as alumina and manganese sulphate from chemical commodity markets. These chemical manufacturing plants then produce technical grade, high purity chemicals.

The technical grade chemicals are purchased by cathode precursor manufacturers who use the technical grade chemicals to produce specific battery grade chemical compounds according to the exact specifications required by their individual cathode active material manufacturer customers. The cathode active material manufacturers formulate cathode active material that is manufactured into the cathode component. The cathode precursor formulation to cathode component manufacture process can sometimes be undertaken by a single supply chain participant.

Typically, the finished cathode material is then mixed with a polymer binder, conductive additives and solvents to form a slurry. This slurry is coated on to the current collector foil backing (as discussed in section 3.6, typically aluminium foil for cathodes), which is then compacted and dried to evaporate the solvent used.

Anode Supply Track

All conventional, and most emerging, lithium-ion battery chemistries rely on carbon for an anode, typically in the form of graphite. This is required to be of a high grade in order to meet stringent process requirements, and demand may be met by either synthetic or natural graphite. Synthetic graphite, produced from petroleum coke, is typically preferred on a technical basis due to its very high consistency and purity (greater than 99 percent) which few natural graphite producers have historically been able to match. However, with a price multiple of up to 10-fold greater than natural flake graphite, manufacturers have significant commercial motivation to use natural graphite where possible. In some cases, the source material may be sufficiently pure as to require no further processing. However, more typically an acid leach is used to further purify lower-grade natural flake graphite while still retaining cost advantage over synthetics.

However sourced, the graphite material is converted into high purity micronized graphite, which is then spheronised by mechanical attrition, before undergoing additional treatment to remove remaining impurities (principally silicon oxides, iron and sulphur). The resulting spherical particles are produced in a variety of standard sizes to suit different end-use scenarios, whereby small particles support faster charging but have a lower power output, and vice versa for larger.

Once spheronised, the graphite is coated with a variety of compounds, typically proprietary to a manufacturer, with the aim of increasing surface area, stability and longevity. Spheronisation, purification and coating is usually, but not always performed by a single supply chain participant.

The final active material may be shipped directly to end users as powder, or in some cases packed into the shape of the anode required. As with cathode active material, in most cases the finished anode material is mixed by the battery producer into a slurry with additives and coated onto a current collector foil backing (as discussed in section 3.6, typically copper).

Electrolyte Supply Track

For most commercial lithium-ion batteries, the core electrolyte solution is based on the lithium hexafluorophosphate salt, dissolved in a non-aqueous, organic solvent such as dimethoxyethane or propylene carbonate.

As commodity chemicals utilised in a number of fields, with a large number of production pathways and globally distributed manufacture, the core constituent ingredients for electrolyte are not typically rate-limited or novel to lithium-ion battery manufacture. Rather, electrolyte manufacturers typically compete on their ability to customise and differentiate their product via the addition of numerous compounds to the base formula to achieve a desired outcome.

Given the intense competition in this space and the large amount of proprietary intellectual property utilised regarding additives, proportions, treatment and mixing, there is significant variance in the finishing process for battery electrolytes.

Separator Supply Track

As noted above, most commercial lithium-ion batteries utilise liquid or gel electrolytes, and therefore rely on a semi-permeable separator membrane. In the vast majority of batteries, this separator is formed from a polymer sheet. Polymer material is sourced from global markets, then heated, layered and processed through a single manufacturing line, resulting in a thin sheet known as precursor film. Depending on the end process requirements, this sheet is then stretched and relaxed at varying temperatures to encourage the formation of pores.

This process may be either 'wet' (in which a plasticizer is added to the mix during heating, then extracted at a later stage via solvent) or 'dry' (in which no plasticizer is added). 'Wet' process allows finer control over the end product, with the ability to tailor the size, number and structure of resulting pores, while 'dry' process is simpler and requires no solvent usage, hence has a lower process cost.

Once the desired pores have formed, the sheet (known as the 'base film') is coated to meet desired specifications. This may include an adhesive, to aid assembly, or a ceramic or HPA coating to improve thermal tolerances and performance.

5.2.2. Key Objectives of the Lithium-ion Battery Value Chain

Generally speaking, the main objectives of the lithium-ion battery supply chain are to:

- Achieve a level of manufacturing productivity that minimises the overall cost of the battery product, resulting in improved customer value that increases markets share and/or supply chain surplus;
- Achieve the battery attributes and levels of battery quality that are required by the market segments targeted by the specific supply chain, therefore increasing market share in those segments; and
- Manage supply risk for end-product manufacturers, therefore ensuring security of supply for target end-customer and resilience of the supply chain.

Optimisation of Battery Manufacturing Cost

Because lowering cost has been a major factor in uptake of lithium-ion batteries over the past two decades, this has been the primary focus of the supply chain. While quality and supply-risk are important factors, lowering cost is likely to remain a major focus at least until electric vehicles achieve price parity with ICE vehicles and other major battery dependent technologies reach maturity.

The average cost of producing a lithium ion cell has decreased from over US$2,500 per kWh in 2000 to around US$200 per kWh today. This is illustrated in Figure 28[151] below. This decrease of approximately 12 percent per annum has primarily been the function of technical improvements in battery chemistries, together with supply chain improvements such as economies of scale in manufacturing processes, manufacturing systems optimisation and competition for input supplies along the supply chain. It is estimated that this cost will halve again to approximately US$100/kWh by 2025. This means that a 40kWh battery pack used in an electric vehicle in 2010 was approximately US$36,000, whereas in 2025 it will be approximately US$4,000.[152] Between 2014 and 2018, there has been an average annual decline in the price of batteries under a large automotive supply contract from US$280 per kWh to between US$120 and US$130/kWh.[153]

[151] Benchmark Minerals (2016), The Lithium Ion Supply Chain Reviewed, September Issue
[152] Ledoux-Pedailes (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment,* IHS Markit, Houston
[153] Leyland, A. (2018), 'Will we have enough lithium in 2025', Benchmark Mineral Intelligence

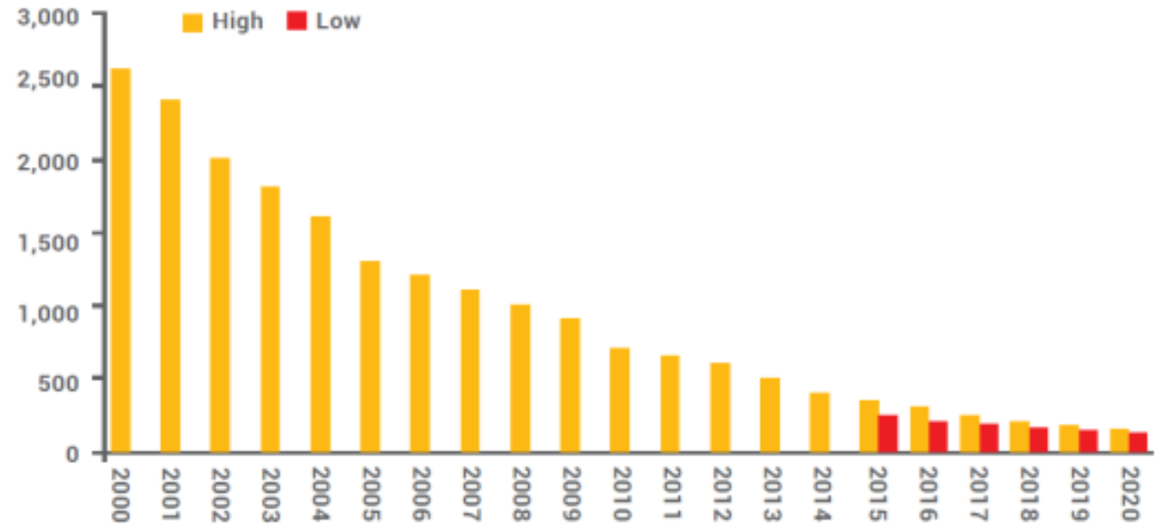

FIGURE 28 – TREND IN THE AVERAGE COST OF PRODUCING A LITHIUM-ION BATTERY

Quality Assurance

Battery quality is a function the quality (or purity) of inputs and quality assurance associated with relatively complex manufacturing processes at each stage of the supply chain. As a result of technical challenges associated with some legacy upstream plants in the PRC (see Section 5.3.1), the quality of technical and battery grade chemicals has become a recent issue for batteries targeting high-end applications.

Managing Supply Risk

Significant capacity at every stage of the lithium-ion battery supply chain upstream from the production of raw materials resides in East Asia, particularly within the jurisdiction of the PRC. As discussed in a later section of this report, the PRC has a demonstrable history of using a range of policy instruments to aggressively defend and promote the development of priority domestic industries, including the lithium-ion battery manufacturing supply chain. The PRC has specific policy frameworks in place that make it difficult for PRC domiciled supply chain participants to transact with downstream participants outside the PRC, except in the case of the end product battery.

This supply chain risk is further exacerbated in the case of the 'critical' raw materials (see Section 4.2) in which the PRC has significant downstream control, such as cobalt. Figure 29[154] below shows the impact of increasing cobalt and lithium prices on the NMC battery pack price, whereby while lithium prices obviously impact battery pack cost, battery pack cost is more sensitive to cobalt prices.

154 Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

2018 NMC 622 Cathode (US$/kWh)

Lithium Carbonate Price US$/t	Cobalt Price $US/lb: US$15	US$25	US$40
US$5,000	-6% / 196	-2% / 205	+2% / 213
US$10,000	-3% / 201	- / 208	+5% / 218
US$14,600	-1% / 206	+2% / 213	+7% / 223

2018 NMC 811 Cathode (US$/kWh)

Lithium Carbonate Price US$/t	Cobalt Price $US/lb: US$15	US$25	US$40
US$5,000	-4% / 121	-2% / 123	+2% / 126
US$10,000	-2% / 124	- / 126	+2% / 129
US$14,600	-1% / 127	+2% / 129	+5% / 132

Figure 29 – Battery Pack Costs for NMC 622 and NMC 811 Cathodes in Different Lithium and Cobalt Price Scenarios

5.2.3. Overall Battery Cost Structure

Cost structures vary across battery chemistries and different supply chains, and are constantly changing with the price of raw materials and improvements in manufacturing processes and scale. However, by way of example, Table 25[155] below summarises the breakdown of the cost of an NMC battery chemistry based on a unit cost of US$23.00 per cell. Almost 60 percent of the total cost is raw materials, with manufacturing processing consuming an additional 37 percent of costs. Overall supply chain margins are typically small at approximately 5 percent. However, as discussed in Section 5.11, they are variable along the supply chain.

Manufacture of the cathode consumes approximately 40 percent of the value of the raw materials, with the anode and separator each consuming an additional 20 percent of the value of the raw materials. Nickel and cobalt account for almost 80 percent of the value of the raw material in a NMC cathode battery chemistry.

Total Cost per Cell	Key Components	Raw Material Costs	Metal Cost in Cathode Active Material
US$23.00	Raw Materials ($13.34) 58%	Cathode ($5.20) 39%	Nickel ($2.60) 50%
	Manufacturing ($8.51) 37%	Anode ($2.53) 19%	Cobalt ($1.45) 28%
	Margin ($1.15) 5%	Electrolyte ($1.60) 12%	Manganese ($0.10) 2%
		Separator ($2.67) 20%	Lithium ($1.05) 20%
		Housing and feedthrough ($1.34)	

Table 25 – Estimated NMC Cell Cost Breakdown

155 Adapted from Berger R (2012) in: CleanTeq (2016), Lithium Ion Batteries (Based on Ni US$7.00/lb; Co US$12.00/lb; Mn US$1.00/lb and Li US$6.50/lb LCE

Even in more advanced NMC chemistries such as NMC 6:2:2, the cathode is still by far the most expensive component of the battery. This is illustrated in Table 26.

Component	Portion of Total Cost	Component	Portion of Total Cost
Separator	5%	Depreciation of equipment	10%
Electrolyte	5%	Fixed costs	8%
Anode	9%	Electricity costs	1%
Cathode	34%	Labour costs	10%
Current collector (copper)	2%	Cost of land	11%
Current collector (aluminium)	4%	Other	1%
Current collector (aluminium)	4%		

Table 26 – Cost Breakdown of a NMC 622 Lithium Ion Battery

5.3. Conversion to Technical and Battery Grade Chemicals

5.3.1. Lithium Hydroxide and Carbonate

The production of lithium carbonate from brine sources has a significant cost advantage over production of lithium carbonate from hard-rock sources because a carbonate is the first product from the brine concentration process. However, because brine based lithium production must transition through a carbonate stage before converting to hydroxide, whereas hard-rock resources can convert directly to hydroxide, hard-rock feedstock can be competitive in lithium hydroxide conversion.

Demand for Lithium hydroxide (LiOH) is expected to grow at a Compound Annual Growth Rate (CAGR) of 16 percent out to 2037, whereas lithium carbonate (Li_2CO_3) will grow at a CAGR of 11percent out to 2037.[156] This is because lithium hydroxide is the preferred feedstock for battery grade chemicals used in NMC battery chemistries, the lithium-ion battery chemistry that is expected to be the dominant chemistry for electric vehicle applications (see Sections 2.2.1and 3.1.4).

The expected growth in demand for lithium hydroxide is forecast in Figure 30[157] below, and is primarily a function of NMC battery demand in the electric vehicle market.

[156] Signum BOX IN: Neometals (2018), An Insiders View of the Lithium Industry, Goldman Sachs
[157] Roskill (2018) IN: Infinity Lithium Corporate Presentation

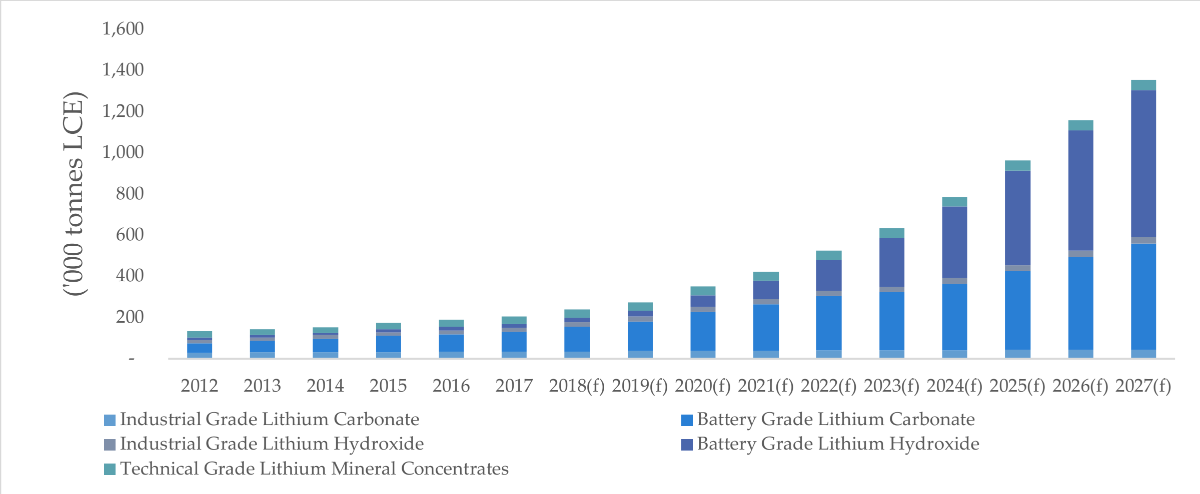

FIGURE 30 – HISTORICAL AND FORECAST MERCHANT SALES OF LITHIUM PRODUCTS (2012 TO 2027)

People's Republic of China Lithium Conversion Industry

The PRC hosts the vast majority of the world's lithium conversion plant capacity. In 2016, the majority of this capacity (55 percent) produced lithium carbonate, with the balance producing lithium hydroxide (26 percent) and lithium metal (19 percent).[158] Most of the feedstock (75 percent) for PRC conversion capacity is spodumene, with brines accounting for approximately 20 percent and local lepidolite production the balance. The viability of these conversion plants is critically dependent on spodumene imports, the majority of which are sourced from Western Australia. Because the PRC does not host any significant lithium hard-rock or brine resources, it is both the world's largest importer and exporter of lithium raw material.[159]

The PRC lithium conversion plant industry commenced in the 1950s when around 18 spodumene and 2 lepidolite based plants began operations. Between 1990 and 2003, approximately 18 plants were closed as more competitive Chilean brine production entered the market. At this point the remaining 2 to 3 plants all had supply contracts with the Western Australian Greenbushes spodumene mine (see Section 4.3.4). The rapid increase in the price of lithium that occured between 2003 and 2008 incentivised owners to recommission closed plants, and additional capacity was bought on stream through retrofitted expansions to these existing plants.[160]

There is widespread consensus that these legacy and retrofitted PRC lithium conversion plants are currently operating substantially below nameplate capacity (in the range of 30 to 70 percent variably). This is understood to be the primary source of current quality issues, with much of this legacy retrofitted infrastructure unable to efficiently convert variable feedstock efficiently. Given there are currently no constraints on the supply of lithium raw material, it is

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[158] Hocking, M., Kan, J., Young, P., Terry, C. and Begleiter, D. (2016), *Lithium 101,* Deutsche Bank Markets Research
[159] Hocking, M., Kan, J., Young, P., Terry, C. and Begleiter, D. (2016), *Lithium 101,* Deutsche Bank Markets Research
[160] Roskill IN: Orocobre (2018), *July Investor Presentation*

this bottleneck in the lithium supply chain that is the main contributor to recent high lithium prices.[161]

To address this, the PRC conversion industry has invested in significant new capacity over the past several years in the form of both brownfields expansions and new plants. Table 27[162] summarises key existing PRC conversion plants and their planned expansions.

Company	Plants	Current Nameplate Capacity (LCE tonnes per annum)	Expansion	Expected Commission	Feedstock Sources	Products
Tianqi	Shehong	17,000			Talison	Carbonate & Hydroxide
	Zhangjiangang	17,000			Talison	Carbonate
Albemarle	Fenyi	10,000	20,000	2018	Talison	Carbonate & Hydroxide
	Pengshan	5,000			Talison	Carbonate & Hydroxide
Ganfeng	Xinyu	29,000	17,600	2018	PMI	Carbonate & Hydroxide
	Ganxian	2,000			Local	Carbonate
General Lithium	Haimen	8,000			Talison (toll),	Carbonate
Ruifu	Feicheng	28,000	10,000		Galaxy	Carbonate & Hydroxide
Yahua	Xuankou X2	8,000			Galaxy; local	Hydroxide
	Meishan	3,000	9,400	2018	Galaxy	Hydroxide
Zhonghe	Guoli	6,000			Local	Carbonate
	Huamen	6,000			Local	Carbonate
RonJie (Youngy)	Meishan	3,000			Local	Carbonate
TOTAL		**132,000**	**57,000**			

Table 27 – Key PRC Lithium Conversion Plants and Expansion Plans

161 Azevedo, M., Campagnol, N., Hagenbruch, T., Hoffman, K., Lala, A. and Ramsbottom, O. (2018), 'Lithium and cobalt – a tale of two commodities', *Metals and Mining June Edition*, McKinsey

162 Merriman, D. (2018), *Bottlenecks in the Lithium Supply Chain: Avoidable or Inevitable?*, Roskill

The following Table 28[163] summarises soon to be commissioned new PRC conversion plants.

Company	Plant	Nameplate Capacity (LCE tonnes per annum)	Expected Commission	Feedstock Sources	Products
Hebei Tianyuan (Optimum Nano)	Tianyuan	15,520	2018	Altura (Pilgangoora)	Carbonate & Hydroxide
Ganfeng	Ningdu	17,500	2018	PMI	Carbonate
General Lithium	Jiangxi	20,000	n.a.	Talison, Galaxy, Pilbara Minerals	Carbonate
Jiangxi SE (JV with Burwill)	Jiangxi	24,440	2018	Tawana/AMA (Bald Hill)	Carbonate & Hydroxide
Sichuan Zhiyuan	Hanwang	14,440	2018	Pilbara DSO (Pilgangoora)	Carbonate & Hydroxide
Greatpower – Jinchuan	Zhenjiang	10,000	2018	TBC	Carbonate
Jiangxi Dongpeng	Xinyu	6,000	2018	Prospect (Zimbabwe)	Carbonate
Fancy Resources	Guandong	10,000	2018	Jourdan, Pilbara, Talison	Carbonate
Lithium Korea	TBC	30,000	TBC	Pilbara	Carbonate & Hydroxide
Nemaska	Shawinigan	33,000	2021	Whabouchi	Carbonate & Hydroxide
TOTAL		**180,900**			

Table 28 – New PRC Lithium Conversion Capacity Scheduled to come on stream

As summarised in Table 29[164] below, the average operating costs of these plants is very much dependent on the nature of the feedstock. Section 7.8.4 contains a more detailed explanation of the economics of lithium hydroxide manufacture.

[163] Merriman, D. (2018), *Bottlenecks in the Lithium Supply Chain: Avoidable or Inevitable?*, Roskill
[164] Hocking, M., Kan, J., Young, P., Terry, C. and Begleiter, D. (2016), *Lithium 101*, Deutsche Bank Markets Research

Conversion Plant Feedstock	Average Operating Cost at Full Capacity
Brine	US$3000 to US$4,000 per tonne
Spodumene	US$4,500 to US$5,000 per tonne
Lepidolite	US$7,000 to US$8,000 per tonne

Table 29 – Average Operating Costs for a PRC Lithium Conversion Plant

Table 27 and Table 28 illustrate the extent of the supply arrangements between current and aspiring Western Australian spodumene producers and the PRC conversion industry. As illustrated in Table 30[165] below, this will continue to be the case for new Western Australian lithium producers and for many new lithium production projects around the world.

Country	Project	Off-taker	Country
Australia	Mount Marion	Ganfeng	PRC
Australia	Bald Hill	Burwill Commodity	PRC (Hong Kong SAR)
Australia	Pilgangoora (Pilbara Minerals)	General Lithium	PRC
Australia	Pilgangoora (Pilbara Minerals)	Ganfeng	PRC
Australia	Pilgangoora (Pilbara Minerals)	Great Wall Motors	PRC
Australia	Pilgangoora (Pilbara Minerals)	Atlas Iron / Sino Steel	PRC
Australia	Pilgangoora (Pilbara Minerals)	Tinci Mining	PRC
Australia	Pilgangoora (Pilbara Minerals)	Posco	South Korea
Australia	Pilgangoora (Altura)	Lionergy	PRC
Australia	Pilgangoora (Altura)	OptimumNano	PRC
Australia	Kwinana (Kidman Resources)	Tesla	United States
Argentina	Cauchari-Olaroz	Ganfeng	PRC
Argentina	Cauchari-Olaroz	Bangchak Petroleum	Thailand
Argentina	Hombre Muerto	Chemphys	PRC
Canada	Whabouchi	Johnson Mathey	United Kingdom
Canada	Whabouchi	FMC	United States
Canada	Whabouchi	Softbank	Japan
Canada	Whabouchi	Northvolt	Sweden
Canada	Whabouchi	LG Chem	South Korea

165 Adapted from: IHS Markit (2018), Lithium and Battery Supply Chain

Country	Project	Off-taker	Country
Canada	Authier	Huan Changuan Lico	PRC
Mexico	Sonora	Nextview New Energy Lion	PRC
Mexico	Sonora	Hanwa Co	Japan
PRC	Ganfeng	LG Chem	South Korea
PRC	Ganfeng	Tesla	United States
PRC	Ganfeng	BMW	Germany
Zimbabwe	Arcadia	Sinomine	PRC
Mali	Bougouni	Suay Chin	Singapore
DRC	Manono	Guanghzhou Tinci	PRC
DRC	Manono	Beijing Nat Batt Technology	PRC
Namibia	Rubicon	Jiangxi Jinhui Lithium	PRC

TABLE 30 – EMERGING LITHIUM PROJECT OFFTAKE AGREEMENTS

The Emerging Western Australian Lithium Conversion Industry

Western Australian lithium production has only ever been exported as spodumene concentrate (and a small amount DSO), primarily to the PRC lithium conversion industry discussed in the previous subsection. Indeed, currently over 90 percent of Western Australian lithium production is exported in the form of spodumene concentrate to the PRC for conversion into lithium carbonate or hydroxide. Furthermore, (as summarised in Table 30) many of the new and soon to be commissioned Western Australian lithium producers will be exporting spodumene concentrate (and even DSO) to the PRC lithium conversion industry.

The economics of lithium conversion plants is determined primarily by the cost of the raw material feedstock (in this case spodumene), key reagents such as sulphuric acid, soda ash and energy. Historically, with the exception of the cost of spodumene, these factors, together with an historical downstream preference for lower cost lithium carbonate, have limited the ability of a Western Australian conversion plants to compete with the PRC conversion industry. However, escalating demand for lithium hydroxide combined with increased supply of spodumene facilitating economies of scale, supply and quality challenges facing PRC plants, and a strategic rationale to invest in capacity outside the PRC (see Section 7.7.2), have rendered investment in Western Australian conversion capacity compelling. While there remains a substantial capital cost differential between the PRC and Western Australia, the operating cost differential has been narrowed as a result of rising costs in the PRC and tempered by transport cost savings (approximately 7 tonnes of spodumene (6 percent lithium content) concentrate are required to produce a single tonne of lithium hydroxide). This economics of lithium hydroxide production is discussed further in Section 7.8.

Tianqi is constructing a processing plant at Kwinana, with Stage 1 works having commenced in October 2016 and a further Stage 2 expansion announced in October 2017 at a total capital cost of AUD $700 million. The facility expects to be producing 48,000 tonnes of lithium hydroxide by end of 2019[166]. Tianqi and construction partners MSP Engineering estimate that Stage 1 alone, at 24,000 tonnes per annum of lithium hydroxide, will represent approximately 60 percent of global production.[167]

Albemarle has plans for even more substantial processing operations, and subject to regulatory approvals proposes to construct a lithium hydroxide plant at Kemerton in Western Australia, producing up to 100,000 tonnes per annum by 2028.[168]

As summarised in Table 31 below, other emerging Western Australian lithium producers also have plans to establish conversion capacity in Western Australia.

Project	Proponent	Anticipated Conversion Capacity	Expected Commissioning
Mt Marion	Neometals	10,000 tonnes per annum lithium hydroxide	2021
Mt Holland Lithium	Kidman Resources, SQM & Western Areas	44,000 tonnes per annum lithium hydroxide	2021

TABLE 31 – ASPIRING WESTERN AUSTRALIAN LITHIUM CONVERTERS

5.3.2. Nickel and Cobalt Sulphate

As is the case for lithium, the manufacturing process that produces battery grade precursor materials for cathode manufacture requires nickel and cobalt feedstock in a specific chemical form, typically a hydrated metal sulphate. In the case of nickel, this is primarily nickel (II) sulphate hexahydrate ($NiSO_4 6H_2O$), and in the case of cobalt, primarily cobalt (II) sulphate heptahydrate ($CoSO_4 7H_2O$).

Nickel sulphate is comprised approximately 22 percent nickel by weight. It can be produced by dissolving high grade nickel products in sulphuric acid in the presence of oxygen. Class 1 nickel powder or briquettes (see Section 4.4.4) are used for this process in order to optimise reaction time between the nickel and sulphuric acid. Theoretically, class 2 nickel products can be used to manufacture nickel sulphate, however, the cost to purify and dissolve lower purity nickel product renders its use sub-economic.[169]

Table 32 below summarises major producers of nickel chemical compounds for the lithium-ion battery supply chain.

[166] *Tianqi Lithium approves $300m Kwinana lithium plant expansion*, Ingram, T, reported Australian Financial Review, 27 October 2017

[167] *Tianqi Lithium Kwinana Lithium Hydroxide Processing Plant Early Commissioning of Non-Process Infrastructure*, published MSP Engineering, 22 March 2018

[168] *Albemarle wins EPA tick for Kemerton lithium plant*, McKinnon, S, published The West Australian Newspaper 15 June 2018; *EPA recommends approval for South West lithium manufacturing plant*, published Environmental Protection Agency, 15 June 2018

[169] Campagnol, N., Hoffman, K., Lala, A. and Ramsbottom, O. (2017), The Future of Nickel: A Class Act, McKinsey & Company

Company	Country	Market Capitalisation – US$ (2018)	Revenues- US$ (2018)
Alconix Corporation	Japan	$0.4B	$1.8B
GEM Co	PRC	$3.2B	$1.6B
Jilin Jien Nickel Industry Co	PRC	$0.3B	$0.5B (est)
Jinchuan Group International Resources Co	PRC (Hong Kong)	$1.7B	$1.1B
Kansai Catalyst	Japan	Unlisted	No reliable estimate
Mechema Chemicals International	Taiwan	$0.2B	$0.1B
Nicomet Industries	India	Unlisted	No reliable estimate
NorNickel	Russian Federation	$28.4B	$9.1B
Seido Chemical	Japan	Unlisted	No reliable estimate
Shaanxi Huaze Nickel & Cobalt Metal Co	PRC	$0.3B	$0.1B
Sumitomo Metal Mining	Japan	$10.4B	$8.2B
Umicore	Belgium	$13.9B	$13.8B
Zenith Chemical Corp	Taiwan	Unlisted	No reliable estimate

Table 32 – Major Global Suppliers of Nickel Chemicals for the Lithium-ion Battery Supply Chain

Cobalt sulphate is prepared by reacting cobalt metal, oxide or hydroxide with sulphuric acid. The solution is then heated to drive off water, resulting in hydrated forms of cobalt sulphate. While all commonly produced cobalt products can be utilised in battery manufacturing, sulphates are the optimum form, requiring the least amount of processing prior to fabrication of the battery cathode.

However, the sulphate compound is highly hydroscopic and will absorb water from the atmosphere, making transport over long distances challenging. For this reason, cobalt sulphate production is typically concentrated closer to downstream customers, primarily in East Asia. For example, approximately 80 percent of refined forms of cobalt suitable for battery use, including sulphates, are produced in the PRC.[170] Alternatively, this challenge could be overcome by manufacturing downstream chemicals in closer proximity to upstream cobalt chemical manufacturing if economically viable.

Global supply of refined cobalt metal is highly convoluted, with a number of precursor forms traded prior to final conversion into sulphates. Further, producers and manufacturers are not necessarily incentivised to be transparent regarding their supply chains, given the human rights concerns relating to production discussed in Section 4.5.3.

[170] *What if China corners the cobalt market?*, published *The Economist*, 24 March 2018

Table 33 below summarises major producers of cobalt chemical compounds for the lithium ion battery supply chain.

Company	Country	Market Capitalisation – US$ (2018)	Revenues – US$ (2018)
Freeport McMoRan Inc	USA	$21.0B	$15.9B
GEM Co	PRC	$3.2B	$1.6B
Glencore PLC	Switzerland	$43.0B	$205.5B
Hitachi Metals	Japan	$5.3B	$8.9B
Jinchuan Group International Resources Co	PRC (Hong Kong)	$1.7B	$1.1B
Kansai Catalyst	Japan	Unlisted	No reliable estimate
NorNickel	Russian Federation	$28.4B	$9.1B
Sumitomo Metal Mining	Japan	$10.4B	$8.2B
Zhejiang Huayou Cobalt Co	PRC	$6.5B	$1.5B

TABLE 33 - MAJOR GLOBAL SUPPLIERS OF COBALT CHEMICALS FOR THE LITHIUM-ION BATTERY SUPPLY CHAIN

Western Australia's Emerging Nickel and Cobalt Sulphate Industry

BHP Nickel West is currently constructing a 100,000 tonne per annum nickel sulphate production facility at its Kwinana nickel refinery.[171] The facility is expected to commence production in the second quarter of 2019, with plans to expand to 200,000 tonnes per annum, at which point it will be the world's second largest nickel sulphate production facility and a major supplier of nickel sulphate to the lithium-ion battery supply chain.[172] Nickel West is also undertaking technical and commercial investigations into the establishment of cobalt sulphate production at its Kwinana Refinery.

5.3.3. Graphite

Lithium-ion battery anode material requires very high quality carbon raw materials. These materials are formed into blocks and baked at 700 to 900^{0}C. The stock is then graphitised in a furnace at temperatures of up to 3,200^{0}C to achieve shape and density specifications. This material is then micronized to the specific battery manufacturer's size specification, typically in the range of 10 to 25 microns.[173] The manufacture of graphite is heavily concentrated in the PRC and Brazil.

[171] *Nickel sulphate project at Kwinana refinery* in *Nickel West – energising our future,* published BHP Billion, 9 August 2017
[172] *Nickel West poised to double up Kwinana lithium-ion supply plans*, McKinnon, S, published The West Australian, 17 October 2017
[173] Benchmark Minerals (2016), The Lithium Ion Supply Chain Reviewed, September Issue

5.4. Cathode Precursor Material

Cathode precursor is typically a mixed metal hydroxide manufactured by mixing liquid nickel sulphate, cobalt sulphate and either aluminium or manganese sulphate in a batch tank. This is then pumped into a reactor and mixed with ammonium hydroxide and caustic soda to precipitate a mixed metal hydroxide.

This is a particularly opaque sector of the lithium-ion supply chain with much cathode precursor manufacturing capability either integrated with conversion capacity or with facilities that produce cathode active material.

BHP Nickel West has indicated that it sees cathode precursor manufacture as its natural end point for the Kwinana Refinery.

5.5. Production of Cathode Active Material

The material that takes in and discharges the lithium-ions is called active material. The production of active material involves two separate procedures. The first is the chemical bonding process between the various precursor active materials. The second process is to adjust the synthesised active materials and coat them onto the electrode current collector. A cathode electrode is typically manufactured by mixing active material powder, binding powder, solvents and additives into a paste and pumping that paste using a coating machine.

The quality of the cathode material is a critical factor in the overall performance of the cell. For the production of high quality batteries, quality control must be in place from the raw material phase, which is why many of the major cell manufacturers such as Panasonic, LG Chem and BYD have developed in-house cathode material production capacity.

The cathode material market is very dynamic and is currently going through a period of de-concentration with more companies entering the marketplace. The 61 percent market share controlled by Umicore, Nichia and Toda Kogyo in 2011 is now substantially more fragmented with a number of major global chemical companies such as BASF, Dow, 3M, Dupont and Mitsubishi having recently entered the market.[174] Furthermore, innovation that leads to new cathode materials and chemistries, intensive competition between major global chemical companies and government policy interference will continue to impact the dynamics of a cathode manufacturing sector.[175]

Table 34 below summarises major producers of cathode active material for the lithium-ion battery supply chain.

[174] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission

[175] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission

Company	Country	Market Capitalisation – US$ (2018)	Revenues – US$ (2018)
3M	United States	$123.6B	$31.7B
BASF	Germany	$84.6B	$74.4B
Beijing Easpring Technology Material Co	PRC	$0.2B	$311.6M
DowDuPont	United States	$156.8B	$62.5B
Formosa Lithium Iron Oxide Corp	Taiwan	Unlisted	No reliable estimate
Hunan Reshine New Material Co	PRC	Unlisted	No reliable estimate
Johnson Matthey	United Kingdom	$8.6B	$18.5B
L&F Material Co	South Korea	$0.9B	$0.4B
LG Chem	South Korea	$22.9B	$22.6B
Minmetals Capital Co	PRC	$4.4B	$2.2B
Mitsubishi Materials Corp	Japan	$49.1B	$60.9B
Nichia Corp	Japan	Unlisted	No reliable estimate
Ningbo Shanshan Co	PRC	$2.7B	$1.3B
Nippon Denko Co	Japan	$0.4B	$0.6B (est)
Shanshan Technology	PRC	$2.3B	$1.3B
Sumitomo Metal Mining	Japan	$10.4B	$8.2B
Tianjin Bamo Technology Co	PRC	Unlisted	No reliable estimate
Toda Kogyo	Japan	$0.2B	$0.1B
Umicore	Belgium	$13.9B	$13.8B

Table 34 - Major Global Suppliers of Cathode Active Material for the Lithium-ion Battery Supply Chain

5.6. Production of Anode Active Material

Because graphite products are relatively cheap and produced ubiquitously, barriers to entry in anode production and margins associated with the business are typically very low.[176] Table 35 summarises the main manufacturers of anode material.

[176] Campagnol, N., Hoffman, K., Lala, A. and Ramsbottom, O. (2017), The Future of Nickel: A Class Act, McKinsey & Company

Company	Country	Market Capitalisation – US$ (2018)	Revenues – US$ (2018)
3M	United States	$123.6B	$31.7B
BTR New Energy Materials	PRC	Unlisted	No reliable estimate
ConocoPhillips	United States	$90.8B	$29.1B
DowDuPont	United States	$156.8B	$62.5B
Hitachi Chemical	Japan	$4.18B	$5.9B
Heraeus	Germany	Unlisted	No reliable estimate
Imerys Graphite & Carbon	Switzerland	Unlisted	$4.8B
Kureha Chemical Industries	Japan	$1.6B	$1.3B
LG Chem	South Korea	$22.9B	$22.6B
LS Corp	South Korea	$2.0B	$8.4B
Mitsubishi Materials Corp	Japan	$49.1B	$60.9B
Nippon Carbon	Japan	$0.8B	$0.3B
Pyrotek	United States	Unlisted	No reliable estimate
SGL Carbon	Germany	$1.4B	$1.0B
Shanshan Technology	PRC	$2.8B	$1.3B
Shin-Etsu Chemical	Japan	$37.8B	$10.8B
Superior Graphite	United States	Unlisted	No reliable estimate
Tokai Carbon	Japan	$4.4B	$0.9B

Table 35 - Major Global Suppliers of Anode Material for the Lithium-ion Battery Supply Chain

5.7. Production of Other Lithium-ion Battery Components

5.7.1. Electrolyte

Electrolytes are manufactured from lithium salt compounds such as lithium hexafluorophosphate ($LiPF_6$) and various solvents. In the case of a liquefied lithium-ion battery (LIB) the electrolyte is a liquid solution. However, in polymer lithium-ion batteries (PLB), the electrolyte can be a gel or solid phase.

In 2017, the global electrolyte market (across all chemistries) was worth approximately US$3.82 billion, and is expected to grow at a CAGR of 9.3 percent to reach US$8.53 billion by 2026.[177] While the surge in global demand has underpinned strong flow-through demand and interest in increased production, long lead times remain a barrier. In particular, the current lithium hexafluorophosphate dominated chemistries require handling of hazardous fluorinated compounds, resulting in stringent process demands that lead to estimated five-to-seven-year build times.[178] Anecdotally, several PRC-based firms are contemplating entry into this sphere.[179]

Table 36 below summarises the major manufacturers of electrolytes.

[177] *Battery Electrolyte - $8.53 Billion Global Market Outlook to 2026*, Wood, L, published ResearchAndMarkets.com, 23 August 2018

[178] *Trends in Lithium Electrolytes*, Clemens, K/Jaffe, S, published Design News Magazine, 27 August 2018.

[179] *Ibid*

Company	Country	Market Capitalisation – US$ (2018)	Revenues – US$ (2018)
BASF	Germany	$84.6B	$74.4B
BYD Co	PRC	$18.8B	$20.4B
Daikin Industries	Japan	$40.0B	$20.8B
Do-Fluoride Chemicals Co	PRC	$1.2B	$0.5B
DowDuPont	United States	$156.B	$62.5B
Guangzhou Tinci Materials Technology	PRC	$1.2B	$0.3B
Hebei Jinniu Chemical Industrial Co		$0.5B	$0.1B
LG Chem	South Korea	$22.9B	$22.6B
Mitsubishi Materials Corp	Japan	$49.1B	$60.8B
Mitsui Chemicals	Japan	$5.1B	$12.1B
panaX ETEC	South Korea	Unlisted	No reliable estimate
Samsung C&T	South Korea	$22.0B	$31.2B
Shanshan Technology	PRC	$2.8B	$1.3B
Shenzhen CAPCHEM Technology Co	PRC	$1.3B	$0.3B
SoulBrain Co	South Korea	$0.9B	$0.7B
UBE Industries	Japan	$2.83B	$5.4B
Zhangjiagang Guotai Huarong New Material Co	PRC	Unlisted	No reliable estimate

TABLE 36 - MAJOR GLOBAL SUPPLIERS OF ELECTROLYTES FOR THE LITHIUM-ION BATTERY SUPPLY CHAIN

5.7.2. Separators

The material that is used to separate the cathode from the anode (separator) is usually made from nylon, polypropylene and polyethylene. Because the separator determines the ion-transportation capability of the battery, its quality has a direct impact on battery performance.

As illustrated in Table 37 Japanese companies are the main players in the production of separators.

Company	Country	Market Capitalisation – US$ (2018)	Revenues – US$ (2018)
Applied Materials Incorporated	United States	$37.9B	$14.5B
Asahi Kasei	Japan	$21.1B	$18.3B
Cangzhou Mingzhu Plastic Co	PRC	$1.0B	$0.5B
Celgard	United States	Unlisted	No reliable estimate
DowDuPont	United States	$156.8B	$62.5B
ENTEK International	United States	Unlisted	No reliable estimate
Evonik Industries	Germany	$16.9B	$16.6B
LG Chem	South Korea	$22.9B	$22.6B
Mitsubishi Materials Corp	Japan	$49.1B	$60.8B
SK Innovation Co	South Korea	$16.5B	$40.7B
Teijin	Japan	$3.7B	$21.1B
Toray Industries Inc	South Korea	$1.3B	$1.9B

TABLE 37 - MAJOR GLOBAL SUPPLIERS OF SEPARATORS FOR THE LITHIUM-ION BATTERY SUPPLY CHAIN

While both ceramic and HPA processes are under refinement, HPA is at present a more mature technology with more widespread adoption (see Section 3.4). Over the medium term, global demand for HPA for use in lithium-ion battery separators is predicted to grow from approximately 2,700 tonnes in 2018 to 15,000 tonnes in 2025.[180]

5.8. Lithium-ion Battery Cell Manufacturers

Lithium-ion battery cell manufacturers assemble the cathode (of various chemistries), anode, electrolyte, separator and other minor components into a functional lithium-ion battery cell.

The major lithium-ion battery manufacturers are the traditional electrical appliance manufacturers, 96 percent of which are located in the PRC, Japan and Korea. Table 38 below lists the major battery cell manufacturers.

[180] *Global Separator High Purity Alumina Demand*, in *FORECAST SURGE IN HPA DEMAND DRIVEN BY LITHIUM-ION BATTERIES*, published Altech Chemicals/Deutsche Bank Market Research, ASX Announcement 21 June 2016

Company	Country	Market Capitalisation – US$ (2018)	Revenues – US$ (2018)
BYD Co	PRC	$18.8B	$20.4B
Continental AG	Germany	$34.7B	$51.2B
General Motors Company	United States	$47.3B	$145.6B
Hon Hai Precision Industry Co (Foxconn)	Taiwan	$43.3B	$151.8B
Johnson Controls	United States	$36.5B	$30.2B
LG Chem	South Korea	$22.91B	$22.6B
Maxwell Technologies	United States	$0.2B	$0.1B
Panasonic Corp	Japan	$29.1B	$70.2B
Samsung C&T	South Korea	$22.0B	$31.2B
Tianjin LISHEN Battery Co	PRC	Unlisted	No reliable estimate
Toshiba Corp	Japan	$19.3B	$49.9B

Table 38 - Major Global Suppliers of Cells for the Lithium-ion Battery Supply Chain

There are a number of other smaller cell manufacturers, namely Ahead Cell Technology, HZM Electronics Co, Shenzhen Easter Battery Co, Dongguan Perfect Amperex Technology and Shenzhen BAK Battery Co.

5.9. Lithium-ion Battery Cell Pack Manufacture

Battery cell pack manufacturers assemble battery cells into battery packs for specific product models across applications for personal and portable electronic devices, ESS and electric vehicles.

The battery pack is a key part of the electric vehicle power train, accounting for approximately 30 percent of the total vehicle value. Of total pack costs, manufacturing costs accounts for approximately 40 percent. Different car manufacturers have different strategies with respect to the sourcing or manufacture of battery packs, with the majority of OEMs producing electric vehicles maintaining a technological core competency around battery pack design and battery management systems to keep some control and profit margin. Nevertheless, strategies can be varied. For example:

- Japanese and Chinese OEMs typically keep a tighter control on all steps up to the segment of the cell and battery pack manufacturing process.
- Tesla produces the majority of its key battery pack components in its California plant in Freemont, including battery packs using cells supplied by Panasonic.
- GM outsources its entire cell and pack manufacturing, including the battery management system.
- BYD designs, produces and assembles in-house the complete electric power train system including cells, battery pack and BMS.

- The Mitsubishi Outlander PHEV's battery pack is assembled through a joint venture between various Mitsubishi subsidiaries, namely GS Yuasa, Mitsubishi Corporation and Mitsubishi Motors Corporation.
- The Nissan Leaf battery pack is supplied by Automotive Energy Supply Corporation (AESC), a company owned by Nissan and NEC.
- BMW designs and develops its core electric drive components including the power electronics, Battery Management System (BMS) and the whole electrical system using Samsung SDI cells.
- Renault assembles its BEC model in its plant and the battery pack including BMS is developed in close partnership with LG Chem, who also provides the cells.

The following Table 39 summarises some of the main battery pack manufacturers.

Company	Country	Market Capitalisation – US$ (2018)	Revenues – US$ (2018)
AC Propulsion	United States	Unlisted	No reliable estimate
All Cell Technologies	United States	Unlisted	No reliable estimate
BYD Co	PRC	$18.8B	$20.4B
China Aviation Lithium Battery Co	PRC	Unlisted	No reliable estimate
Contemporary Amperex Technology Co (CATL)	PRC	$23.3B	$0.6B
Continental AG	Germany	$34.7B	$51.2B
EnerDel	United States	Unlisted	No reliable estimate
Exergonix Inc	United States	Unlisted	No reliable estimate
FDG Electric Vehicles	PRC (Hong Kong)	$0.3B	$0.1B
GS Yuasa Corp	Japan	$2.1B	$3.7B
General Motors Company	United States	$47.3B	$145.6B
Guoxuan High-Tech Co	PRC	$2.3B	$0.7B
Hitachi Chemical	Japan	$4.2B	$5.9B
Johnson Controls	United States	$36.5B	$30.2B
LG Chem	South Korea	$22.9B	$22.6B
NEC Corp	Japan	$7.1B	$23.5B
Panasonic Corp	Japan	$29.1B	$70.2B
Samsung C&T	South Korea	$22.0B	$31.2B
Shaanxi J&R Optimum Energy Co Ltd	PRC	$.8B	$1.4B
Tesla Inc	United States	$52.72B	$11.8B
Tianjin LISHEN Battery Co	PRC	Unlisted	No reliable estimate
Wanxiang Group	PRC	$2.38B	No reliable estimate
XALT Energy	United States	Unlisted	No reliable estimate

Table 39 - Major Global Suppliers of Battery Packs for the Lithium-ion Battery Supply Chain

It would seem there has been global over-capacity in battery manufacturing since at least 2014, with this primarily having been the result of initially overly optimistic assumptions regarding electric vehicle demand. Indeed, in 2014 it was estimated that the PRC was utilising around 10 percent of capacity, Japan 40 percent, Korea 30 percent, the United State 25 percent and

European Union (EU) 22 percent.[181] It was also estimated that new battery plant builds would not be necessary until around 2019.[182]

However, in recent years, the global lithium-ion battery industry has undergone a significant expansion. In 2016, there were at least 12 lithium-ion battery factories under construction with multi-gigawatt hour production capability. This represented a capital expenditure of approximately US$20 billion, with about 70 percent of this expenditure in the PRC.[183] These plants were constructed by a number of major players, including Samsung SDI, Panasonic, LG Chem, Tianjin Lishen, Amperex Technology, Boston Power and Tesla.

The Lithium-ion Battery 'Mega-factories'

The term 'Battery Megafactory'[184] refers to large (annual capacity in excess of 1GWh of cells), often significantly vertically integrated, lithium-ion battery manufacturing facilities. 'Battery Megafactories' are becoming increasingly commonplace as the mechanism through which the battery industry leaders dramatically scale-up production to meet expected global demand for lithium-ion batteries.

There are currently approximately 25 operational lithium-ion battery 'mega-factories' and 36 in the construction pipeline out to 2023, for a total capacity of 470GWh.[185]

As illustrated in the below Figure 31[186], approximately half of the 'mega-factory' capacity coming online by 2023 will be in the PRC, with a further 10 percent in throughout Asia. This will serve to reinforce the Asian region's dominance in the lithium-ion battery manufacturing space.

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[181] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission
[182] Levedeva, N., Di Persio, F. and Broon-Brett, L. (2017), *Lithium Ion Battery Value Chain and Related Opportunities for Europe,* European Commission
[183] Benchmark Minerals (2016), The Lithium Ion Supply Chain Reviewed, September Issue
[184] Benchmark Mineral Intelligence
[185] Leyland, A. (2018), 'Will we have enough lithium in 2025', Benchmark Mineral Intelligence
[186] "Benchmark Mineral Intelligence IN Neometals: Lithium Battery Insider"

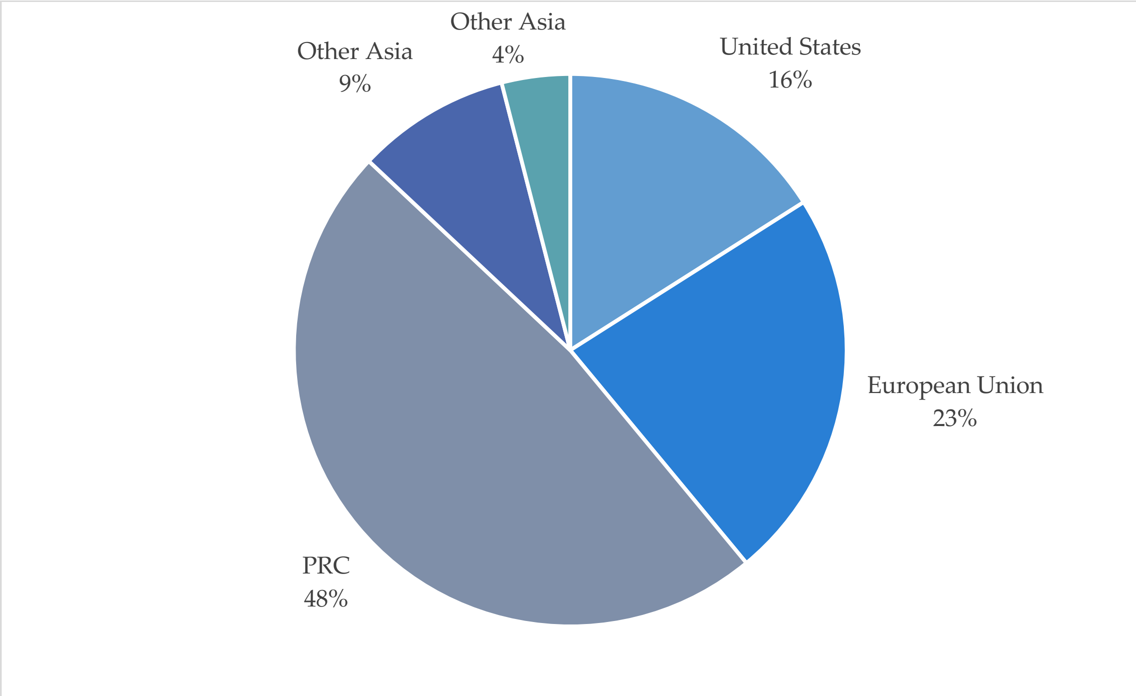

Figure 31 – Geographical Distribution of New Battery Manufacturing Capability Coming on Stream

Furthermore, as illustrated by Table 40[187] below, the vast majority of new capacity coming on stream both in Asia and globally represents new investments by existing Asian battery manufacturers.

Battery Manufacturers Investing in GigaFactories (Major Capacity Additions)	2016 (GWh)	2020 (GWh)
Tesla	0	35
Panasonic	5	6
LG Chem	7	25
Samsung	5	6
CATL	4	50
Lishen	3	20
BYD	2	10
OptimumNano	4	20

Table 40 – New Battery Manufacturing Capacity Coming on Stream by Battery Manufacturer

[187] Ledoux-Pedailes (2018), *Are Electric Vehicle Makers Putting the Cart Before the Horse: Limited Battery Raw Materials could Impact EV Deployment*, IHS Markit, Houston

Sonnen Battery Manufacturing Plant - South Australia

In February 2018, German battery manufacturer Sonnen GmbH announced it will establish a battery manufacturing plant in South Australia to capitalise on what is considers to be the fastest global growth market for rooftop solar storage. Sonnen is the world's largest producer of household solar energy storage solutions and currently has manufacturing operations in Germany and the United States.

The South Australian plant is anticipated to produce approximately 10,000 solar storage batteries per annum for the first five years.

The SonnenBatterie product to be manufactured is a lithium iron phosphate (LiFePO4) battery and is available in storage sizes ranging from 2kWh to 16kWh (in 2kWh increments).

However, Sonnen will import the battery cells, and will rely on local supply for the rest of the materials.[188] This effectively means that the South Australian Sonnen plant will be assembling finished battery components and will not be engaged in downstream processing of raw materials or the manufacture of battery cell components.

In September of this year, Sonnen announced that it will use the former General Motors Holden factory for this purpose and as its central shipping facility for Asia and the South Pacific region.[189]

5.10. Recycling Lithium-ion Batteries

Greater recycling of waste batteries and increased re-use or second use will bring benefits for both the environment and the economy by reducing waste and providing additional economic activity. If they can be recovered, recycling will also mitigate the dependence on certain critical materials such as cobalt.

Recycling lithium-ion batteries is a complex and costly process hindered by the absence of a standardised product across the lithium-ion battery market, which has resulted in a wide variety of chemistries and battery formats. Additional complexities arise from the need for facilities designed for the dismantling and pre-treatment of large electric vehicle batteries to reach sizes compatible with recycling processes.

There are three main methods for recycling lithium-ion batteries:

- **Mechanical**
  Mechanical treatment includes crushing and physical separation of components, and recovery of the 'black mass', which contains valuable metals such as cobalt, nickel, manganese and lithium.

- **Pyrometallurgical**
  In this process, spent lithium-ion battery cells are processed at a high temperature without any mechanical pre-treatment, with batteries loaded into the furnace directly. This type of processing recovers cobalt, nickel, copper and iron in the form of a metal alloy. Metals such as aluminium, manganese and lithium are lost in the slag, and plastic and other organic components are incinerated.

188 Reuters (2018), Germany's Sonnen to set up a battery plant in South Australia – February 22, 2018

189 http://www.manmonthly.com.au/news/sonnen-manufacture-batteries-adelaide/

- **Hydrometallurgical**
  These methods include mechanical pre-treatment. Followed by metal recovery from the 'black mass' by means of leaching, precipitation, solvent extraction, ion-exchange resins and bioleaching. This method can be used to recover cobalt, nickel, copper and iron, as well as lithium at high purity. It is often preceded by a thermal pre-treatment process to remove organic compounds and graphite which adversely affect the leaching and solid-liquid separation steps of the recycling process.

In most cases vehicle batteries are designed for the life of the vehicle, that is, for around 12 to 15 years. However, estimates of average vehicle battery life can be as low as 5 years.[190] Most electric vehicle manufacturers already have standard operating procedures in place for waste batteries and contracts in place with recyclers.[191]

Australia does not have any specific lithium-ion battery collection or transfer infrastructure, with batteries that are recovered typically collected with other 'e-waste'.[192] A number of operations such as PF Metals, MRI (Aust) Pty Ltd, Powercell, Sims E-Recycling and TESS-AMM collect lithium ion batteries and either perform limited processing or simply export the spent batteries to plants in Asia for recycling. Larger electric vehicle and ESS waste battery processing capacity will need to be in place by the early 2020s in Australia as the first significant wave of domestic battery waste from these sources emerges.

The below Table 41[193] illustrates several scenarios for estimated waste lithium-ion batteries in Australia.

[190] Lewis, H. (2016), *Lithium-ion Battery Consultation Report,* Helen Lewis Research
[191] Lewis (2016) IN: Randle Environmental Consulting and Blue Environment (2016), Waste Lithium Ion Battery Projections, Department of Environment and Energy
[192] Randle Environmental Consulting and Blue Environment (2016), Waste Lithium Ion Battery Projections, Department of Environment and Energy
[193] "Randle Environmental Consulting and Blue Environment (2016), Waste Lithium Ion Battery Projections, Department of Environment and Energy"

Category	Projection	2016 (t)	2036 (t)	CAGR
Total Li-Ion	Best	3340	137,618	20.4%
	High	3340	187,984	22.3%
	Low	3340	100,073	18.5%
Handheld	Best	2770	67,912	17.3%
	High	2770	89,115	19.0%
	Low	2770	51,512	15.7%
EV	Best	571	55,655	25.7%
	High	571	79,754	28.0%
	Low	571	38,359	23.4%
ESS	Best	1161	14,051	13.3%
	High	1161	19,115	15.0%
	Low	1161	10,202	11.5%

TABLE 41 – PROJECT AUSTRALIAN LITHIUM-ION BATTERY WASTE

5.11. Overall Competitive Dynamics of the Lithium-ion Battery Value Chain

5.11.1. East Asia's Competitive Advantage

It is clear from the discussion in the preceding subsections, that with the exception of primary production of raw materials (which is dependent on the geography of natural resources), almost all of the mid-stream and the vast majority of the downstream lithium-ion supply chain is located in Korea, Japan and particularly the PRC. The PRC is the world's largest producer lithium based chemicals, cobalt based chemicals, flake graphite, spherical graphite, lithium-ion anode material, lithium-ion anodes and lithium-ion batteries. Current trends in investment strongly indicate that this will continue to be the case for the foreseeable future. Indeed current expansion plans are expected to push the PRC's share of lithium-ion battery production to more than 60 percent by 2020.[194]

The dominance of the East Asian region in the lithium-ion supply chain is primarily the function of four main factors. These are discussed in the following subsections.

Economics Associated with First Mover Advantage

Lithium-ion batteries were first commercialised in the early 1990s by Japanese company Sony. With the vast majority of personal and portable electronic devices manufactured in East Asia, local battery manufacturing facilities have continued to expand over the course of the past

[194] Resources and Energy Quarterly June 2017

three decades to meet demand from this sector. This has resulted in substantial installed lithium-ion battery manufacturing capability and expertise in the East Asian region.

This has meant that operators in the region have been able to respond quickly and cost effectively to increased demand from the electric vehicle sector through brown-fields expansion of existing facilities, using intellectual property and expertise that has been developed over the past 30 years. Other regions do not possess this very significant advantage.

Very Large Regional Market

The East Asian region is a very significant current and future market for all lithium-ion battery product applications. The large and growing populations is a significant market for personal and portable electronic devices (see Section 2.4), a sector for which the East Asian region is also the world's largest manufacturer and exporter, as well as for ESS (see Section 2.3). In particular, as discussed in detail in Section 2.2, the PRC is the world's largest electric vehicle market and with a current market penetration rate of only approximately 1.4 percent, presents significant future growth.

Ceteris paribus, there is significant logistical productivity to be accrued by locating large-scale battery production facilities in close geographical proximity to manufacturing facilities that are producing products that use those batteries that, in turn, service very large local and export end product markets.

Cost Structure that is aligned with the Economics of the Supply Chain

As summarised in Table 42[195] below, the barriers to entry in the lithium-ion battery supply chain upstream from the production of raw materials and their chemical products are mostly low to medium in the midstream sectors, and medium in the downstream sectors.

	Upstream Resources	**Lithium Compounds**	**Cathode Materials**	**Lithium Hexafluorro - phosphate**	**Electrolyte**	**Batteries**
Entry Barrier	High	High	Low	Medium	Low	Medium
Capital Requirement	High	Medium	Low	Low	Low	Medium
Production Know-how	Medium	High	Low	High	Low	Medium
Clear Industry Standard	Yes	Yes	No	Yes	Yes	Yes
Access to Raw Materials	Medium	Hard	Medium	Medium	Medium	Easy

TABLE 42 – COMPETITIVE DYNAMICS OF THE LITHIUM-ION BATTERY SUPPLY CHAIN

This results in the lithium-ion battery supply chain operating under a typical 'manufacturer's smile' margin profile. By virtue of high barriers to entry that are the result of the fact that natural resources are geographically constrained and fundamentally limited, upstream producers of raw materials and their derivatives are able to extract relatively large margins. Similarly,

[195] Ganfeng Lithium (2018) IN: NeoMetals: Insider's View of Lithium

downstream producers of final products who by virtue of significant and sustained marketing investment 'own' large segments of the end-customer base are able to extract relatively larger margins. However, across most of the mid-stream barriers to entry are much lower, resulting in more intensive competition and lower profit margins.

This is evident in the following Figure 32[196], which illustrates the return on equity for a selection of PRC companies operating in the lithium-ion battery supply chain. While, in response to escalating demand and limited capacity, margins have increased along the supply chain in the past few years, average margins are consistently higher in the upstream and downstream, with historical margins in the mid-stream having been as low as a few percent. As production capacity increases to meet demand and the sector matures, there will be downward pressure on margins along the supply chain, particularly those of mid-stream operators where there is more intense competition.

Operations that necessarily operate on low margins favour jurisdictions that are characterised by low capital and operating cost structures, such as East Asia. This is common to most manufacturing and the manufacturing of lithium-ion batteries is no different. While it can be argued that the gap in operating costs between the PRC, Japan and Korea and Western Australia is narrowing, the gap in capital costs, particularly between the PRC and Western Australia remains significant.

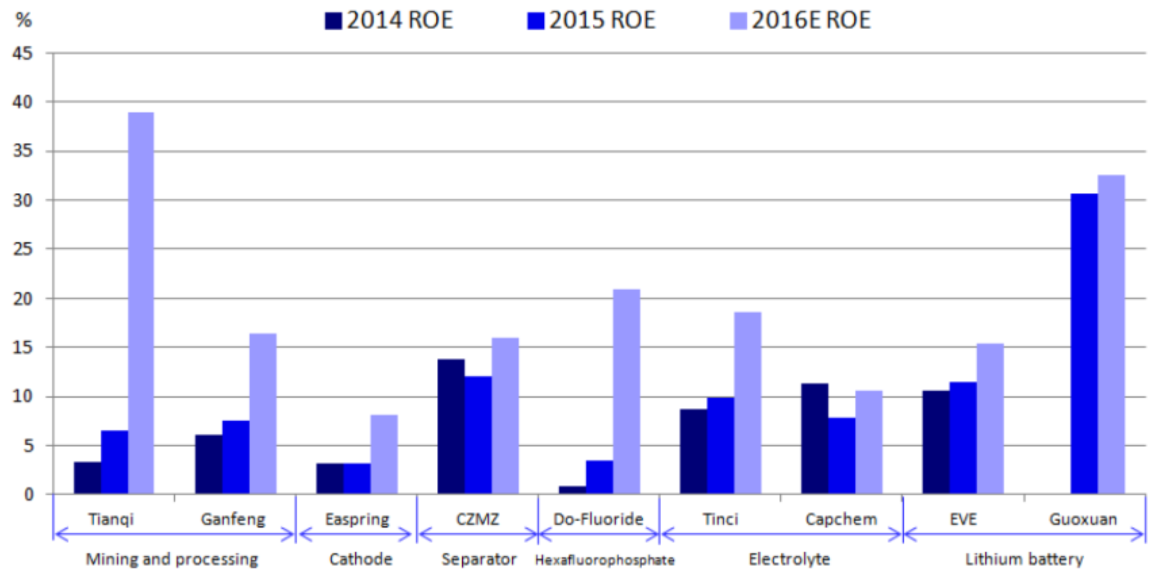

FIGURE 32 – PRC LITHIUM-ION BATTERY SUPPLY CHAIN PARTICIPANT RETURN ON EQUITY

Facilitative Industry Policy

While not unique to East Asian jurisdictions, governments in East Asia, particularly the PRC implement aggressive industry development policy frameworks. In the lithium-ion battery industry these policies are designed to encourage FDI in domestic lithium-ion battery manufacturing capacity along the supply chain, render domestic participants in the lithium-ion battery supply chain more competitive in global markets, and grow domestic demand for products based on domestically manufactured lithium-ion batteries. These policy frameworks and those of other jurisdictions are discussed in detail in Section 6.

[196] Bloomberg IN: Campagnol, N., Hoffman, K., Lala, A. and Ramsbottom, O. (2017), The Future of Nickel: A Class Act, McKinsey & Company

5.11.2. There are Reasons to Establish Some Capacity Outside the PRC

The concentration of supply in a specific jurisdiction presents risk to any supply chain. In the case of the lithium-ion battery supply chain, the concentration of key stages of the supply chain in the PRC is of particular concern to downstream operators outside of the PRC.

As mentioned previously, the PRC has a track record of implementing very aggressive foreign trade and investment policy designed to substantially enhance the global competitiveness of its domestic industries. A recent and relevant example of this is in the rare earths industry.

Precedence: Rare Earths Industry

A recent example of supply chain risk revolving around PRC trade and investment policy is the rare earths industry.

There are eight light rare earth elements (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium and gadolinium), eight heavy rare earth elements (terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium and yttrium), as well as scandium which classified as neither a heavy or light rare earth. The value of rare earths is contained in the unique chemical, catalytic, magnetic, optical, electrical and metallurgical properties that individual rare earths possess. These properties render specific rare earths critical inputs to processes such as petroleum fluid cracking, glass manufacturing and polishing, metal alloying, as well as products such as automobile catalytic converters, phosphors, ceramics, neodymium-iron-boron magnets, battery alloys and a range of other speciality hi-tech products, include defence applications.

The PRC hosts approximately 50 percent of known global rare earth resources. As a result of being able to cost effectively produce large volumes of light rare earths as by-products from State owned iron ore projects located in Inner Mongolia, and heavy rare earths through State owned operations that recover heavy rare earths from a geology that is almost unique to areas in the southern provinces of the PRC using low cost hydraulic mining, the PRC is also the world's largest producer of rare earths.

Securing domestic supply of rare earths has been a policy priority of the PRC Government since the early 1990s[197]. In 2005, the PRC Government began implementing policies designed to gain control of the market in rare earths. In 2008, the PRC Government declared rare earths a *protected mineral commodity,* rendering exploration and production of rare earths in the PRC an activity exclusively controlled by the State.

This policy position has been executed through the following specific initiatives that have impacted on the global market dynamics for rare earths:

- **Organisation of Domestic Production**
  The PRC Government is currently in the process of establishing three rare earth production districts and two integrated rare earth production systems nationwide. Under this system light rare earths will be produced from the Northern District, with the Bautou Steel Rare Earth Hi-tech Company having been granted monopoly rights to mine and process rare earth ores in the Northern District. Other existing rare earth operators in the Northern District are required to merge with Bautou or cease operations. The Southern District will focus on the production and processing of heavy rare earths, with 80 percent of production and processing being consolidated into

[197] Morrison, W. (2011), *China's Rare Earth Industry and Export Regime: Economic and Trade Implication for the United States,* Congressional Research Services

three Government-owned operators, Minmetals Corp., Aluminium Corporation of China and Ganzhou Rare Earth Mineral Industry Company. Foreign companies are prohibited from mining rare earths in the PRC and are restricted from participating in rare earth smelting and separation projects unless they form joint ventures with PRC partners.

- **Attempts to Acquire Offshore Rare Earth Resources**
  PRC Government owned enterprises have made at least two attempts to acquire major rare earth resources outside of the PRC. In 2005, China National Offshore Oil Company (CNOOC) embarked on a US$18.5 billion bid for Unocal Corporation, which at the time owned Molycorp and the Mountain Pass project (which was mothballed at the time). The bid failed as the result of significant political pressure within the United States that revolved around concerns over the transfer of United States oil reserves to a company controlled by the PRC Government. In May 2009, China Non-Ferrous Metal Mining Co (CNMC) attempted to acquire a major stake in Lynas Corporation, the owner of the Australian Mt Weld project. However, the Australian Government Foreign Investment Review Board (FIRB) requested a number of changes to the transaction, including a requirement that CNMC owned less than 50 percent and that CNMC appointed directors comprised less than 50 percent of the Board membership. CNMC subsequently rescinded its offer.

- **Export Controls**
  From the mid-1990s when the PRC Government provided domestic rare earth producers incentives to export rare earths in the form of rebates on export taxes, the PRC Government has progressively imposed restrictions on rare earth exports. This commenced with a ban on trade in concentrates in 2005. Then during the period 2006 to 2009, the number of PRC companies licensed to export rare earth products decreased from 47 PRC domestic companies and 12 foreign joint venture companies to 22 domestic companies and nine foreign joint ventures. In 2007, the PRC Government implemented an export duty to manage and control the variety and quantity of rare earth exports from licensed rare earth export companies. Initially set at 10 percent, these duties have progressively increased to between 15 and 25 percent depending on the specific rare earth product.

  However, perhaps the most controversial aspect of PRC rare earth market control is its regime of rare earth export quotas. The PRC has applied a rare earth export quota on domestic and foreign joint ventures that has decreased since 2005, and decreased dramatically since 2010 to a total of approximately 30,000 tonnes per annum. Since 2010, foreign joint venture producers have only been allocated approximately 25 percent of the export quota. Using 2005 as the base year, this action by the PRC Government has removed approximately 40,000 tonnes per annum of rare earths from the ex-PRC global market. [198]

The PRC Government responded to global concerns over its rare earth market policies in a White Paper published in 2012.[199] In this paper the PRC Government states that '…*it [PRC] will continue to follow the relevant regulations of the WTO rules, strengthen scientific management of this [rare earths] industry, supply rare earth products to the global market, so as to make its due contribution to the economic development and prosperity of the world economy.*'

[198] Technology Metals Research and Chinese Ministry of Commerce (2013)

[199] Information Office of the State Council (2012), *Situation and Policies of China's Rare Earths Industry,* The People's Republic of China, Beijing.

The White Paper notes the rapid development of the PRC rare earth industry and its importance as a source of supply for the global industry. However, it also notes significant challenges that this industry now presents the PRC, including:

- Rapid exploitation of PRC rare earth resources has resulted in significant depletion of known *in situ* reserves;
- The use of outdated production processes and techniques in the mining and processing of rare earth ores has resulted in damaged surface vegetation, soil erosion and acidification and general pollution;
- Sub-optimal industry structure;
- Significant divergence of price and value of the rare earth products; and
- Significant increase in illegal trade of rare earths.[200]

In addition to uncertainty with respect to security of supply, the PRC market controls resulted in rapid escalation in the price of many rare earths[201], to the extent that the average difference between the PRC domestic price and the export price of key rare earths grew to 180 percent.

A significant increase in the price of key rare earths up to 2011 had a dramatic effect on the cost of sourcing rare earths for the technology industries outside of the PRC. For example, the value of rare earth imports to the United States increased 4.3 fold in 2011 from US$199 million to US$860 million. This occurred in an environment where the United States total volumetric imports of rare earths had declined from a peak of approximately 27,000 tonnes in 2006 to around 14,000 tonnes in 2011. The sharp increase in value in 2011, is the result of the average price per tonne of rare earths imported from PRC increasing from US$10,000 per tonne to US$77,000 per tonne.

While foreign companies are not permitted to mine, smelter or separate rare earths in the PRC, they are encouraged to invest in downstream rare earth processing facilities located in the PRC and in the development of new rare earth applications and products. This is seen by many analysts as an attempt by the PRC Government to encourage foreign firms to invest in the development of a PRC hi-tech manufacturing industry and to transfer knowledge to PRC in exchange for access to the PRC's rare earth resources.

The global rare earth market control actions undertaken by the PRC Government invoked a range of strategic, political and legal government responses from jurisdictions that host significant technology industries for which rare earths are an important raw material input. These are summarised in Table 43 below.

[200] Information Office of the State Council (2012), *Situation and Policies of China's Rare Earths Industry,* The People's Republic of China, Beijing.
[201] Morrison, W. (2011), *China's Rare Earth Industry and Export Regime: Economic and Trade Implication for the United States,* Congressional Research Services

Country	Response
United States	In 2011 a United States Congressional Caucus in Rare Earths was implemented with a view to re-establishing a domestic rare earth supply chain in order to reduce the reliance of the United States' technology industry on Chinese supply of rare earths[202].
United States, Japan and European Union	In March 2012, the United States, Japan and the European Union announced they were jointly initiating a World Trade Organisation (WTO) case against China's restrictive policies pertaining to rare earths, as well as on tungsten and molybdenum.
Germany	In 2013, the German Federal Ministry of Economics and Technology released *The German Government's Raw Materials Strategy: Safeguarding and Sustainable Supply of Non-Energy Minerals Resources for Germany*. This strategy is designed to ensure that government activities at the Federal level are concentrated on giving firm and effective backing to Germany's private sector efforts aimed at securing raw materials from international sources. This will be achieved through a combination of domestic and international raw materials policy (including bilateral raw material partnerships) and support for research. Rare earths is a critical raw material for German industry.

Table 43 – International Responses to PRC Rare Earth Trade and Investment Control

Most recently, the PRC has advocated through the International Organisation for Standardisation to have a global standard for rare earth products implemented, that if adopted would favour rare earth products produced from PRC raw materials over those produced by other mineralisations, such as those found in Australia. This proposal is currently being challenged by a number of nations.

While not precisely the same circumstances (i.e. the PRC has limited domestic primary production in many lithium-ion battery minerals, but does have significant mid-stream industry), similar circumstance are evolving in the lithium-ion battery industry, causing some international concern. This concern is evidenced by the rationale behind the declaration of 'critical' raw materials or minerals (see Section 4.2) by jurisdictions and the investment in various components of the lithium-ion battery supply chain that is currently taking place ex-PRC.

This presents a potential opportunity for Western Australia that is discussed further in Section 7.7.2.

202 Morrison, W. (2011), *China's Rare Earth Industry and Export Regime: Economic and Trade Implication for the United States,* Congressional Research Services

6. The International Policy Framework

Given the demand outlook for lithium-ion batteries and the technology's capacity to both disrupt and enhance traditional global industries such as automotive manufacturing, electricity generation and distribution, and consumer electronics, it is unsurprising that governments around the world are enacting a range of policy measures designed to protect their domestic lithium-ion battery industry capacity and attract new investment.

These policy measures can be broadly categorised as follows:

- **Subsidies and Economic Support** - includes a wide range of economic incentives provided to corporations and consumers to encourage the production and/or purchase of lithium-ion battery enabled products. These policies are designed to create a domestic end market (primarily in electric vehicles) and/or enhance domestic lithium-ion battery capability. Generally speaking, the results of demand stimulation policy in this area have been mixed, and in most cases attempts to incentivise investment in domestic industry have failed to detract from East Asia's dominance.

- **Public-Private Partnerships** - includes a range of measures whereby public funds are deployed to encourage, underwrite or otherwise assist a commercial venture operating or aspiring to operate in the lithium-ion battery supply chain.

- **Regulatory Easement and Concessions** - includes modifications to existing industry regulation in order to provide preferential treatment designed to encourage investment in the domestic lithium-ion battery supply chain.

- **Trade Restrictions** - includes taxes, quotas and embargoes designed to protect and enhance the competitiveness of domestic lithium-ion battery supply chain participants.

- **Soft Influence** - involves the use of diplomatic, regional or institutional pressure to secure preferential outcomes for a country's lithium-ion battery supply chain operators.

The following subsections describe key elements of the global policy framework according to these categories.

6.1.1. Subsidies and Economic Support

People's Republic of China

With the largest population of any country, PRC consumer choices have a commensurately large impact on world markets, as do government policies that influence or distort those choices.

Most significantly, for a variety of reasons (not the least of which is public health) the PRC has embraced electric vehicles, with domestic consumption now some 40 percent of global demand and predicted to increase at a CAGR of over 30 percent for the period 2017-2021[203]

[203] *China Electric Vehicle Industry Research Report 2017-2021 - Research and Markets*, published BusinessWire, 14 November 2017; *China Electric Vehicle Market*, TechSciResearch,

compared to a predicted global 21.4 percent for 2018-2026.[204] With a penetration rate of only 1.4 percent, significant additional spare capacity exists to allow this trend to continue.

Driving this adoption has been a number of subsidy policies, worth approximately US$60.7 billion for the period 2015-2020, and for a midsize sedan constituting nearly a quarter of the total value of the car.[205] Specific regulatory requirements, discussed below, have restricted the impact of these subsidies mainly to domestic industry.

The PRC is also encouraging the development of battery re-use and recycling, particularly in the context of batteries formerly used in electric vehicles. Released for comment in February 2018, the Chinese Ministry of Industry and Information Technology has instituted guidelines requiring electric vehicle manufacturers to provide technical information on battery structure and repair, enabling a secondary industry for recycling and repair. Additional commentary, released without concrete detail, indicates tentative support for a requirement imposed on electric vehicle manufacturers to fund and support a unified whole-of-life tracking platform and recycling network.[206]

United States of America

As a strongly federal democracy, with individual states possessing much greater powers to determine their own regulations and taxation environment than in Australia, government policy in the United States has evolved in a somewhat piecemeal fashion, and is characterised by competition between individual states to attract investment to their particular jurisdiction. Further, the transition from the globalist Obama period to a more mercantilist Trump administration is likely to lead to a dramatic shift in policy approaches moving forwards.

The most significant period of United States federal government investment in battery-enabled technologies occurred from approximately 2009 onwards, with the Obama administration adopting a range of forward-looking measures designed to spur development of domestic capacity. In this category, most relevant was the expansion of a Bush-era subsidy on electric vehicle production, worth US$7,500 per vehicle and largely unrestricted otherwise, although capped at a lifetime production of 200,000 vehicles per manufacturer. As of the date of this report, a number of United States' automotive manufacturers are set to be reaching or at this limit, including Tesla Motors at an estimated 194,000 and General Motors at 182,000.[207] Competitors Nissan and Ford are likely to benefit for at least another fiscal year, at 120,000 and 108,000 electric vehicles sold respectively. The Trump administration has indicated it does not support the subsidy continuing, and hence this is unlikely to be further extended.

2017; *China's electric-vehicle market plugs in* (2017), Hertzke, P et al, McKinsey Quarterly, July 2017

[204] *The global electric vehicle market is growing at a CAGR of 21.4% for the forecast period*, PRNewsWire London, published 11 April 2018

[205] *Electric Cars: China's highly-charged power play*, published Financial Times China, 12 October 2017; *China's electric-vehicle market plugs in* (2017), Hertzke, P et al, McKinsey Quarterly, July 2017

[206] *China unveils policy for NEV battery recycling*, published China Daily Xinhua, 27 February 2018

[207] *Tesla and GM's incentives are about to run out*, LeSage, J, published Business Insider, 28 June 2018

Japan

Japan attained an early lead in battery-enabled technologies, spurred through first-mover advantages in solar-photovoltaic panels and early-model electric vehicles such as the Toyota Prius and the Nissan Leaf, resulting in a strong concentration of technical skills, knowledge and specialist manufacturing capacity. Government initiatives supporting this growth included some of the first subsidies of electric vehicles in 1996, progressively expanded to cover all non-ICE vehicles, and subsidies for lithium-ion ESS for both individuals and businesses, including commercial subsidies of up to 100 million yen (approximately US$980,000)[208] and utility-scale grants totalling US$780 million to install battery storage at power plants and substations.[209] Solar power incentives and generous utility feed-in prices also contributed indirectly to battery uptake.[210]

Over recent years, however, and partly as a response to the growing dominance of the PRC in the battery manufacturing sphere, Japan has shied away from lithium-based energy storage and the electric vehicle market to instead prioritise and promote the development of hydrogen fuel cells as an alternative to ICEs. This approach has met with little success, with significant barriers to widespread adoption including a general lack of interest overseas, high infrastructure costs and a small install base.[211] Broadly, the perception is that the Japanese government and manufacturers have persisted with this approach in an attempt to 'leapfrog' the present dominance of the PRC over lithium-based technologies and secure an early lead on the next wave of energy storage.[212]

South Korea

As home to some of the largest battery manufacturing plants outside the PRC, South Korea has a significant and mature manufacturing ecosystem predominantly led by LG Chem and Samsung SDI. Despite benefitting from early government support, concessional rates and research and development partnerships during the 2000s, direct subsidy and support to manufacturers has largely ceased.[213]

Instead, government policy has largely shifted to consumer-side subsidies and incentives centred on electric vehicle adoption and ESS that complement home and industry-scale installation of solar photovoltaic. South Korea offers some of the most generous subsidy rates for electric vehicle purchases, both at a national and provincial level, with Jeju province in particular offering up to US$20,000 towards electric vehicle purchases as part of a carbon-neutral goal by 2030. As a result, 28 percent of all electric vehicles sold in Korea are purchased

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[208] *Japan launches subsidies for lithium-ion battery storage*, Colthorpe, A, published PVTech East Asia 17 March 2014
[209] *Japan's METI to roll out energy efficiency and storage subsidy*, published PV Magazine, 9 January 2015
[210] *Panasonic eyes storage boost as Japan's solar incentives wane*, published Japan Times, 27 February 2017.
[211] *Japan's Big Carmakers Gang Up In Support Of Hydrogen Fuel Cell Vehicles, At Least Officially*, Schmitt, B, published Forbes Magazine 19 May 2017; *As Electric Cars' Prospects Brighten, Japan Fears Being Left Behind*, Soble, J, published New York Times, 9 January 2018
[212] *Ibid; Japanese Government Partners With Manufacturers On Solid State Battery Research*, Hanley, S, published Clean Technica 7 May 2018
[213] *Can the US Take Charge in the Global Battery Market?*, Smith, E, American Energy Innovation Council, 22 March 2017

in that province.[214] When paired with tax concessions, the total impact can be to reduce electric vehicle costs by up to 55 percent.[215]

In a further attempt to boost domestic battery consumption, the South Korean government also offers generous subsidies and emissions credits worth a total of approximately US$400 million over the period 2016-2020 to utility-scale solar providers to equip generation capacity with lithium-ion battery storage solutions. The policy is expected to drive a 33 percent increase in installations and deliver approximately 500MWh of additional demand for batteries, all of which is likely to be domestically fulfilled.[216]

India

In a similar position to the PRC, with a very large population base and significant public health concerns, India has made significant efforts to encourage electric vehicle uptake, a market predicted to reach some US$5 billion by 2024 at a growth rate of 26 percent per annum[217]. Supporting this, the Modi administration has set a target to ensure that all new vehicles sold in India are fully electric by 2030.[218]

In an effort to ensure the benefits of this predicted growth are captured domestically, India has adopted a business-friendly approach to encourage domestic and foreign capital to invest in local manufacturing capacity. Position statements by the Indian government have focused on a desire to ensure the present dominant PRC manufacturers do not control supply and lock out domestic producers[219], as well as to address a perceived glut of low-quality 'e-rickshaws' and difficulties securing reliable imports.[220] Despite a series of statements and press releases, however, the precise nature of the subsidies and incentives to be offered has yet to be detailed, leading to some observers questioning the strength of the commitment offered.[221] Concerns have also been raised as to the ability of potential domestic plants to source feedstock once established, pointing to the aggressive expansion of Chinese lock-in and offtake agreements in lithium worldwide.[222]

Malaysia

A regional hub for manufacturing and industry, Malaysia has not significantly focused on lithium-ion batteries until recent years. Primarily focused on electric vehicles, likely motivated by the same public health concerns as the PRC and to reduce reliance on imported fuels, the

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214 *Promoting electric vehicles in Korea*, Kim, S, Yang, Z, published International Council on Clean Transportation, 19 January 2016

215 *Ibid*

216 *Who will benefit from South Korea's solar-plus-storage initiative? Probably not outsiders*, Deign, J, published 5 October 2016

217 *Battery makers worry lithium will replace oil in the import bill*, Pulakkat, H, published Economic Times India, 16 April 2018

218 *Government to give incentives to battery makers as it promotes electric vehicles*, published Economic Times India, 24 March 2018

219 *Govt eyes made-in-India Lithium ion batteries to lower cost of electric vehicles*, published Hindustan Times, 27 May 2017

220 *Ibid; The future of mobility in India*, Bundun, R, published The National Abu Dhabi, 22 July 2017

221 *India says to give incentives to battery makers as it promotes electric vehicles*, published Reuters, 23 March 2018; *India to Give Incentives to Lithium-ion Battery Makers,* Barrera, P, published Lithium Investing News, 26 March 2018

222 *Battery makers worry lithium will replace oil in the import bill*, Pulakkat, H, published Economic Times India, 16 April 2018

Malaysian government has enacted a National Green Technology Master Plan (NGTMP) and Electric Mobility Blueprint (EMB), aiming to have 100,000 electric vehicles registered by 2030. With previous import tax exemptions now wound back, the NGTMP and EMB aim to see electric vehicles produced locally in significant quantities, and through government-owned Malaysian Green Technology have contracted Dutch company, The New Motion, to design, develop and assist the deployment of 300 fast-charge stations in larger cities across Malaysia[223].

A generally favourable investment climate has seen some foreign interest in establishing local manufacturing capacity for electric vehicles and battery elements. Applications given high-tech pioneer status by the Malaysian Investment Development Authority can access a range of benefits, including tax exemptions of up to five years.[224] Notable partnerships to date include a joint venture between PRC manufacturer BAIC and Malaysian Amber Dual, establishing a small manufacturing plant in Gurun with a production capacity of 2,000 electric vehicles per annum at a cost of US$51 million, as well as two Australian partnerships. Western Australian based Altech Chemicals has recently submitted an application for pioneer-status for a US$170 million high-purity aluminium plant to be based in Johor, with a production capacity of 4,500 tonnes per annum (see Section 4.7.2). A joint venture between Malay entities ARCA Corp and the Malaysian Automotive Institute, Swinburne University of Technology and AutoCRC to design and manufacture lithium batteries suitable for public transport network e-buses in Malaysia[225] was also announced in 2014.[226]

Thailand

Under military leadership and with stronger central-state control, Thailand has since approximately 2015 made pronounced efforts to engage with battery-enabled industries, particularly in the promotion of electric vehicles and related infrastructure. Through the government-supported Electric Vehicle Association of Thailand, researchers and private industry have been encouraged to collaborate on joint projects, while the government has offered tax breaks and eliminated excise duty on electric vehicles.[227] These include tax holidays of up to eight years, elimination of import tariffs on plant and machinery, and a sliding scale of corporate tax waivers increasing directly with the number of components of the electric vehicle that are built domestically.[228]

Response to the scheme has been mixed, with existing supply chain concerned about the knock-on effect to existing operators. Due to a concerted effort in the close of the 20th century, Thailand is presently an ICE automotive hub, with approximately 800 tier-1 firms and around 2,000 tier-2 and tier-3 operators supporting 18 domestic Thai manufacturers and a yearly production of 2,850,000 vehicles. With electric vehicles typically requiring 20 or fewer components, as opposed to around 2,000 on a conventional car, the effect on local

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223 *Malaysia aims to grow EV charging infrastructure*, Harman, A, published Wards Auto News, 15 October 2015

224 *Incentives in Manufacturing Sector*, published Malaysian Investment Development Authority

225 *Malaysia to set up ASEAN's first lithium ion battery plant for vehicles*, published Edge Markets Review, 7 February 2014

226 *MAI previews Malaysian-funded E-Bus prototype*, Lye, G, published Paul Tan's Automotive News/Driven Communications, 16 November 2015

227 *ASEAN entering the era of electric vehicles*, Shani, N, published ASEAN Centre for Energy, 1 November 2017

228 *Thai incentives for hybrids, PHEVs, EVs include tax holidays – excise tax for imported green cars slashed*, Tan, D, published Paul Tan's Automotive News/Driven Communications, 4 April 2017

employment is unlikely to be positive[229], which has implications for the longevity of these policies once the country returns to civilian rule.

Philippines

In a somewhat novel political climate, the Philippine government, while generally supportive of electric vehicles and battery-enabled industry, has pursued several different policy positions in spurring their uptake. This has led to a degree of internal confusion and market fragmentation. An early focus on 'e-trikes' through a government-sponsored 'lease-to-own' model jointly bankrolled by the then-Aquino administration (US$100 million) and the Asian Development Bank (US$300 million)[230] has seen generally low participation, with the Department of Energy investigating further incentives to spur take-up in remote communities.[231] However, the incoming Duterte administration has expressed antipathy to the idea of distortion through direct subsidy, indicating that further action to encourage electric vehicle adoption is likely to be through an expansion of tax credits already offered.[232]

Poland

Leveraging an existing reputation as a regional production hub for car manufacturing and accessories, together with mature logistics and supply chains, Poland has the potential to emerge as a European leader in lithium-ion battery manufacturing. With a range of policies strongly favourable to FDI, including income, real estate and payroll tax concessions or exemptions, investment grants of up to 50 percent of project costs, and government advocacy and support in European Union grants applications[233], Poland has recently identified electric vehicle manufacture, chemical refinement, and renewable energy systems as priority sectors.[234]

As a result, LG-Chem has announced that the Kobierzyce Special Economic Zone in southern Poland will host the first large-scale European Lithium-ion battery plant. Precise details have not been disclosed, however the total contribution by LG-Chem is reportedly US$1.63 billion, with production of approximately 100,000 battery packs per annum and construction to be completed by 2019.[235] This has been followed by Belgian materials giant Umicore announcing a €660 million cathode precursor plant, Guotai-Huarong Poland (a Chinese majority-owned venture) announcing a US$45 million electrolyte factory, and British Johnson Matthey Battery Systems opening a smaller-scale battery plant focused on e-bikes and consumer

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[229] *Thailand's electric vehicle initiative set to lead ASEAN region,* Sammy, J, published Motion Digest, 12 June 2017

[230] *Philippines To Launch 100,000 Eco-Friendly 'E-Trikes'*, Icamina, P, published Asian Scientist Magazine, 7 January 2013

[231] *DOE promotes E-trike in rural areas*, Philippines Department of Energy, published 19 November 2017

[232] *Tax credits with 'sunset provision' urged for e-vehicles*, Philippines Department of Energy, published 13 June 2018

[233] *Investment Incentives* in *Poland Country Commercial Guide – US State Department Office of Investment Affairs Investment Climate Statement,* available https://export.gov; *Why Poland is a top FDI destination*, published EuroNews 23 January 2018.

[234] *Ibid*

[235] *Europe's largest electric battery factory to be built in Poland*, Radio Poland, 12 October 2017; *Poland Will Become Home To Europe's Largest Battery Factory Next Year – Courtesy Of LG Chem*, Kane, M, published Inside EVs magazine, 16 October 2017

technologies.[236] The precise incentives offered to each entrant do not appear to have been publicly disclosed, however as a result southern Poland is on track to secure a dominant position in European-wide battery manufacture and assembly.

Germany

With a long tradition of manufacturing, and established supply chains stretching across Europe, Germany is particularly exposed to battery-enabled industries through its large automotive sector. With an ambitious target of one million electric vehicles by 2020 (from a base of under 100,000 in 2017) significant subsidies have been announced, including €4,000 for all electric vehicles, a 10-year exemption from vehicle taxes, and a reduced rate on electricity used to charge electric vehicles. An additional €300 million is to be spent on an expanded fast-charge network.[237] The impact of these seem to have been very minor, with electric vehicle sales increasing by only 3 percent to date[238].

Despite German carmakers being responsible for the vast majority of overseas investment in battery plants and electric vehicle manufacture (at some €4.7 billion over the period 2016-2018 and far ahead of the United States at €335 million[239]) relatively little of this has resulted in domestic projects. In response, German federal and several state governments have attempted to attract domestic investment with a range of cash incentives or concessionary loans. Typically, these rely on existing arrangements designed to bootstrap the economic development of the former German Democratic Republic, and hence increase progressively towards the Polish border, offering up to 40 percent reimbursement of project costs.[240] Adoption has been relatively slow, with the Federal Economic Minister expressing impatience and noting a lack of investment would ensure that the 'added value' would be captured by Asia instead.[241]

Some recent domestic successes have included PRC firm CATL committing in July 2018 to construct a large battery cell manufacturing facility in Thuringia in order to fulfil a US$4.7 billion long-term contract to supply cells to BMW. BMW and the German government are understood to have contributed to the project for an undisclosed amount.[242] In 2017, Daimler commenced a US$550 million upgrade of an existing battery-pack plant in Kamenz[243] (albeit using imported cells) while Terra E is expected to make a final investment decision on one of five sites to

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[236] *Umicore picks Poland for battery materials plant*, Shotter, J, published Financial Times, 1 June 2018; *Powered: Poland picked for battery materials plant*, published Poland IN English, 4 June 2018; *Poland's e-mobility program: seeking 'green credentials'*, published Deutsche Weekly, 10 October 2016

[237] *Germany Approves Incentives For EVs, Plans For A Million On The Road By 2020*, Kane, M, published Inside EVs, 19 May 2016

[238] *Dynamics in the global electric-vehicle market*, Hertzke, P et al, published McKinsey Automotive & Assembly, July 2017

[239] *German automatkers biggest spenders on electric cars*, published Agence France-Presse, 12 March 2018

[240] *Grants for investments – effectively reducing investment costs*, published Germany Trade and Invest, available www.gtai.de

[241] *German minister to carmakers: Invest in electric cars or lose out*, published Reuters Technology, 16 April 2018

[242] *China's CATL to build its first European EV battery factory in Germany*, Preisinger, I; Bryan, V, published Reuters Business News, 9 July 2018

[243] *Germany lures auto companies to less-developed east with incentives*, Gibbs, N, published Automotive News Europe, 17 July 2018

construct a 34GWh per annum battery plant, supported by US$6.2 billion in subsidies from the German Ministry of Education and Research.[244]

6.1.2. Public-Private Partnerships

European Union

Together with individual country contributions and support to accelerate battery-enabled industry within Europe, the European Union itself through several arms has also directly contributed. Of note is the 'Battery Alliance', which is a consortium of approximately 80 stakeholders established in late 2017 to pursue whole-of-chain initiatives and secure supply and manufacture of lithium-ion batteries in Europe.[245] Through a strategic plan presently in development, and paired with industry expectation of funding and grants from European Commission and European Investment Bank, the Battery Alliance aims to host up to 20 'Gigafactories' within Europe to meet European demand alone.

While concrete commitments to date have been limited, a sizeable recent grant was made through InnovFin Energy Demonstration Projects in May 2018, whereby Swedish company Northvolt was awarded a €52.5 million loan to build a demonstration line and research facility in Västerås, Sweden. With an initial 125MWh annual production capacity to demonstrate vertical integrated process from cathode and anode materials, through to fully packed final batteries with custom electronics, Northvolt aims to scale to a 32GWh factory by 2020 in Skellefteå with additional funding.[246] The European Innovation Council Open Design Competition also announced in February 2018 the funding of a €10 million prize to the first entity designing a battery suitable for electric vehicle usage that offered a 600 kilometre range, while recharging in under 5 minutes.[247]

People's Republic of China

While predominantly focused on regulatory controls and demand-side initiatives, the PRC is also willing to engage with perceived industry leaders, especially where the potential for technology transfers exists. Most prominently, Tesla has committed to constructing a 500,000 electric vehicle per annum production plant in the Lingang Free Trade Zone near Shanghai.

Neither Tesla nor the PRC government have disclosed the precise level of investment, however the deal is notable as the first major wholly-owned battery sector manufacturing investment made in the country since the lifting of capital controls (discussed further below). The Shanghai municipal government has been reported as making a sizeable capital cost contribution, ameliorating Tesla shareholder concerns regarding its dwindling cash reserves, and is expected to double Tesla's worldwide production capacity.[248] During recent earnings calls to United States investors, Tesla CEO Elon Musk has reported that no additional equity funding will

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[244] *Germany to Take on Tesla With Gigafactory Rival,* Parkin, B, published Bloomberg News, 3 August 2017

[245] *European Battery Alliance*¸ published European Commission

[246] *EU to support Northvolt's European battery project with InnovFin backing*, published European Investment Bank, 12 February 2018

[247] *EIC Horizon Prize for 'Innovative Batteries for eVehicles'*, published European Commission Research and Innovation, 22 February 2018

[248] *Tesla to open Shanghai electric car factory, doubling its production*, Gibbs, S, published The Guardian Newspaper 10 July 2018

be sought for the plant, which would be financed through local PRC loans.[249] The output of the plant will also allow Tesla to de-risk production and sidestep the rising reciprocal tariffs, which had resulted in Tesla car prices in the PRC rising to more than 70 percent higher than in the United States.[250]

United States of America

In addition to the subsidies discussed in the previous section, the United States federal government provided significant stimulus grants and concessional loans in the wake of the Global Financial Crisis, as part of the American Recovery and Reinvestment Act, to boost the domestic battery-enabled industry. Prominent examples included:

- **A123 Systems**
  A US$249 million loan was provided to A123 Systems in 2009 to licence and commercialise proprietary battery chemistry developed at the Massachusetts Institute of Technology, and construct a 550MWh battery plant in Livonia, Michigan. Together with Michigan State tax credits, total government support for this project reached U$400 million. As a result of questionable commercial decisions and poor quality control, A123 filed for bankruptcy in 2013 and its assets were purchased by PRC-owned Wanxiang Group, including rights to the MIT-developed intellectual property.[251]

- **LG Chemical**
  A US$151 million loan was provided to LG Chem to develop a battery cell manufacturing plant in Holland, Michigan, which was completed in 2011. Michigan provided a further US$125 million in tax credits, and LG Chem established an electrolyte production plant nearby in 2012. The award of funds became controversial after significant delays at the plant, and a key supply agreement failed to complete, resulting in the first commercially usable cells not being produced until late 2013.[252] LG Chem was required to repay approximately US$842,000 in grant funds together with a US$1.2 million fine after LG Chem was found to have fulfilled battery orders at its South Korean plant, instead claiming for reimbursement for time United States employees spent on non-work-related activities.[253]

- **ReVolt Technologies**
  A US$5 million loan was provided to ReVolt Technologies in 2010 to commercialise a novel zinc-based battery chemistry and construct a cell production plant in Portland, Oregon. Additional state funds totalling approximately US$5 million were provided in grants and long-term concessional loans by Oregon State. ReVolt filed for bankruptcy in late 2012, with its assets liquidated[254], after failing to raise sufficient additional capital to finish prototyping and begin production.

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[249] *Tesla posts bigger-than-expected loss, bigger-than-expected revenue*, Geuss, M, published Ars Technica, 2 August 2018

[250] *Tesla goes big in China with Shanghai plant*, Goh, B, published Reuters Business News, 10 July 2018

[251] *What Happened to A123?*, Bullis, K, published MIT Technology Review, 25 May 2012; *Wanxiang Gets Final Approval to Buy A123 Systems*, Loveday, E, published PluginCars, 31 January 2013

[252] *Holland's LG Chem plant built 2 years ago produces first lithium ion batteries*, Harger, J, published Michigan Live newspaper, 2 August 2013

[253] *Michigan Battery Firm LG Chem Returns $842K In Stimulus Funds After Waste Allegations*, McMahon, J, published Forbes Magazine, 13 February 2013

[254] *ReVolt Technology officially files bankruptcy*, Kish, M, published Portland Business Journal, 13 November 2012

- **Exide Technologies**
  A US$34.3 million loan was provided to Exide Technologies in 2009 to increase production at its Columbus, Ohio battery plant.[255] Exide filed for bankruptcy in 2013 as rising battery materials costs made production uneconomic. The company has subsequently successfully restructured.[256]

- **EnergDel**
  A US$118.5 million grant was awarded in 2009 to EnergDel to construct a battery manufacturing plant in Indiana, combined with another $80 million in state grants. EnerDel's parent company Ener1 filed for bankruptcy protection in 2012, after increased competition from international battery manufacturers.[257]

- **Nissan Motor Company**
  A $1.6 billion concessional loan was provided to Nissan Motor Company in 2010 to retool an assembly plant in Smyrna, Tennessee, to produce finished lithium-ion battery packs and an assembly plant for its Leaf electric vehicle. Tennessee provided a further US$70.7 million in property tax abatement[258]. As of February 2018, Nissan has sold all its battery manufacturing operations to GSR Capital, a Beijing-headquartered Chinese private investment group backed by the Hubei province government, as part of a worldwide retreat from vertical battery supply chain integration.[259]

- **General Motors**
  A US$105 million concessional loan was provided to General Motors in 2009 to construct a battery manufacture plant in Michigan using imported cells from South Korea for its Volt electric vehicle. GM was offered an additional US$106 million in state tax credits from Michigan state, while subsidiary Compact Power was awarded US$100 million in part-cash refundable battery credits. As a result, and through linked suppliers, the Volt electric vehicle has been estimated by some commentators to have attracted almost US$3 billion in government support.[260] Take-up of the Volt has been below expectations and a number of production problems led to GM missing all sales targets before dropping targets in 2011 and stopping production for five weeks in 2012.[261]

- **Tesla Motors**
  A $465 million concessional loan was provided to Tesla Motors in 2010 to build an electric vehicle factory in Fremont, California. Tesla paid back the loan, with interest, nine years ahead of schedule in May 2013.[262] Tesla Motors and Panasonic together later managed

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[255] *Exide Technologies to create 200 jobs in Columbus,* Hernandez, A.V, published Ledger-Inquire newspaper, 13 August 2009

[256] *Battery maker Exide Technologies files for bankruptcy*, published Reuters Business News, 10 June 2013

[257] *Battery maker Ener1 in Chapter 11 despite U.S. grant*, Stemptel, J, Rampton, R, published Reuters Business News, 27 January 2012

[258] *Ford, Nissan, Tesla to get U.S. technology loans,* Krolicki, K, published Reuters Business News, 23 June 2009; *Nissan's expanding battery plant at Smyrna auto factory may add jobs for global operation*, Broden, S, published USA Today, 21 January 2018

[259] *Nissan Ends Its Battery Business, Sells Out Completely To GSR Capital*, Kane, M, published InsideEVs, 8 August 2017; *Nissan's expanding battery plant at Smyrna auto factory may add jobs for global operation*, Broden, S, published USA Today, 21 January 2018

[260] *Chevy Volt Costing Taxpayers Up to $250K Per Vehicle*, Gantert, T, published Michigan Capital Confidential, 21 December 2011

[261] *Chevy Volt: Why production was halted and what it means*, published Washington Post, 6 March 2012

[262] *Tesla Pays Off Government Loan 9 Years Early*, Shahan, Z, published Clean Technica, 23 May 2013

to instigate a 'bidding war' between five American states – Arizona, Texas, New Mexico, California and Nevada – in competing to host its US$5 billion battery 'Gigafactory'. Awarded in 2014, Nevada secured the factory with a tax incentive package worth approximately US$1.2 billion over 20 years, including sales tax, property tax and payroll tax abatement.[263]

As demonstrated above, these incentives have had mixed success in generating long-term acceleration of domestic battery-enabled industry. In general, those targeting primarily electric vehicle production have seen more success. As a result, the Trump administration has expressed reservations about continuing to provide government support and concessional loans to the battery sector.[264]

In addition to direct financial subsidy or support, the United States government provides a wide-ranging program of research and development tax concessions, providing credits of up to 13 percent on qualified research costs, including wages, contract expenses and some legal costs. Battery-enabled enterprise is generally capable of fulfilling these criteria.[265] Accelerating research and development in battery technology, the United States Department of Energy has formed the Joint Centre for Energy Research together with fourteen public universities, research facilities and private companies. The Centre aims to distribute total of US$120 million worth in grants to 23 research and development projects over the period 2014 to 2019.[266]

Canada

Capitalising on a growing expertise in 'clean tech', Canada has recently enacted a variety of industry support initiatives designed to benefit and accelerate domestic production and growth of the lithium-ion battery segment. These include a grant in December 2016 of C$1.9million to support a pilot cathode manufacturing plant built by Nano One Materials Corp[267], an April 2018 C$3.4 million grant to Springpower International to develop lower-cost methods of mass producing lithium-based cathodes and silicon/carbon composite anodes[268], and a C$56,000 grant to E3 Metals Corp to scale up and refine lithium concentration technology to better manufacture lithium hydroxide at scale.[269] Notably, these grants have been awarded under a variety of policy programs, including Sustainable Development Technology Canada, the National Research Council of Canada's Industrial Research Assistance Program and Innovation, Science and Economic Development Canada's Automotive Supplier's Innovation Program.

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263 *Nevada governor strikes $1.25B tax deal with Tesla to build battery factory*, Geuss, M, published Ars Technica, 9 May 2014; *Ford, Nissan, Tesla to get U.S. technology loans,* Krolicki, K, published Reuters Business News, 23 June 2009

264 *This government loan program helped Tesla at a critical time. Trump wants to cut it.*, Overly, S, published The Washington Post, 16 March 2017

265 *R&D Tax Credits for the High-Risk Battery Business*, Goulding, R, et al, published R&D Tax Savers USA,

266 *Ibid*

267 *Nano One Receives $760,145 Milestone Payment from SDTC*, Nano One, published 19 June 2018

268 *Government of Canada Invests in Cutting-Edge Clean Technology*, Sustainable Development Technology Canada, published 11 April 2018

269 *E3 Metals awarded Government of Canada funding for advancement of lithium concentration technology*, E3 Metals Corporation, published 28 June 2018

Argentina

While part of the 'Lithium Triangle' alongside Chile and Bolivia, Argentina has lagged behind its more business-friendly neighbour Chile in developing its natural resources. In addition to regulatory relief, discussed below, Argentina has invested in research and development in extractive techniques to improve recovery rates from its brine resources, which are frequently found with higher magnesium levels than in neighbouring Chile and Bolivia, adding to the cost of production. The National Scientific and Technical Research Council (CONICET) has part-funded a research centre together with the National University of Jujuy and lithium producer Orocobre Ltd to allow efficiencies of production and provide training of Orocobre employees.[270]

Chile

Chilean production of lithium brines has been well established for some time. However, the escalation in demand for the resource has seen a renewed interest in capturing additional value from natural resources, including internal pressure within the recently elected Pinera government to create a state-owned enterprise along the model of the Chilean state owned copper mining company, Corporación Nacional del Cobre (CODELCO) to capitalise on the large known reserves presently owned by CODELCO or the Chilean government directly.[271]

More traditionally, the Chilean state development agency CORFO has invited bids from international corporations to develop downstream processing within Chile, including high-purity battery-grade chemicals and lithium cathode precursors. Leveraging state control of lithium export quotas, CORFO has offered exclusive access to approximately 16,000 tons LCE produced in-country by Albemarle Corporation, in exchange for which Albemarle will be permitted to increase production to 140,000 tonnes LCE per annum.[272] Twelve bids have been received as of January 2018, half from PRC-owned or linked companies[273], with no final decision yet made.[274]

Supporting this has been a series of comparatively small investments in domestic capacity and upstream usage of lithium. This has included most recently funding the University of Chile's design of the 'Elibatt 4.0' battery (although no business case could be made for domestic production), and investing 140 million pesos into a University of Antofagasta pilot project to prototype a miniaturised battery for consumer electronics.[275]

Bolivia

The third member of the 'lithium triangle', Bolivia has historically had lower levels of production than its neighbours and an uncertain political climate. In contrast to recent changes of

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[270] *Argentina is set on becoming a lithium superpower, but there's one big problem*, Gilbert, J., published Financial Post, 28 December 2017

[271] *Will lithium stocks gain from Chile's new government?* Chatsko, M., published The Motley Fool 28 February 2018

[272] *Chile approves increase in lithium quota for Albermarle*, published Reuters Market News, 10 March 2018; *Argentina and Chile expected to lead global lithium production*, published Santiago Times, 8 January 2018; *Lithium: the challenge of a new industry*, published Business Chile Magazine, 13 April 2017

[273] *Chile receives 12 bids for value-added lithium projects*, published Reuters Commodities, 11 July 2017

[274] *Argentina and Chile expected to lead global lithium production*, published Santiago Times, 8 January 2018.

[275] *Lithium: the challenge of a new industry*, published Business Chile Magazine, 13 April 2017

government in both Chile and Argentina, the Morales centre-left government has been in office since 2006 and has maintained a consistent policy of state-centric development of natural resources. Accordingly, the state-owned Yacimientos de Litios Bolivianos (YLB) lithium miner has been the primary driver behind exploitation of Bolivia's lithium reserves, as part of an overall vertical integration strategy involving the conversion of an old Soviet-era tin factory complex into a cathode and battery pack production facility.[276] Several management issues have so far stymied significant production, with the cathode production facility required to import feedstock from the PRC, production from YLB's brine facilities nine years delayed and at less than a quarter of a nameplate 480 tonnes per annum, and no international market for the simple battery packs produced.[277]

Recent developments have seen an announcement of a 51:49 YLB-controlled joint venture with German company ACI-Systems GmbH, the winner of an eight-party bid, in a US$2.2 billion agreement to construct a domestic lithium hydroxide plant, with first output of 5,000 tonnes per annum expected in 2019, and later production of a revitalised cathode precursor and finished battery plant.[278] Expectations are high, with the Bolivian government stating an income guidance of US$1 billion per annum.

Brazil

With large reserves, Brazil has long mined lithium, although primarily for the domestic industrial market and applications in grease, lubricants and ceramics. The national market is regulated, with export and production controlled by the National Commission for Nuclear Energy (CNEN). Historic production has relied on acid-leach processes, which do not meet battery-grade standards, and as a result domestic Brazilian beneficiation and processing of mined ores is almost exclusively carried out by the state-owned Brazilian Lithium Company (CBL).

As a federative country, however, individual Brazilian states compete to attract international investment and boost state economies. Minas Gerais, the location of a majority of Brazil's current lithium output, has made recent attempts to capitalise on the lithium-ion battery boom and encourage downstream investment. Through its investment vehicle Minas Gerais Development Company, the state government has made a bid to acquire a 33 percent stake in CBL for an undisclosed sum[279], complementing a 10 percent equity position for US$4.8 million in UK-based OXIS Energy to enable OXIS to set up a lithium-sulphide battery cell plant in Minas Gerais state.[280]

At a federal level, Brazilian government action is less coordinated. A number of free trade zones have been established targeting a range of industries potentially battery-enabled[281], while the Brazilian National Development Bank (BNDES) offers a concessional 0.9 percent interest rate for solar energy projects and battery-enabled storage.[282]

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[276] *Bolivia seeks investors to power up lagging lithium output*, Alper, A, published Reuters Commodities, 28 December 2017
[277] *Ibid*
[278] *Bolivia hires ACI Systems for its first lithium factory*, Molina, P-S, published PV Magazine, 25 April 2018
[279] *Codepar acquires 33% of CBL*, published Oxis Energy, 1 May 2018
[280] *OXIS Energy begins manufacturing in Brazil*, published Oxis Energy, 23 May 2018
[281] *Brazil Free Zones*, Zamora, C, published Healy Consultants Group PLC
[282] *Brazil's BNDES reduces interest rate for loans for large-scale solar from 1.7% to 0.9%*, Bellini, E, published PV Magazine 7 March 2018

Philippines

As a major producer of both nickel and cobalt, critical battery elements, the Philippines has demonstrated appetite to secure additional downstream processing capacity in-country. Tax incentives managed by the government Board of Investments include up to six years for 'pioneer' firms locating in less-developed industries, duty exemption for parts and supplies, deductions for labour costs and exemption from wharfage or customs fees for up to eight years.[283]

Publicity relating to take-up of these initiatives is limited, although relevant projects seem to be concentrated in the areas of utility-scale energy storage systems, including a recently announced 48MWh battery joint venture between government-owned National Grid Corporation and Aboitiz Power, while Solar Philippines has deployed a 150MW photovoltaic plant backed by a similar-sized ESS and a 2MW micro-grid[284], understood to have been enabled by these concessions. Given the comparatively low electrisation rate of the Philippines, and the highly fragmented nature of an island archipelago with problems of quite literal grid islanding, there is a strong argument for projects of this nature to become the dominant means of supplying electricity in the region.[285]

Germany

Interestingly, to an extent German policy initiatives through state-owned export finance provider KfW IPEX have worked at cross purposes to attempts to develop a domestic industry discussed above. Providing project finance to joint ventures and large infrastructure deals outside Germany, often to enable German firms to then sell products or services to the now-funded entity or project, KfW IPEX has recently enabled a large number of battery-enabled projects outside Germany, including the Hornsdale Power Reserve in South Australia[286], Altech Chemicals' high-purity aluminium plant in Malaysia[287], the Bulgana Green Power Hub wind farm and battery facility in Victoria[288], and a spherical graphite project in Tanzania[289].

6.1.3. Regulatory easements and exemptions

People's Republic of China

While direct subsidies of electric vehicles constitutes the bulk of PRC central government support, an important secondary consideration stems from the policies of several cities, including Beijing, Hong Kong and Shanghai, that offer preferential treatment to electric vehicles in matters of licencing, registration and traffic control. For example, licence fees in Shanghai are usually approximately US$16,000 but are waived for electric vehicle registrations;

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[283] *Philippines corporate tax credits and incentives*, Lim, M, published PWC Philippines, 30 June 2018

[284] *Philippines' largest electricity supplier planning 48MW ancillary services battery – reports*, Colthorpe, A, published Energy Storage News, 23 July 2018

[285] *Electricity-Sector Opportunity in the Philippines The Case for Wind- and Solar-Powered Small Island Grids*, Ahmed, S.J, Logarta, J.D, published Institute for Energy Economics and Financial Analysis, May 2017

[286] *Giant battery against blackout*, Siegmund, A, published KFW Stories, 26 June 2018

[287] *Malaysian alumina project secures KfW IPEX funding*, Bermingham, F, published Global Trade Review, 7 February 2018

[288] *Neoen to break ground on Bulgana Green Power Hub*, published Neoen 21 March 2018

[289] *Tanzania : How Epanko graphite fits well for battery anode material*, published Rutilance, 3 August 2017

in Hong Kong vehicle first registration tax (FRT) is waived for new electric cars up to a cap of HK$97,500; and in Beijing electric vehicles are not affected by traffic control restrictions and have preferential access to the capped number of licences offered each year.[290]

In addition, the PRC incentivises domestic advanced battery production generally, including exempting lithium-ion, nickel-metal hydrides, and other NMC chemistries (but not lead-acid) from payment of consumption taxes.[291]

Argentina

While its lithium brine resources are among the largest in the world, the policies of the previous de Kirchner socialist government, including forced nationalisations, currency controls and imported capital restrictions, have dampened development. Elected in 2015, the Macri government has aimed to promote development through easing these regulatory restrictions, including reportedly offering concessional royalty rates, expedited development approvals, capped 1.5 percent taxes on infrastructure spending, and the removal of profit repatriation requirements.[292]

Chile

Under regulation enacted in the 1970s and 1980s declaring lithium a 'strategic metal' due to its potential role in nuclear power generation, Chile has regulated exports via permitting, historically capped at 80,000 tonnes per annum. This has limited production and dampened foreign investment. As noted above, however, the recently elected Pinera government has overseen a relaxation of this policy, implementing agreements with existing producers Albemarle Corporation and SQM[293] to allow increased exports in exchange for preferential access to lithium production to bootstrap downstream producers.

A legacy of state control has left a somewhat fraught regulatory environment, however, which is still resolving. Most recently, land access and tenure issues have flared between state-owned CODELCO and Salar Blanco (50 percent owned by Australian company Lithium Power International), each granted competing interests over the Salar de Maricunga by competing Chilean government entities.[294] The resulting legal action has been editorialised as an opportunity for the Chilean government to demonstrate its commitment to embracing foreign capital, with implications for a number of incipient partnerships with international firms including Tesla Motors.[295]

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290 *Electric Vehicles to Get Free Rein on Beijing Roads*, Yu, R, published Wall Street Journal 21 May 2015; *Electric Cars: China's highly-charged power play*, published Financial Times China, 12 October 2017

291 *Notice on levying consumption tax on batteries*, published PRC Ministry of Finance, 2015

292 *Lithium-rich Argentina invites Indian firms*, published The Hindu Business Line, New Delhi, March 15 2018; *Prospective lithium player in Argentina*, analysis RB Milestone Group, 27 April 2018

293 *Chile approves increase in lithium quota for Albermarle*, published Reuters Market News, 10 March 2018; *Argentina and Chile expected to lead global lithium production*, published Santiago Times, 8 January 2018; *SQM strikes deal to expand lithium production*, Peters, B, published Investor Business Daily, 18 January 2018

294 *Private firm takes on CODELCO for control of Chile lithium deposit*, Camero, F, published Reuters Commodoties 9 May 2018.

295 *Ibid; Commentary: why Tesla is turning to Chile for its lithium*, Home, A, published Reuters Stock News 7 February 2018

Indonesia

The development of battery metal policies in Indonesia has been an ongoing issue for the predominantly export-focused nation. Formerly one of the largest global exporters of nickel ore, export controls were implemented in 2014 in an attempt to encourage domestic smelting of the raw ore into higher-value concentrates. This met with only limited success, and in January 2017 these controls were relaxed to grant export licenses to companies processing at least 30 percent of their low-grade ore in-country.[296] The policy was met with mixed reception, with local producers predicting the policy shift, apparently prompted by budget concerns, would damage relations with the PRC and those PRC companies which had invested in Indonesian nickel smelters to secure their own supply.[297]

6.1.4. Restrictions and requirements

People's Republic of China

In addition to price subsidies, the PRC government has further implemented a range of non-monetary measures to boost domestic electric vehicle consumption, although through central planning controls and mandatory quotas rather than positive inducements. Under a 'dual credit' system, all domestic manufacturers of private vehicles are required to produce a minimum number of electric vehicles, with varying credits awarded for size, class and range of vehicle, or purchase credits from compliant manufacturers.[298] Originally intended to apply from April 2018, the scheme has been delayed to 2019, anecdotally due to strong industry pushback regarding inability to meet targets.[299]

Given the significance of the battery segment to the PRC's 'Made in China' long-term centralised planning for its economy, it is unsurprising that PRC has used its market position to cement its current dominance in the East Asian region. In a move viewed by some as aimed at locking out prior established Korean and Japanese competitors and allowing the growth of a domestic industry of scale, the PRC Ministry of Industry and Information Technology (MIIT) has long used export controls and licensing of 'standard' batteries to favour domestic production. Most recently, MIIT released a draft update to its 'Automobile Battery Industry Standard Conditions' requiring domestic battery manufacturers to massively increase their minimum production capacity from 0.2GWh per annum to 8GWh in order to attain 'standard' status and qualify for subsidies and environmental certification.[300] At present, the only manufacturers capable of producing at that scale are PRC majority-owned, namely CATL, BYD and Lishen. Korean-supplied batteries continue to be excluded from eligibility for Electric Vehicle subsidisation.[301]

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296 *Indonesia eases export ban on nickel ore, bauxite*, published Reuters Commodities, 12 January 2017

297 *Ibid*

298 *Ibid; Comparing US and Chinese Electric Vehicle Policies,* Ia Shier, B. published Environmental and Energy Study Institute, 28 February 2018

299 *China sets target for electric car quota, but delays rollout*, McDonald, J, published USA Today 29 September 2017

300 *Chinese government virtually blocking Korean batteries from entering Chinese market*, Herh, M, published Business Korea 24 November 2016

301 *Electric cars with S. Korean batteries still excluded from receiving subsidies in China,* Dong-In, L, Eun-Joo, L, published Maell Pulse Business News Korea 11 April 2018

Despite this, the PRC government has opened its exploration or production companies to outside investment, although anecdotally with a strong preference towards minority partners or passive capital. Revised in July 2017, the 'Catalogue for the Guidance of Foreign Investment Industries', updating a previous 2015 release, has removed a large number of industries from the 'Negative List' or 'Restricted list', freeing them from previous restrictive measures such as equity ratio restrictions and board and senior executive controls, and indeed reclassified many as 'Encouraged'.[302] Included in the list of now uncontrolled sectors are mining and beneficiation of lithium ore, smelting of rarer metals, and manufacturing, research and development of lithium-ion batteries and electric vehicles.

This has led to a raft of new partnerships and joint ventures, or additional capital investments, announced between foreign carmakers and PRC domestic partners, including between BMW and Brilliance Automotive[303] and Volkswagen and FAW Group[304], both of which have received approval to increase their existing joint venture stake to take majority control from their PRC partner.

United States of America

As with most other developed nations, the United States has a range of emissions restrictions and requirements imposed on all vehicles. While these are most relevant to internal combustion engine vehicles, they can also indirectly support the uptake of electric vehicles through a range of means, including greater visibility and increasing the cost of non-electric vehicle competitors, thus contributing to the rise of battery-enabled industry.

Most relevant in this role is the Californian Zero Emission Vehicle Program (ZEV). First adopted in 1990, the Californian Air Resources Board under the ZEV Program requires a certain number of vehicles manufactured in California to be ZEV, primarily, battery-powered electric vehicles. As of January 2018, the Program mandates a minimum of 5 million ZEVs by 2030, enabled by a $2.5 billion investment in hydrogen fuelling stations and 10,000 fast-chargers by 2025, and imposes minimum requirements of 16 percent of vehicles manufactured be ZEV by 2025, with a further 6 percent 'transitional' (typically hybrid petrol/electric).[305] Californian policy is widely regarded in the United States as representing best-practice, and hence the ZEV Program and related targets have also been adopted by an additional nine United States (state) jurisdictions as binding on their own industry, namely Connecticut, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, and Vermont.[306]

The ability of California to set its own emissions standards (and the reason for other States choosing to accept them as binding) stems from the United States federalist arrangement. Generally, atmospheric environmental controls and standards fall under Federal government control. Under the federal Clean Air Act, however, the State of California has from 1970 been granted unique authority to impose more stringent environmental protection and emissions

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302 *The New 'Negative List' for foreign investment*, Jianwen, H, published King & Wood Mallesons Beijing, 6 July 2017

303 *BMW Group expands footprint in China with BMW Brilliance Automotive joint venture*, published BMW Group, 9 July 2018;

304 *VW signs deals for EVs, autonomous driving in China,* Sheahan, M, published Automotive News Europe, 10 July 2018

305 *California ZEV law gets simpler, more challenging*, Weissler, P, published SAE International, 7 December 2017; *California Governor orders 5M ZEV target for 2030; more hydrogen fueling and EV charging stations*, published Green Car Congress, 26 January 2018

306 *ZEV Program*, published Centre for Climate and Energy Solutions

reductions standards than would otherwise apply, which other United States (state) jurisdictions may choose to adopt.[307] This exemption has allowed California to act as a national leader on electric vehicle uptake, and through the mandatory targets has prompted a large domestic battery-enabled industry. However, the Trump administration has, as of August 2018, announced its intention to rescind this exemption and reduce or remove other Obama-era vehicle emissions standards.[308] The effect of this on the domestic electric vehicle industry is uncertain at this time, but is likely to have a detrimental effect on growth and investment.

6.1.5. Soft power and informal approaches

People's Republic of China

In addition to more direct incentives and inducements, the PRC exerts more subtle pressure on suppliers and business partners to preference domestic enterprises. While specific references for such policies are understandably difficult to source, notable recent examples include:

- A widespread understanding amongst electric vehicle manufacturers operating in the PRC that domestic battery suppliers must be used in order for their electric vehicles to qualify for government subsidies.[309]
- Threats of 'negative influences on the development of economic and commercial relations' in response to Chilean regulators blocking the sale of a US$5 billion stake in state-owned lithium miner SQM to the PRC-owned Tianqi Lithium.[310] Chile sells a majority of its copper production (a critical economic sector) to the PRC, and the PRC had previously committed to supporting the economic development of the country through its 'Belt and Road' initiative.[311] The sale was approved following pressure from the Chilean President Piñera.[312]
- The quasi-unionisation of around 35 PRC companies active in the Democratic Republic of Congo into the 'Union of Mining Companies with Chinese Capital', founded at the behest of the PRC embassy and with the approval of the Congolese Minister of Mines.[313] The association comes on the heels of the exit of many Western miners from the region following environmental, child and slave labour concerns, and continues a pattern of aid, grants and gifts to the Congolese government by the PRC, including construction of a new Parliament building.[314]

[307] 42 U.S. Code § 7507 - *New motor vehicle emission standards in nonattainment areas*
[308] *Trump's Fuel-Efficiency Rollback Breaks With 50 Years of Precedent*, Meyer, R, published The Atlantic Magazine, 2 August 2018
[309] *This Chinese battery maker will soon surpass Tesla in capacity*, published South China Morning Post, 1 February 2018
[310] *China warns Chile against blocking $5bn SQM lithium deal*, published Financial Times, 26 April 2018
[311] *China invites Latin America to take part in One Belt, One Road*, published Reuters Business News, 23 January 2018
[312] *Tianqi Lithium buys $1.4bn stake in Chile's SQM*, published Financial Times, 17 May 2018
[313] *China marks cobalt, copper ascendancy in Congo with new group*, Bloomberg News, published 18 June 2018
[314] *China to build Congo's new €50m parliament for free*, Shaban, A.R.A, published Africa News 23 May 2017

7. Western Australia's Competitive Position in the Lithium-ion Battery Supply Chain

Commentator enthusiasm with respect to precisely how far Western Australia can progress from a primary producer of battery minerals, down the lithium-ion battery supply chain to battery (or even ESS or electric vehicle) manufacture ranges from almost unbridled[315], to cautious scepticism.[316]

Australia (and Western Australia) is a rules based, open economy. International trade, underpins the industries that drive economic growth for the nation, and provide the goods and services that support the lifestyle enjoyed by Australians. The open nature of the Australian economy is a fundamental pillar of the Nation's economic prosperity.

For reasons explained in the following subsections, the analysis in this report strongly indicates that the likelihood of Western Australian based industry being competitive in the global lithium-ion battery supply chain decreases dramatically in stages beyond the production of battery pre-cursor materials. The possibility of creating a domestic battery chemical industry, whose competitiveness can be sustained in the global lithium-ion battery supply chain represents a significant opportunity for Western Australia to value-add to its primary minerals production. It is an opportunity that should be celebrated and pursued, but not taken for granted. This is discussed in the following subsections.

7.1. Western Australia is Not the Only or Cheapest Producer of Battery Minerals

As discussed in detail in Section 4, Western Australia hosts significant resources of many of the battery minerals and has been producing and exporting several key battery minerals for many decades. This, combined with the quality of those mineral products (see Section 5.3) is the fundamental basis for any competitive advantage that Western Australia may possess in the lithium-ion battery supply chain.

However, it is also evident from the analysis in Section 4 that Western Australia:

- Is not the only producer of these minerals, with significant resources and production in all of the battery minerals occurring in other nations, including nations with established resources industry infrastructure and trade relationships with downstream operators in the lithium-ion battery supply chain, particularly those domiciled in the PRC.
- Is not the lowest cost producer of any battery minerals, with average Australian production costs typically residing in the middle quartiles of the global cost curve (albeit this needs to be balanced with the typically relatively high quality of Western Australian battery mineral products, particularly with respect to the production of lithium hydroxide and Class 1 nickel products) and there are some minerals such as

[315] Future Smart Strategies (2018), *Lithium Valley: Establishing the Case for Energy Metals and Battery Manufacturing in Western Australia*, Regional Development Australia, Australian Government, Perth

[316] Department of Industry, Innovation and Science (2018), *Resources and Energy Quarterly*, June 2017 Edition, Australian Government, Canberra

graphite whereby the cost advantage held by other jurisdictions and product substitution is likely to render Western Australian production uncompetitive.

- There is significant investment taking place across the globe designed to commercialise various battery mineral resources that will compete directly with Western Australian production of key battery minerals, and some of that investment is by foreign downstream operators designed to secure internal supply.

As such, while Western Australia's established and emerging production in key battery minerals provides a fundamental basis for a competitive advantage (including a 'first-mover' advantage) that has allowed Western Australian industry to secure supply chain relationships in the short-term, the sustainment of this advantage should by no means be taken for granted.

7.2. Western Australia is a Critical Upstream Participant in the Dominant East Asian Supply Chain

The discussion in Section 5 clearly demonstrates that all elements of the lithium-ion supply chain downstream from primary production of raw materials are concentrated in East Asia, particularly the PRC. The analysis in Section 5.11 demonstrates that there are fundamental economic and commercial reasons as to why this is currently the case and is likely to remain the case for the foreseeable future. Furthermore, the policy frameworks discussed in Section 6 only serve to reinforce the competitiveness of East Asia at all stages of the lithium-ion battery supply chain downstream from primary production of raw materials.

Importantly, Western Australia is a major, and notwithstanding the caution noted in Section 7.1 above, critical supplier of inputs to the globally dominant East Asian lithium-ion battery supply chain. This is evidenced by the extent of offtake arrangements between Western Australian producers of battery minerals and downstream operators in East Asia, particularly the PRC, and the nature of offtake arrangements for lithium and nickel conversion plants that are being developed in Western Australia (see Section 5.3.1).

There is a tendency for some commentators to be critical of these circumstances, citing a 'dig-it-and-ship-it' mentality in the Western Australian resources industry. Such criticism is somewhat void of economic and commercial reality associated with international markets when operating in an open economy, and fails to recognise the very significant technical, environmental and social credentials of the Western Australian resources industry that underpin Western Australia's only source of competitive advantage in the upstream lithium-ion battery supply chain.

7.3. Western Australia Doesn't Have the Industry Structure to Support Significant Downstream Activity

Australia and Western Australia's Manufacturing Cost Disadvantage

The Australian manufacturing industry is characterised by a global total product cost[317] disadvantage. A number of factors contribute to this including, generally speaking, higher material, energy, transport, taxation, capital and overhead costs in delivering end-products.

[317] Product cost includes all costs that drive the final price of a produced good including labour, materials, energy, transport, capital, overheads and taxation.

However, the main driver of disadvantage is overall Australian manufacturing labour productivity which is between 60 and 65 percent of the international benchmark.[318]

Australia's productivity adjusted labour costs for high skill jobs in manufacturing is more competitive than the productivity of its lower-skilled labour productivity. This suggests that Australian based manufacturing that involves a higher skill mix is more likely to be competitive. However, even in elaborate manufacturing, Australia struggles to be sustainably competitive. For example, in sectors such as aerospace and medical technology manufacturing, Australia is 15.1 percent and 7.1 percent more expensive than say, the United States which is a leader in these sectors. Again, while a range of cost factors contribute to this, it is the productivity adjusted cost of labour that has the greatest impact.[319]

This cost structure renders the Australian manufacturing industry one of the World's most volatile. As illustrated in Figure 33[320] below, the average Australian manufacturing industry swells 20 percent above its trend size in upcycles and 20 percent below its trend size during downturns. To put the implications of this in context, during the Global Financial Crisis and its immediate aftermath, Australia lost 6,000 manufacturing firms.[321] Indeed, a recent survey of Australian manufacturers indicates the loss of a single customer would have a moderate to significant negative impact on 30 percent of Australian manufacturers, whereas 10 percent would be forced to cease trading.[322]

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318 McKinsey and AlphaBeta IN: Advanced Manufacturing Growth Centre (2017), Sector Competitiveness Plan

319 McKinsey and AlphaBeta IN: Advanced Manufacturing Growth Centre (2017), Sector Competitiveness Plan

320 OECD IN: Advanced Manufacturing Growth Centre (2018), *Advanced Manufacturing: Building Resilience in Australian Manufacturing*

321 Advanced Manufacturing Growth Centre (2018), *Advanced Manufacturing: Building Resilience in Australian Manufacturing*

322 Advanced Manufacturing Growth Centre (2018), *Advanced Manufacturing: Building Resilience in Australian Manufacturing*

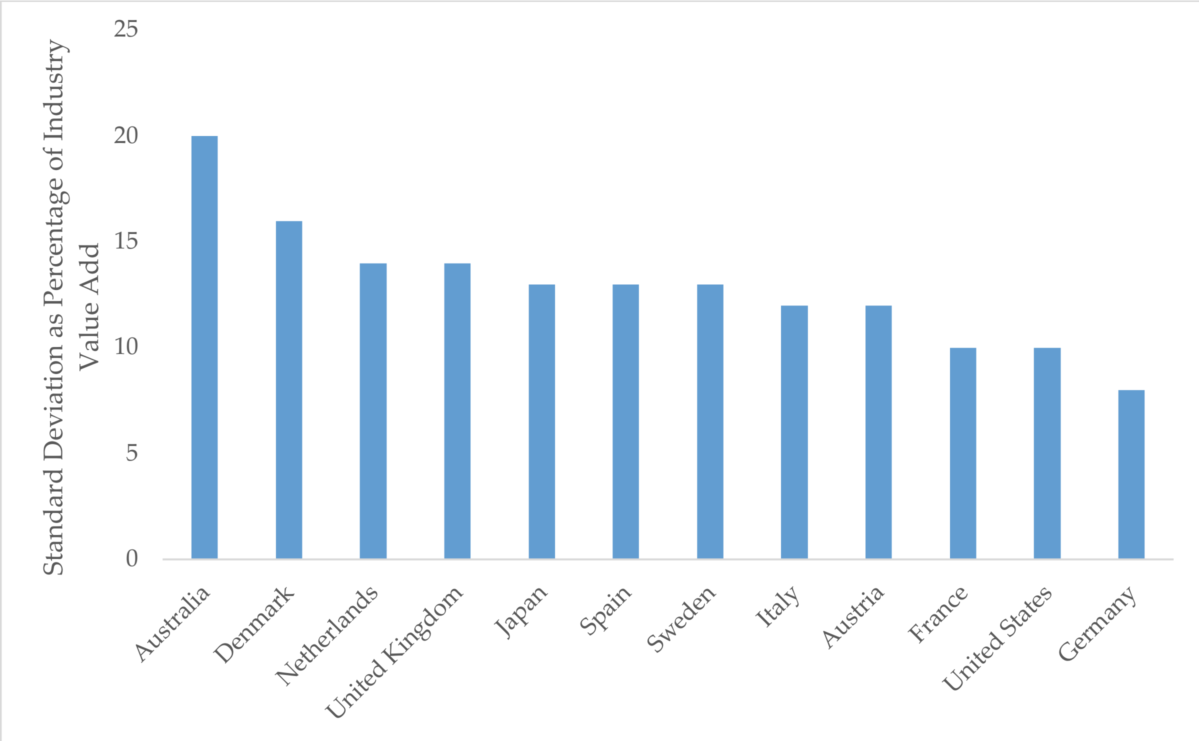

FIGURE 33 – AVERAGE VOLATILITY OF INTERNATIONAL MANUFACTURING INDUSTRIES

This phenomenon means that it is unlikely that Australian manufacturing can be globally competitive in sectors that are characterised by low barriers to entry, resulting high levels of competition and low margins that favour jurisdictions characterised by low cost structures. This is the case for much of the midstream lithium-ion battery supply chain and is further evidenced by the nature of the Australian manufacturing sectors that have expanded and contracted in recent years. This is summarised in Table 44[323] below.

323 Australian Bureau of Statistics IN: Advanced Manufacturing Growth Centre (2018), *Advanced Manufacturing: Building Resilience in Australian Manufacturing*

Growth Sectors	Contracting Sectors
Beverage and tobacco (+33%)	Machinery and equipment (-6%)
Cheese and other diary (+19%)	Polymer and rubber products (-6%)
Non-metallic mineral products (+15%)	Pulp, paper and converted paper (-10%)
Shipbuilding (+14%)	Wood products (-12%)
Furniture and other (+8%)	Printing (-12%)
Food products (+7%)	Fabricated metal (-12%)
Basic chemical and chemical (+4%)	Textile, leather, clothing and footwear (-17%)
	Transport equipment (-20%)
	Primary metal and metal products (-22%)
	Mining and construction machinery (-23%)
	Motor vehicle and motor vehicle parts (-30%)

TABLE 44 – CHANGE IN SIZE OF AUSTRALIAN MANUFACTURING INDUSTRIES (2012 TO 2016)

In the chemical manufacturing processes immediately downstream from mineral production, some of this cost disadvantage can, in some circumstances be mitigated by the ability to leverage from existing infrastructure and reagent suites. This is discussed in the following subsection.

Limitations to Local Supply of Inputs

The argument that Western Australia hosts resources of most battery minerals, produces as by-products many of the reagents used in the lithium-ion manufacturing processes, and therefore has a fundamental basis for greater participation in the lithium-ion battery supply chain is only partly correct.

While Western Australia may host resources of most of the mineral products used to manufacture lithium-ion batteries, it does not produce all those minerals. In most cases where Western Australia does not produce specific minerals, the absence of production is because that production would not be cost competitive in the global market place. In all cases of Western Australian battery mineral resources and production, Western Australia does not host the downstream industry that can competitively convert that production to the inputs for battery manufacture. Indeed many of the inputs such as manganese sulphate are commodity products that are readily available from multiple sources on the global market.

With respect to reagents, it is true that existing Western Australian industry produces some inputs to downstream lithium-ion battery manufacturing. For example, metal refineries in Western Australia produce sulphuric acid as a by-product for their own consumption and smelters in Western Australia produce excess acid. While this could serve to mitigate some of the cost disadvantage in some sectors of the manufacture of technical and battery grade chemicals and battery precursors, most local reagent production is small compared to that which is produced by Asian smelters and the large Asian chemical industry. This limits the scale that can be achieved based exclusively on domestic reagent supply, with larger scale production likely at least partly dependent on imported reagents.

Processes downstream from precursor manufacture require a wider variety of inputs, which in the case of Western Australia would mostly also need to be imported.

This means that any significant operations downstream from precursor manufacture in the lithium-ion battery supply chain operating in Western Australia would likely be importing a significant volume of the inputs to the manufacturing process, including many of the mineral products for which Western Australia currently hosts resources. Furthermore, many of these inputs would be derived primarily from Asian manufacturers.

Together, these dynamics present economic challenges to the ability of any Western Australian downstream lithium-ion battery supply chain to compete with established Asian competitors.

7.4. Small Domestic Market for Lithium-ion Batteries

As discussed in Section 2.5, Australia is not a major market with respect to any of the megatrends that are driving demand for lithium-ion batteries. This means that the Australian domestic market is unlikely to provide levels of demand for lithium-ion batteries that are adequate to drive economies of scale necessary to render a domestic battery manufacturing industry competitive with imported batteries, particularly those produced in East Asia.

While anticipated population growth of Australia to approximately 30 million by 2030 will grow the Australian economy commensurately, both driving additional demand for batteries derived from all three megatrends (see Section 2), growth in the Australian economy is likely to be mainly in the primary and tertiary industries. As discussed in Section 7.3, significant structural change would be required for the Australian economy to host regionally competitive manufacturing – a secondary sector - outside of niche areas that demonstrate economics that are more characteristic of elaborate rather than mass manufacturing (see Section 7.7.3).

It is true that if geo-political circumstances were to dictate an aggressive energy self-sufficiency policy framework that incentivised battery manufacturing in Australia this may change. But for the time being, Australian energy policy remains focused on the use of comparative advantage and international trade to deliver energy security[324] for the nation (i.e. domestic natural gas, thermal coal and renewable resources, as well as imported petroleum products).

As such, to be viable, a mainstream Australian battery manufacturing industry would require access to export markets. Due primarily to distance to major markets and a lack of fundamental competitive advantage discussed in previous sections, an Australian mainstream battery manufacturing industry is unlikely to be competitive with the East Asian supply chains in international battery markets. The importance of a large adjacent market in underpinning the viability of a battery manufacturing industry is borne out by the fact that the only battery manufacturing facilities and future investments are in regions with very large end-user markets, namely East Asia, Europe and North America (see Section 5.9).

[324] Energy security is defined as reliable and affordable source of energy.

7.5. Western Australia Doesn't and is Unlikely to Have a Competitive Policy Framework

As discussed in detail in Section 6 many jurisdictions around the globe have implemented very aggressive industry incentives and protection mechanisms, as well as market controls that are designed to grow their domestic lithium-ion battery related industries.

Much of the policy that is discussed in Section 6 would present Australia with legal issues in relation to its many bilateral and multi-lateral international trade agreements (see Section 8.3) and compliance with the Australian Constitution (see Section 8). Additionally, the anti-competitive, anti-free market nature of many of those policy initiatives is not aligned with the general Australian political ethos and would be unlikely to be supported by Australian governments. Finally, many of those policies would require significant public resource, which an Australian government is unlikely to commit to a single industry.

Noting that, in any case, the policies identified in Section 6 have had very mixed results, it is highly unlikely that a downstream lithium-ion industry in Western Australia would be operating with the same incentives and protections afforded too many of its competitors.

7.6. But Western Australia Does Have Some Significant Advantages

Notwithstanding the challenges set out in the previous subsections, Western Australia does have some important competitive advantages with respect to participating in the lithium-ion supply chain, albeit these are very much confined to upstream elements.

7.6.1. High Quality Lithium Hydroxide Production

The quality of Western Australia's spodumene resources, combined with native extractive metallurgy capability results in a high quality feedstock for the local domestic lithium conversion sector that is currently emerging. While scale production is yet to be demonstrated, pilot plants have demonstrated that the lithium hydroxide produced from these plants is likely to be of very high quality.

As discussed in Section 5.3.1, by virtue of its advantages in the manufacture of NCM battery chemistries, demand for lithium hydroxide is likely to increase significantly. This, combined with the current quality issues associated with PRC conversion plants (see Section 5.3.1), means that Western Australia has an opportunity to become a supplier of very high quality lithium hydroxide at volume to the global lithium-ion battery cathode active material precursor chemical sector. In turn, this could potentially underpin a domestic precursor sector that then supplies the global cathode active material manufacturing sector.

However, this state of affairs is not inevitable, and should not be taken for granted. As discussed in detail in Section 5.3.1, there is currently significant investment in new lithium conversion capacity in the PRC which will likely ultimately overcome the current quality challenges and be cost competitive with prospective Western Australian lithium hydroxide product. Furthermore, many of the emerging lithium mining operations are financed by offtake agreements with operators of PRC conversion plants, providing commercially important certainty of supply and further securing current market positions.

7.6.2. High Quality Nickel Sulphate Production

Primarily through Nickel West's operations (see Section 4.4.5), Western Australia produces relatively large volumes of Class 1 nickel product, global production of which is currently constrained (see Section 5.3.2).

The investment by Nickel West in a nickel sulphate production facility at its Kwinana nickel refinery will ultimately see it become the world's largest producer of nickel sulphate. This creates an opportunity for Western Australia to entrench itself as a supplier of high quality technical grade nickel sulphate to the global lithium-ion battery cathode active material precursor chemical sector, and even perhaps underpin a domestic precursor sector that then supplies the global cathode active material manufacturing sector.

Nickel sulphate based compounds are also a key input to NCM battery chemistries. As the feedstock for the production of technical grade nickel sulphate, Class 1 nickel products deliver vastly superior production economics and end-product quality. This is primarily because their high level of purity (at least 99.8 percent) means that only 2,000 ppm of impurities remain to be removed.

7.6.3. Potential High Quality Cobalt Sulphate Production

While there are no immediate concrete plans to establish cobalt sulphate production in Western Australia, Nickel West is currently undertaking economic and technical studies to assess the feasibility of establishing cobalt sulphate production at its Kwinana Refinery.[325]

Cobalt sulphate based compounds are also a key input to NMC battery chemistries.

7.6.4. Established Trade Relationships with the PRC

Primarily through its iron ore and LNG industries, Western Australia has long-standing and deep trading relationships with PRC industry and extensive sub-national diplomatic relationships with the PRC. As demonstrated by the analysis in Section 5.3.1, this is being replicated in the lithium-ion battery supply chain. Western Australia also has strong and long-standing trading relationships with Japan and Republic of Korea (ROK).

The value of these relationships with respect to underpinning Western Australia's role as a major upstream player in the global lithium-ion battery supply chain should not be underestimated, or taken for granted.

7.6.5. Strong Industry Regulation

The regulatory framework which oversees the development and operations of minerals projects in Western Australia is globally well regarded from a sovereign risk, as well as environment and social impact management perspective. This renders Western Australia an attractive resources project investment destination[326], making it relatively easy to finance economically viable battery mineral production projects.

This strong regulatory framework also underpins the ability of Western Australia to demonstrate environmentally and socially responsible production of battery minerals. With consumer markets becoming increasingly socially and environmentally conscious, and demanding that

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325 *World's Top Miner Charges into Cobalt* (2018), Stringer, D, published Bloomberg, 6 August
326 Fraser Institute (2018)

product traceability can demonstrate products meet these expectations, the ability to demonstrate this will likely be an increasingly important competitive advantage for Western Australian battery mineral production.

7.7. How Far Can Western Australia go?

7.7.1. Major Global Supplier of Technical and Battery Grade Chemicals to the Global Lithium-ion Battery Supply Chain

Provided regulation remains consistent and predictable, Western Australia should remain a competitive producer of several battery minerals (particularly lithium, nickel and cobalt) for the foreseeable future. This is based on the quality of product, position on the global cost curve, installed production infrastructure and trade relationships with respect to those minerals.

Similarly, *ceteris paribus*, the emerging domestic production of technical grade lithium hydroxide and nickel sulphate should be able to establish itself as a major large-scale source of high-quality technical grade material for the lithium-ion battery supply chain. However, history tells us that we should not take this for granted, particularly given the investment in new lithium conversion capacity that is currently underway in the PRC and Western Australia's mixed historical success with downstream processing.

While technically complex, the conversion of technical grade lithium, nickel and potentially cobalt chemical products to battery grade products is not a major step from an economic perspective and is possibly viable in Western Australia.

However, as discussed in detail in Section 5.11, subsequent stages of the lithium-ion battery supply chain, including cathode active material manufacture, have low barriers to entry, and are thus highly competitive, operating on relatively low margins. They are also variably energy intensive and would likely require the importation of various inputs. As such, it is unlikely that Western Australia would be able to sustain a competitive position in the global supply chain beyond the manufacture of battery grade precursors.

7.7.2. Geopolitical Risk as a Market Force

As discussed in Section 5.11.2, the concentration of mid-stream and downstream capacity in the PRC is represents supply chain risk to end-user of lithium-ion batteries. This risk means that both PRC and non-PRC supply chain operators are motivated to develop some capacity outside of the PRC in order to satisfy their downstream customers that they can guarantee supply irrespective of any market control measures that might implemented by the PRC and at least in the short term, to ensure quality. PRC operators are also possibly motivated to invest in ex-PRC capacity to generate cashflow outside of the PRC, enabling greater latitude in ex-PRC expansions.

Western Australia is currently a target of actual and potential downstream (conversion plant) investment by both PRC and non-PRC based downstream operators on this basis. However, further downstream investments designed to manage this risk will more likely be targeted at jurisdictions that can present more favourable manufacturing economics than Australia (see Section 7.3).

7.7.3. Niche Market Applications: The Case for Military Batteries

As discussed in Section 7.3, Australia (and Western Australia) has a fundamental cost disadvantage in even advanced manufacturing. Much of this cost disadvantage is a function of the productivity adjusted cost of labour in Australia. However, Australia's productivity adjusted cost of labour is much more competitive in skilled labour areas than in unskilled. Furthermore, a recent survey of 50 Australian manufacturing businesses across a range of sectors[327], found that the following factors were key determinants of manufacturing sector resilience in Australia:

- Technical leadership (70 percent of respondents)
- Product diversity (64 percent of respondents)
- Research and development (58 percent of respondents)
- Export focus (56 percent of respondents)
- Flexible production (54 percent of respondents)
- Niche market focus (52 percent of respondents)
- Access to a diverse customer base (50 percent of respondents)[328]

This suggests, as has been cited by some other commentators, that Western Australia may be more competitive in the lithium-ion battery supply chain servicing high-tech export oriented end-customers in niche markets where quality is a significantly greater determinant of end-customer purchasing decisions than product cost. Servicing such markets would reduce the sensitivity of Australian participation in the downstream supply chain to the resilience issues discussed in Section 7.3.

One such potential market that has been suggested is military lithium-ion battery applications. In a modern high-tech defence context, where powered devices are ubiquitous across all possible military theatres and operational scales, the ability to deliver that power is obviously critically important. Accordingly, there is significant interest in the potential for new energy material batteries to improve existing and enable new defence capabilities.

Appendix 6 compares desired characteristics of batteries for defence purposes to civilian purposes. In general, the key differences between defence and civilian battery demand are twofold:

- Many defence applications are at the forefront of technical capacity. As an example, directed energy weapons require vastly higher power density than any civilian purpose, while the energy density needs of a battery powered submarine are far in advance of any electric vehicle. Such demand, coupled with government defence procurement budgets and grants processes, presents a *prima facie* attractive market for battery manufacturers.

- This demand is tempered by the equally novel requirements for safety, reliability, security of supply and demonstrated maturity of process found in the defence sector. Unlike in civilian applications, where cost is the primary determinant of customer value, defence procurement policies will weigh bids and proposals on numerous other grounds. Track record, demonstrated industry experience, perceived or actual links to foreign entities or governments of concern, supply chain and logistics, and socio-political policy considerations may all influence defence acquisition decisions.

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327 Automotive and automotive parts (n=13), construction and mining equipment (n=14), diary product manufacturing (n=9), shipbuilding (n=12) and other sectors

328 AlphaBeta and McKinsey & Co. IN: Advanced Manufacturing Growth Centre (2018), *Advanced Manufacturing: Building Resilience in Australian Manufacturing*

At a global level, most Western/NATO defence demand is therefore met by large, established suppliers based in the United States or Western Europe. These suppliers have been subject to extensive security clearance processes and due diligence, have high familiarity with process and manufacturing requirements, have years if not decades of experience, have deep links with relevant research and development institutions coupled with extensive in-house capabilities, and are able to operate at highly competitive economies of scale. Other substantive players of sufficient size such as the PRC or Russian Federation tend to meet requirements through state institutions or state owned enterprises, while smaller defence forces such as Australia's benefit from reciprocal arrangements with larger powers, or purchase readily available hardware on the open market.

The extent to which defence purposes and applications have the potential to materially alter or impact the production, performance and economics of lithium battery production at a global scale is, therefore, limited. Technology transfer can and does occur, and advances in meeting high-specification defence needs will over time shape the mass market. However, while lucrative, for the most part defence procurement occurs in isolation and parallel to civilian supply and demand, with significant barriers to entry.

As with other modern defence forces, the Australian Defence Force (ADF) has significant interest in the potential for new battery chemistries to improve and enable defence capabilities. A technical review of ADF policy in this area is beyond the scope of this paper, however for present purposes several recent developments in this area are relevant.

Notably, there is a degree of public and industry interest in the ability of the defence sector to spur development of Australian domestic industry.[329] Aside from the potential economic benefits, commentators have generally pointed to the relative lack of downstream processing or beneficiation of battery metals within Australia, particularly lithium, and posited that the Australian defence sector could serve as a catalyst to the development of such.

This enthusiasm appears to be at odds with publicly released policy of the ADF. While some recent developments in the battery industry have been catalysed by Defence interest and investment, notably in proton batteries[330] (of particular interest from a safety and security of supply perspective, requiring only carbon and water) and a founding stake in the proposed Future Battery Industries Cooperative Research Centre (see Section 8.6.1)[331], the position of the ADF as a whole appears to be one of cautious interest and further study. Lead-acid batteries are seen as fulfilling the short-to-medium term role in military land vehicles, with lithium-ion batteries regarded as 'immature' and requiring further development[332], while the final SEA 1000/FSM Collins-class submarine replacement design's utilisation of diesel paired with lead-acid battery technology is understood to be motivated by concerns relating to reliability and

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329 *Australia's Future Submarine: the great battery debate*, Greenfield, P, published *The Strategist/Australian Strategic Policy Institute*, 14 April 2016; *A French-led lithium revolution for Australia*, Senator Rex Patrick, published *Defence Connect Newsletter*, 22 May 2018; *Ultracharge does military battery deal with Indonesian factory*, Birney, M, published *The West Australian,* 12 June 2018

330 *Australian uni develops smaller, cheaper battery*, Latimer, C, published *The Sydney Morning Herald*, 8 March 2018

331 *Battery CRC bidders bring big bucks,* Milne, P, published *The West Australian* 25 June 2018

332 *TECHNICAL NOTE | Review of Battery Technologies for Military Land Vehicles*, Sims, B, Crase, S, published Department of Defence, Science and Technology, January 2017

safety.[333] However, the Defence Science and Technology Group has, in collaboration with the United States Naval Surface Warfare Centre, established a Lithium-ion Battery Safety Research Facility in 2016, aiming to investigate the potential failure risks of lithium batteries in a naval context and with a view to future adoption over the medium term.[334]

Therefore, while recent developments are encouraging from at least a research and development perspective, there is a long road to travel before an Australian military battery industry could be reasonably contemplated. Even were such an industry to eventuate, its competitiveness would be benchmarked against the leading, and far larger, defence industries in the United States and Western Europe, likely limiting the scope of any successes to a niche within a niche.

7.8. Western Australia and Lithium-ion Battery Supply Chain Economics

7.8.1. Nature of this Analysis

Constructing an accurate and meaningful quantitative model of the lithium-ion battery supply chain is a challenging task. The complexity and diversity of lithium-ion battery supply chain relationships; wide variety of both source and characteristics of supply-chain inputs, intermediate and final products; variety of production processes at various stages of the supply-chain; the proprietary and commercial-in-confidence nature of supply-chain relationships, processes and related revenue and costs; and constant innovation along the supply chain, means that the development of a representative quantitative model that can be relied on for strategy and policy formation is a formidable, and arguably futile, task.

To overcome these challenges, this analysis adopts a comparative approach based on data that is available in the public domain, and is designed to demonstrate, from a quantitative perspective, activities along the lithium-ion battery supply-chain where Western Australia possess competitive advantages or disadvantages, together with the likely quantum of that advantage or disadvantage. While the analysis does explore downstream aspects of the lithium-ion battery supply chain, given the study's practical purpose the main focus of the analysis is upstream and upper mid-stream sectors where investment is currently taking place or being reasonably contemplated.

7.8.2. Western Australian Construction and Manufacturing Economics

Generally speaking, the two main factors that restrict Western Australia's competitiveness to varying degrees along the lithium-ion battery supply chain are comparative construction and manufacturing economics. Western Australia's construction cost disadvantage impacts activity along the entire supply chain, whereas its manufacturing cost disadvantage is more relevant in the later midstream and downstream aspects of the lithium-ion battery supply chain. These are discussed in the following subsections.

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[333] *Australia's future submarine: a Class with no equals*, Ohff, H, published *The Strategist/Australian Strategic Policy Institute*, 16 January 2017

[334] *Powering the Future of Submarine Fleets*, published Department of Defence, Science and Technology, 5 September 2017

Western Australian Construction Competitiveness

The development of downstream lithium-ion battery manufacturing capability in Western Australia would require the construction of sophisticated chemical processing and manufacturing facilities. Generally speaking, the capital expenditure associated with such facilities can vary significantly. In the case of implementing additional chemical processing capability to existing plants, this can be in the range of tens of millions of dollars. However, new plant construction can range from several hundred millions of dollars to over a billion dollars.

Construction cost surveys indicate that compared to most jurisdictions across the globe, construction costs in Western Australia are relatively high. The following Figure 34[335] compares the average per metre construction cost of a high-tech factory in Perth, Western Australia, with major regional centres in other key jurisdictions.

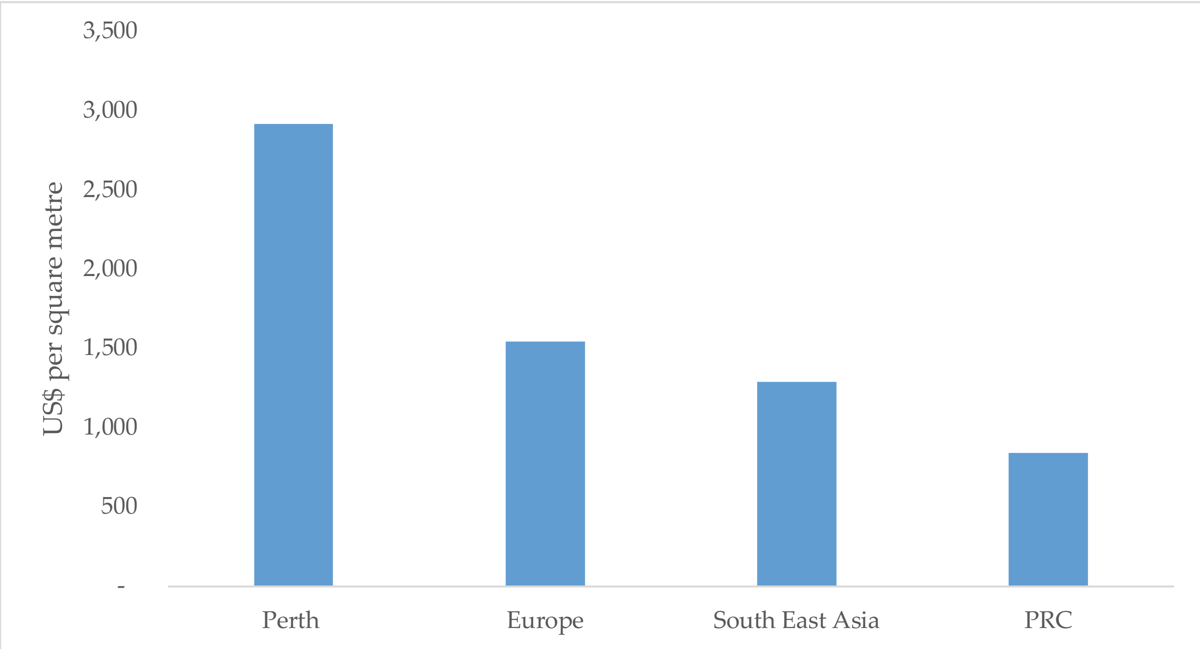

Figure 34 – High Tech Factory Construction Cost Comparison (2017)[336]

Of particular relevance to the case for establishing downstream capability in Western Australia is that fact that, generally speaking, factory construction costs in South East Asia generally are around 50 percent of those in Perth, and in the case of the PRC, even lower at 30 percent. A range of factors contribute to this construction cost differential, primarily trade and unskilled labour rates and the cost of major construction materials. In almost all circumstances construction related labour is lower in other jurisdictions and material costs are lower by virtue of lower embedded labour cost and larger domestic markets that drive economies of scale. The following Figure 35[337] summarises average construction related costs of various jurisdictions relative to those costs in Perth.

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335 Turner & Townsend (2017), International Construction Market Survey

336 European average costs based on Paris (France), Munich (Germany), Warsaw (Poland), Madrid (Spain) and Istanbul (Turkey); South East Asia average costs based on Bangalore (India), Singapore and Kuala Lumpur (Malaysia)

337 Turner & Townsend (2017), International Construction Market Survey

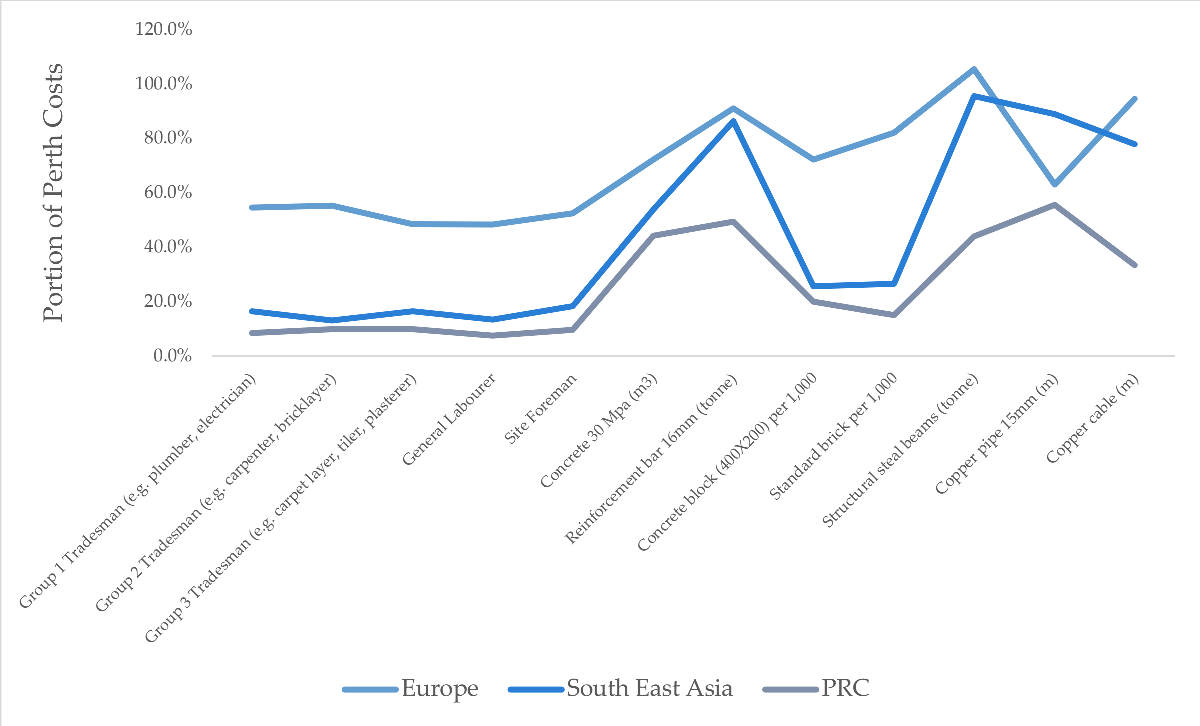

Figure 35 – Average Key Construction Labour and Materials Costs as a Portion of Perth Costs

Downstream production facilities will also involve significant investment in plant and equipment. As discussed in Section 7.5, Western Australia also has a cost disadvantage with respect to elaborate or advanced manufacturing systems that produce this equipment, typically making it more competitive to import equipment modules.

Western Australia's significant capital cost disadvantage means that the financials for all downstream operations will demonstrate a return-of capital metric that is comparatively higher to a similar operation in most competing jurisdictions, implying longer payback periods and lower profitability. In short, compelling reasons would be needed to justify paying three times as much to build a facility in Western Australia.

Western Australian Manufacturing Competitiveness

Downstream from primary production, the lithium-ion battery supply chain progressively shifts from chemical manufacturing processes, to processes that are more akin to product manufacture. As discussed in Section 7.5, in most sectors Australia (and Western Australia) is not a competitive manufacturing economy. According to the Deloitte Manufacturing Competitive Index, Australia's manufacturing industry is the world 21st most competitive and scores significantly lower than the major East Asian, European and North American manufacturing industries. This is illustrated in Figure 36[338] below.

[338] Deloitte (2017), 2016 Global Manufacturing Competitiveness Index Rankings

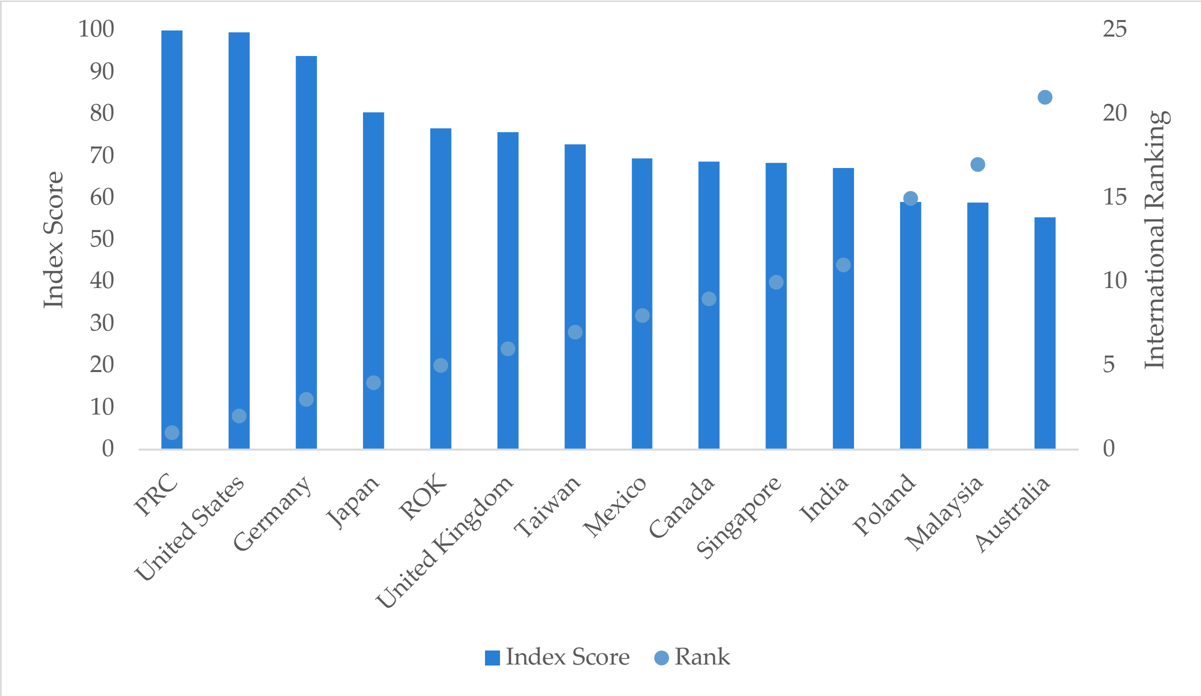

FIGURE 36 – COMPETITIVENESS OF INTERNATIONAL MANUFACTURING INDUSTRIES

Given that a major contributing factor to Australia's manufacturing competitive disadvantage is its relatively higher productivity adjusted cost of labour (see Section 7.3), the notion that increasingly automated manufacturing processes should reduce the extent of this disadvantage is often cited. This is partly true, but should be considered with some caution.

Firstly, higher productivity adjusted labour costs is only one source of this disadvantage, and while it is a significant one, other factors such as higher input costs and construction costs continue to remain a challenge. Secondly, few plants are, or are likely to be, capable of being fully-automated, meaning that Australia's higher productivity-adjusted labour costs will still apply, and as discussed in Section 7.3, automation is less likely to render obsolete the highly-skilled positions required by higher stages of the battery supply chain. Finally, and most importantly, this argument falsely assumes that competing manufacturing regions will not also implement automated manufacturing systems, while still retaining much of their capital and other operating cost advantages.

The fact is that in most cases the overseas manufacturing industries with which Australia would compete are already more automated than Australia's. Figure 37[339] below compares manufacturing sector robotic density among key jurisdictions in the lithium-ion battery manufacturing sector, with the global average and that of Australia. Notably, the robotic intensity of the PRC manufacturing industry is already comparable with that of Australia's. This relativity is not expected to improve - global shipments of multi-purpose industrial robots are expected to grow by 150 percent to 2020, with the PRC being a major driver of that growth.

[339] International Federation of Robotics (2018), World Robotics 2017

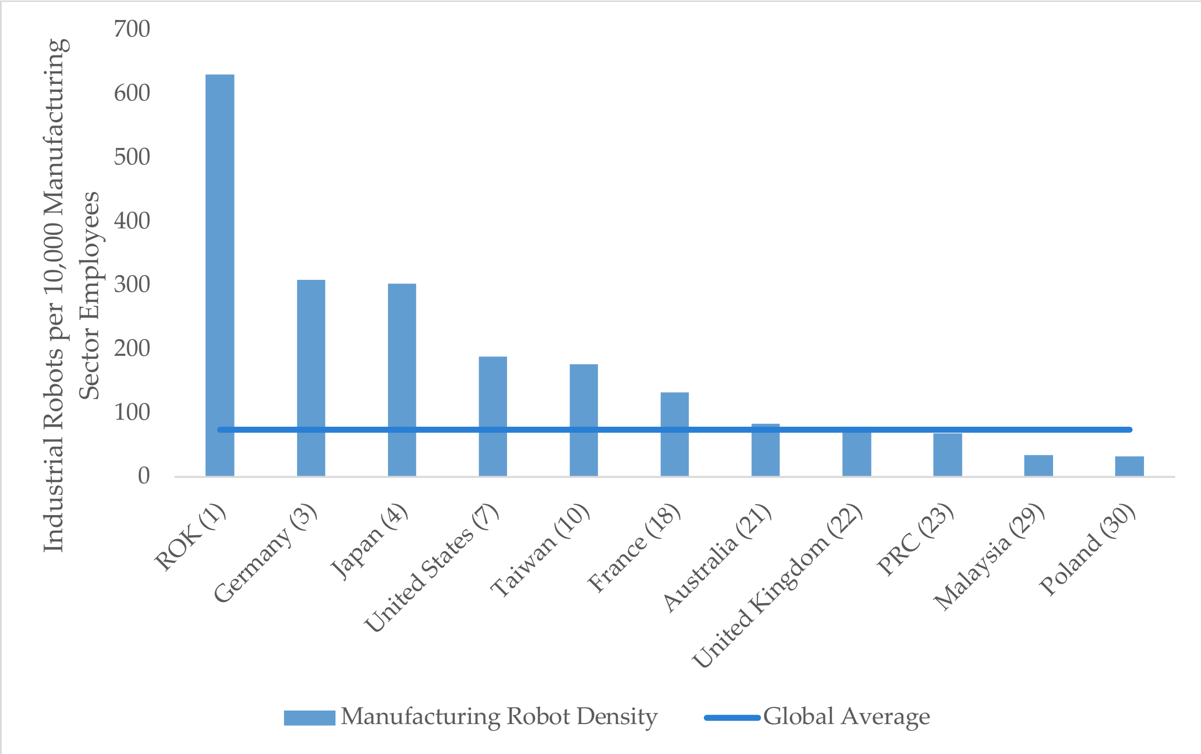

Figure 37 – Robotic Density of Selected Manufacturing Sectors

7.8.3. Western Australian Battery Mineral Production, Employment and Royalty Forecasts

Spodumene (Lithium) Concentrate Production

Consistent with the global increase in demand for lithium has been a dramatic increase in the price received for Western Australian spodumene (lithium) concentrate. Figure 38[340] below compares the average annual price received for Western Australian spodumene (lithium) concentrate with the average annual lithium carbonate spot price.

340 Department of Mines, Industry Regulation and Safety and Metalary Metal Prices

FIGURE 38 – AVERAGE PRICE RECEIVED FOR WESTERN AUSTRALIAN SPODUMENE (LITHIUM) CONCENTRATE AND AVERAGE LITHIUM CARBONATE SPOT PRICE

The 16 percent CAGR in price received for Western Australian spodumene (lithium) concentrate since 2011-12 coincided with a 29 percent increase in production of spodumene (lithium) concentrate, and in some instances direct shipment of spodumene ore. Based on current project forecasts (see Table 23), Western Australian spodumene (lithium) concentrate is expected to increase by a further 12 percent CAGR out to 2022-23. This is illustrated in Figure 39 below.

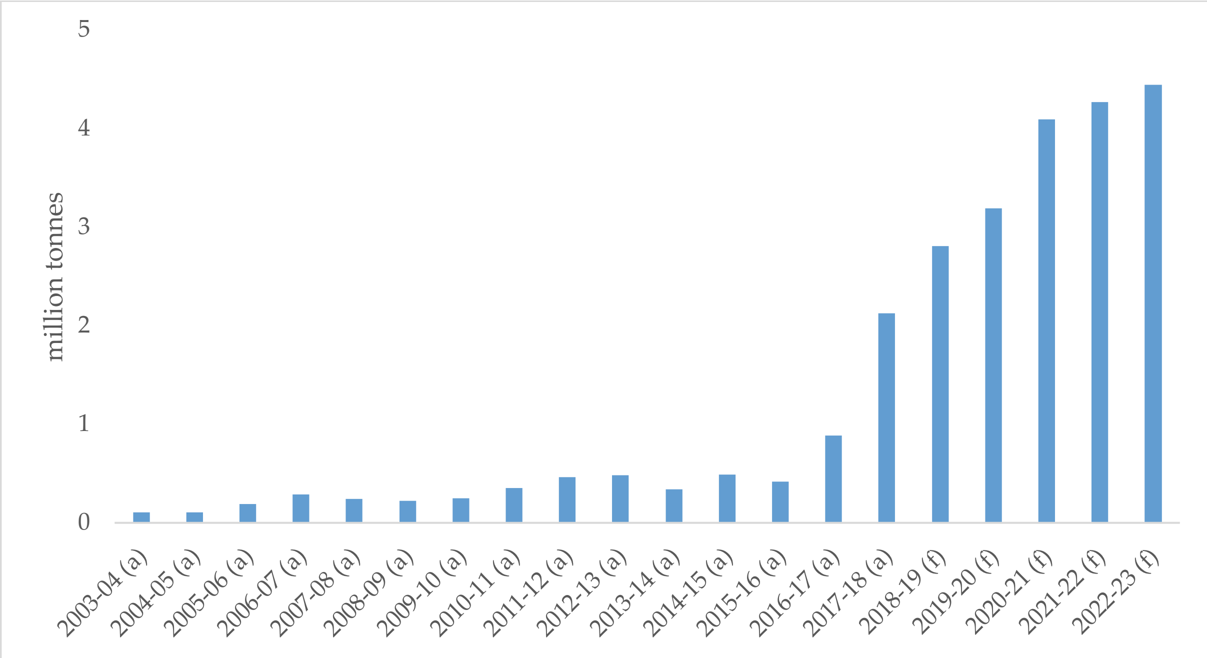

FIGURE 39 – HISTORICAL AND FORECAST WESTERN AUSTRALIAN SPODUMENE (LITHIUM) CONCENTRATE PRODUCTION

In 2017-18, Western Australia produced spodumene (lithium) concentrate with a total value of A$1.6 billion. Based on the production forecast illustrated in Figure 39 above and the weighted average price received for Western Australian spodumene (lithium) concentrate over the past four years, it is estimated that by 2022-23, Western Australia will be producing spodumene (lithium) concentrate with a total value of approximately A$3.0 billion.

Figure 40[341] below illustrates an approximate operating cost curve for current and imminent Western Australian spodumene (lithium) concentrate production. While all current and imminent production is clearly profitable at current spodumene (lithium) concentrate prices, there is significant variance in operating costs among Western Australian production.

341 Adapted from Roskill (2018) Production Cost Data

FIGURE 40 – WESTERN AUSTRALIAN SPODUMENE CONCENTRATE OPERATING COST CURVE (SELECTED CURRENT AND IMMINENT PRODUCTION)

Class 1 Nickel Production

Since 2003-04, Western Australian nickel production has ranged from a peak of approximately 230,000 tonnes in 2012-13 to a low of approximately 160,000 tonnes in the past couple of years. The value of Western Australia production peaked at approximately A$8.0 billion in 2006-07, reaching a low of A$2.1 billion in 2016-17. This is illustrated in Figure 41 below.

FIGURE 41 – WESTERN AUSTRALIAN NICKEL PRODUCTION

Figure 42 below, illustrates the average price received for Western Australian nickel production.

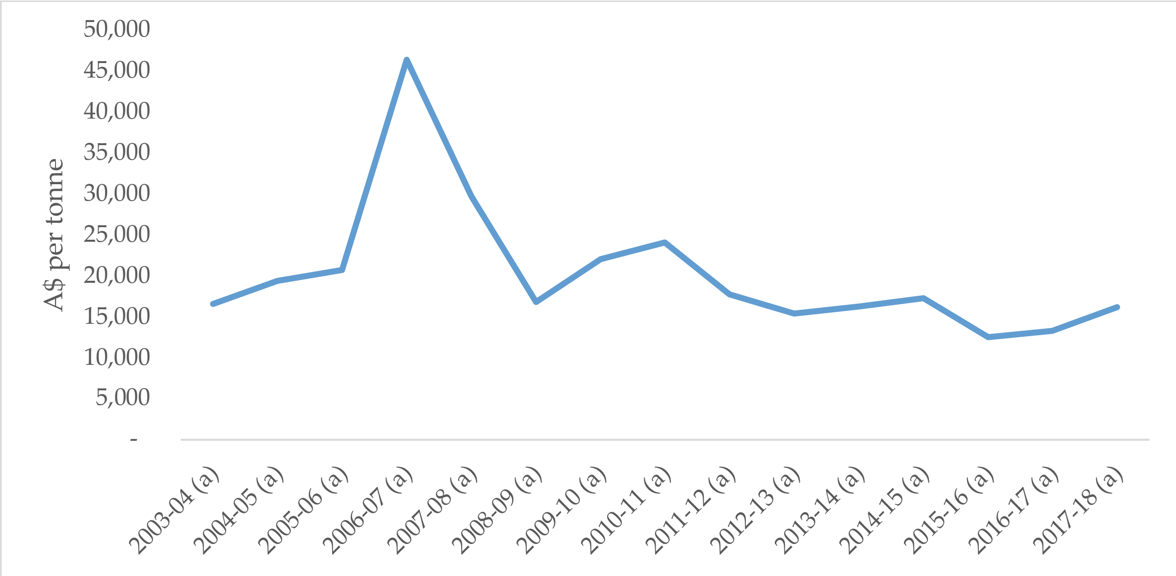

FIGURE 42 – AVERAGE PRICE RECEIVED FOR WESTERN AUSTRALIAN NICKEL PRODUCTION

It is estimated that approximately 97,000 tonnes (or 60 percent) of Western Australian final nickel product is in the form of Class 1 nickel briquettes and powder suitable for conversion to nickel sulphate chemical compound that can be used in the manufacture of lithium-ion battery cathode precursor material.

Generally speaking, battery grade nickel sulphate receives a price premium of approximately US$2,000 to US$4,000 over the LME nickel metal price[342], with premiums closer to US$2,000 per tonne more common, and higher premiums typically characteristic of less liquid markets. Given that approximately 0.25 tonnes of Class 1 nickel product is required to produce 1 tonne of nickel sulphate, even if the lower end of this price differential is sustained, there is significant opportunity to increase Western Australian nickel revenue.

Cobalt Production

Since 2003-04, Western Australian cobalt production has ranged from approximately 3,800 tonnes in 2010-11 to a peak of approximately 6,200 tonnes in 2012-13 and 2013-14. Since 2003-14, the value of that production has been as low as A$145 million in 2011-12 and has high as $500 million currently. This is illustrated in Figure 43 below.

342 S&P Global (2018), LME Explores Nickel Sulphate Premium Contract to Expand Battery Metal Futures, 4 September 2018

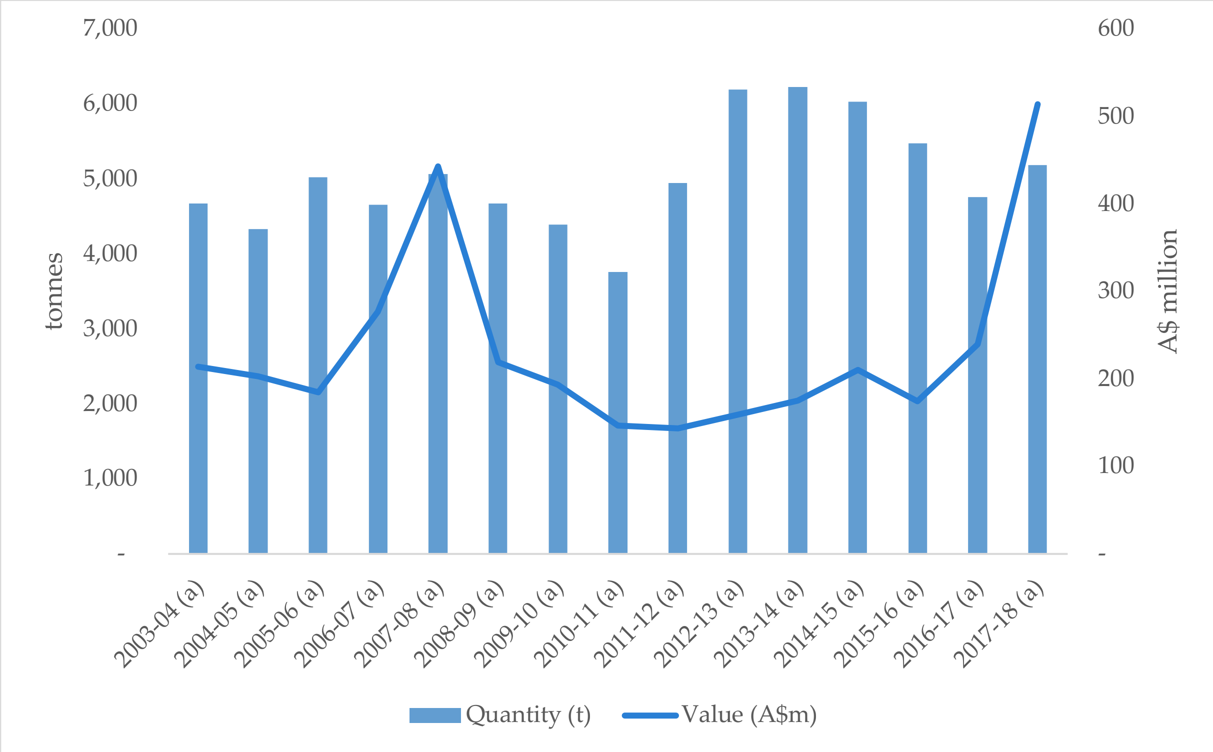

Figure 43 – Western Australian Cobalt Production

Figure 44 below illustrates the average price received for Western Australian cobalt production. Cobalt sulphate markets are more volatile than nickel sulphate, trading at both a premium and discount to the metal price in recent times.[343] This is largely a function of the PRC's dominance in cobalt chemical supply and the relatively illiquid market.

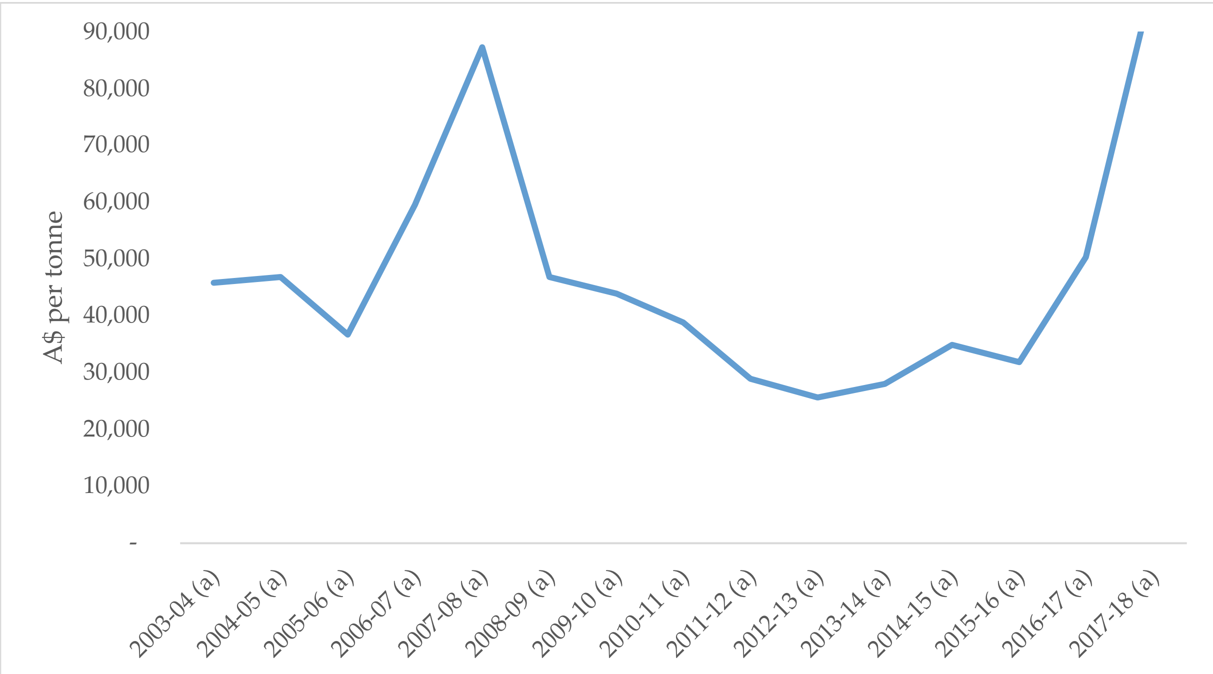

Figure 44 – Average Price Received for Western Australian Cobalt Production

343 Thomson Reuters (2018), 'Battery Chemical Surplus Sparks Plunge in Cobalt Price'

Economic Impact

Currently, operational Western Australian spodumene mining and concentration operations directly employ around 1,000 site workers.[344] Planned new mining operations and expansions to existing mining operations is estimated to generate at least 700 construction jobs and around at least 630 new operational jobs. The Western Australian nickel and cobalt production industry currently employs approximately 3,500 people in operational roles.

In 2016-17, the Western Australian Government collected royalties from minerals and petroleum production totalling approximately A$5.7 billion. The iron ore sector, North West Shelf Grants and gold sector collectively accounted for 95 percent of this royalty revenue, with iron ore accounting for 80 percent in its own right. Royalties collected from lithium production (primarily spodumene concentrate[345]) accounted for approximately 0.5 percent of royalty revenues. Western Australia's 2016-17 royalty receipts are summarised in Table 45[346] below.

Sector	2016-17 Royalty Receipts (A$ million	Percentage of Total
Iron Ore	$4,619	80.4%
North West Shelf Grants	$573.0	10.0%
Gold	$262.9	4.6%
Alumina	$81.1	1.4%
Copper, Lead & Zinc	$59.9	1.0%
Nickel	$49.2	0.9%
Lithium	$29.5	0.5%
Mineral Sands	$14.3	0.2%
Diamonds	$13.0	0.2%
Petroleum	$3.4	0.1%
Other	$39.1	0.7%
TOTAL	$5,744.9	

Table 45 – Western Australian Government Minerals and Petroleum Royalty Receipts (2016-17)

Based on the current royalty rate that applies to spodumene (lithium) concentrate (5.0 percent), the current and imminent production profile, and the weighted average price received for Western Australian spodumene (lithium) concentrate over the past four years,

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344 Estimated from reported operational workforce for Greenbushes, Mt Marion, Pilgangoora (Pilbara Minerals) and Pilgangoora (Altura Mining), as well as estimates of average staff on site from Department of Mines, Industry Regulation and Safety (2017), *Minerals and Petroleum Statistics Digest*, Western Australian Government, Perth

345 A relatively small volume of direct shipping ore in recent times has attracted a higher royalty rate of 7.5 percent.

346 Department of Mines, Industry Regulation and Safety (2017), *Minerals and Petroleum Statistics Digest*, Western Australian Government, Perth

royalty receipts from the sector are expected to reach approximately A$80 million in 2017-18 and grow to around A$150 million by 2022-23. This is illustrated in Figure 45 below.

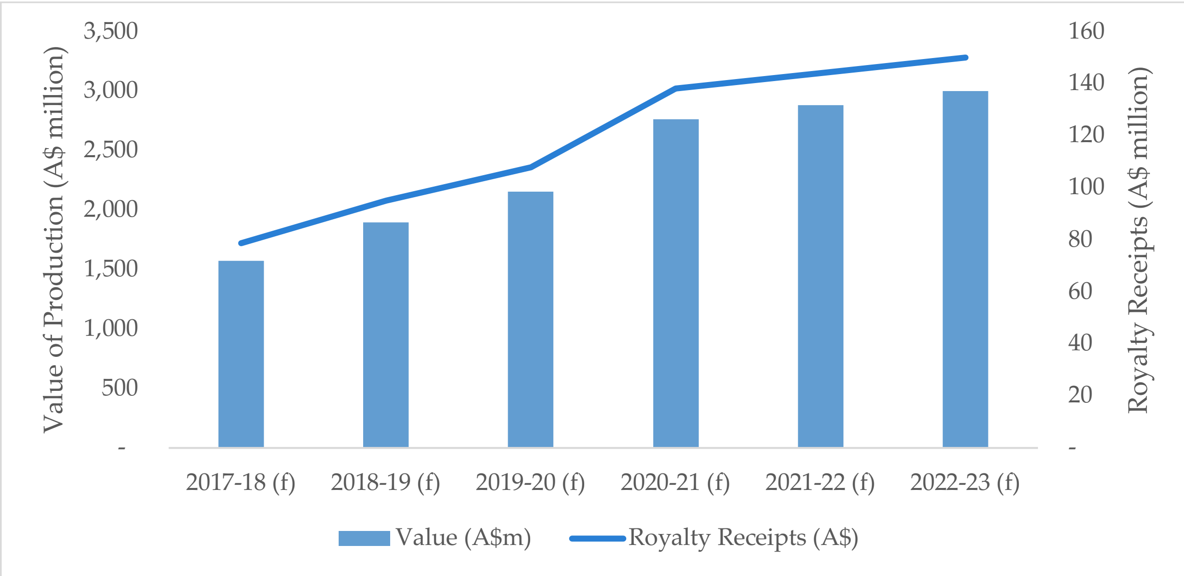

Figure 45 – Expected Western Australian Royalty Receipts Based on Production Forecasts and Current Prices

7.8.4. Western Australian Battery Chemical Production Forecasts

Lithium Hydroxide

Based on current construction of lithium hydroxide conversion plants and announced plans for such plants, lithium hydroxide conversion capacity in Western Australia will reach between an estimated 48,000 tonnes and 200,000 tonnes by 2022-23, depending on the extent to which projects that are as yet to commence construction proceed, and proposed plants are expanded to their full proposed nameplate capacity.

On this basis, the expected Western Australian lithium hydroxide conversion sector will consume between approximately 15 and 60 percent of forecast spodumene concentrate production in 2022-23.[347] This means that in the absence of additional conversion capacity, Western Australian spodumene (lithium) concentrate production will remain export oriented.

In the production of lithium hydroxide from spodumene (lithium) concentrate, the spodumene (lithium) concentrate typically represents between 50 and 70 percent of the cash costs, depending on price.[348] As such, operating costs for lithium hydroxide plants that use spodumene (lithium) concentrate as the feedstock are highly sensitive to relatively volatile spodumene concentrate prices.

The following figure is based on third-party forecast lithium hydroxide cash cost curve for 2021.[349] While the lowest cost Western Australian lithium hydroxide production is expected to be among the world's most competitive (some analysts suggest future North American production may have lower cash costs), it demonstrates that the cash cost advantage of the

[347] Approximately 7 tonnes of spodumene (lithium) concentrate is required to produce 1 tonne of lithium hydroxide.
[348]Adapted from Roskill (2018) Production Cost Data
[349] Roskill (2018) Production Cost Data

lower cost Western Australian producers is only marginally below that of the lowest cost PRC converters. Cash costs do not include transport to market costs. It is likely that when transport costs are included, Western Australian lowest cost lithium hydroxide will be broadly competitive with lowest cost PRC lithium hydroxide in East Asian, European and North American markets, albeit the Western Australian lithium hydroxide should at least in the short term be of higher quality.

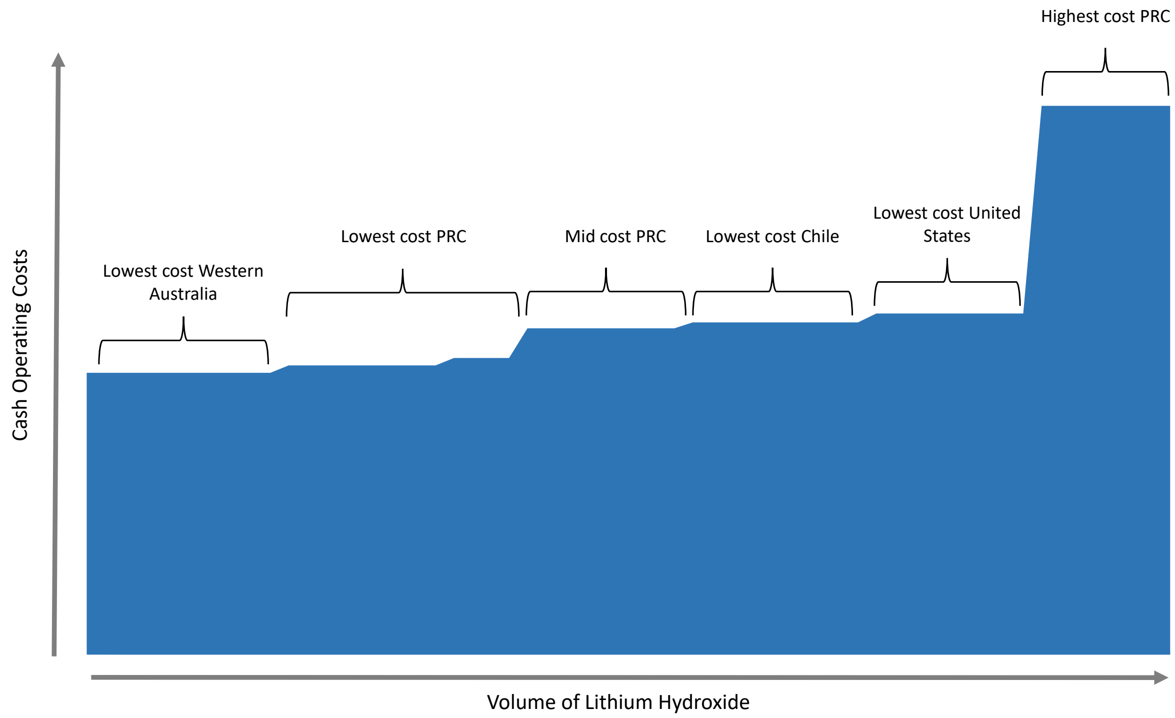

FIGURE 46 – EXPECTED LITHIUM HYDROXIDE CASH COST CURVE 2021

7.8.5. Economics of Precursor Manufacture

As the result of a lack of data in the public domain, determining precise cost comparators for this opaque stage of the lithium-ion battery supply chain is difficult.

Nevertheless, as discussed previously, the manufacture of cathode precursor material, while technically complex and requiring discrete supply chain relationships, is not a major process step from the manufacture of technical and battery grade chemicals. Furthermore, the ability to leverage from existing infrastructure and to some extent, locally produced reagent suites, mitigates potential cost disadvantages.

7.8.6. Economics of Cathode Active Material Manufacture

The manufacture of cathode active material is still largely a chemical manufacturing process, albeit a substantially more complex one and depending on final product, includes some processes more akin to product manufacturing.

In the case of a NMC 333 cathode chemistry (see Section 3.2), it is estimated that the raw materials (primarily nickel sulphate, manganese sulphate, cobalt sulphate and lithium hydroxide) account for approximately 50 percent of the production cost. The second most significant cost is the energy consumed by the sintering kiln, whereby a 6.5 tonne per day facility is expected to consume approximately 25,250 kWh per day.[350] The manufacturing process also requires other inputs such as binders and solvents and consumes significant volumes of process water.

As discussed in Section 5.11.1, the manufacture of cathode active material is a particularly competitive sector of the lithium-ion battery supply chain and is dominated by very large global chemical and industrial manufacturing companies, competing on relatively low margins, operating primarily in low cost jurisdictions. This, combined with a relatively large capital cost requirement and the operating cost profile discussed above, renders Western Australia less likely to be a competitive location for cathode material manufacturing.

7.8.7. Economics of other sector of the lithium-ion battery supply chain

As discussed in Section 5.6, the manufacture of anode active material is a relatively simple process that is dominated by the PRC by virtue of its relatively low input costs. The manufacture of electrolyte (see Section 5.7.1) is complex, revolving around wide range of chemical inputs, and is a capital intensive process utilising considerable proprietary intellectual property associated with well-established manufacturing plants in key battery manufacturing jurisdictions. In the case of separators (see Section 3.5) and current collectors (see Section 3.6), the products are manufactured by established large-scale plants located in major global industrial centres. It is highly unlikely that Western Australia could develop competitive manufacturing capability in anode active material, electrolyte, separator, binder or current collector sectors of the lithium-ion battery supply chain.

The subsequent stages of battery cell manufacture and pack assembly are more akin to conventional mass product manufacturing. For reasons discussed in Section 7.8.2, Western Australia is unlikely to be globally competitive in these downstream activities.

[350] Ahmed, S., Nelson, P., Gallagher, K., Susarla, N. and Dees, D. (2017), 'Cost and energy demand for producing nickel manganese cobalt cathode material for lithium-ion batteries;, Journal of Power Sources, Iss. 342, pp. 733 to 740

8. Policy Recommendations

The following Table 46 summarises the policy recommendations of this study.

SET THE RIGHT STRATEGY AND NARRATIVE	
1	The Western Australian Government and participants in the Western Australian lithium-ion battery supply chain should work together to establish a clear strategy designed to allow Western Australia and Western Australian industry to optimally capitalise on its competitive advantage in the global lithium-ion supply chain and sustain that competitive advantage.
2	Government and industry leadership should use an agreed narrative to promote Western Australia's prospects in the lithium-ion battery supply chain that is evidence-based, realistically achievable, clearly linked to the strategy, and very importantly recognises the importance of Western Australia's mining and emerging chemical processing industries as the fundamental source of Western Australia's competitive advantage in the lithium-ion battery supply chain, supporting their social licence to operate.
BUILD ON EXISTING TRADE RELATIONSHIPS	
3	Western Australian Trade Commissions, Austrade and the Commonwealth Department of Foreign Affairs and Trade should work with the various nations with which Western Australia and Australia already have extensive trade relationships and existing or prospective facilitative trade agreements, to optimise Western Australian supply of upstream products to the global lithium-ion battery supply chain and to attract FDI that builds upstream production capacity in Western Australia.
PROJECT INVESTMENT AND OPERATIONAL CERTAINTY	
4	The primary mechanisms for optimising project investment and operational certainty for the upstream lithium-ion battery industry in Western Australia should be in the form of specific improvements to the Strategic Industrial Area policy framework and the implementation of a time-bound machinery of government mechanism that facilitates all advanced lithium-ion battery supply chain projects under the existing Lead Agency framework.
NEW INDUSTRY DEVELOPMENT INCENTIVES	
5	To incentivise investment in conversion plants and upstream lithium-ion supply chain chemical manufacturing in Western Australia, the Western Australian Government should give consideration to the following: ▪ In accordance with the net-back principle that applies to the design of Western Australia's minerals royalty regime, operations that convert a mineral concentrate directly to a marketable chemical that has a higher primary constituent content should be charged a prescribed royalty rate that is between the current netback principle based mineral concentrate rate (5.0 percent) and the metal rate (2.5 percent), provided that the price differential between the two tax bases is such that the lower rate provides an incentive. ▪ Conduct further analysis and modelling to determine if there is an economic case for using the royalty regime to incentivise investment in Western Australian battery chemical precursor production capacity. ▪ As is always the case, consideration should be given to ensuring that Western Australia's overall taxation framework optimises the productivity of all Western Australian industry.
TARGETED RESEARCH AND DEVELOPMENT	
6	While there may be discrete areas of battery technology innovation where Australian science is at the cutting-edge, the proposed Future Battery Industries Cooperative Research Centre should carefully ensure that the vast majority of its resources are targeted at underpinning and expanding Australia's (primarily Western Australia's) competitive advantage in the lithium-ion battery supply chain, as articulated in this report.
7	The Commonwealth Government give consideration to revoking the recently imposed $4 million cap on cash rebates for smaller businesses under the R&D Tax Incentive Program.

TABLE 46 – SUMMARY OF RECOMMENDATIONS

Sub-section 8.1 below explains the parameters within which policy options have been considered by this study, as well as the objectives of the policy recommendations that have been made. It also explains why the general theme of some policy initiatives designed to progress Western Australia's interests in the lithium-ion battery supply chain that have been promoted by other commentators have not been considered appropriate measures by this study.

Sections 8.2, 8.3, 8.4, 8.5 and 8.6 detail the specific policy recommendations of this study. These are summarised as follows:

8.1. Parameters for Policy Recommendations

As discussed in the introduction to this report (see Section 1.2) the policy recommendations made by this study should meet two important criteria:

- **Recommendations must be legal** – that is, policy recommendations cannot contravene the *Commonwealth of Australia Constitution Act 1901*, or require major renegotiation of international trade agreements to which Australia is party.
- **Recommendations must be policy initiatives that an Australian government would normally implement** – that is, they should be consistent with Australia's rules based, open economy, as well as its general political and socio-economic norms and practices.

Establishing such boundaries could reasonably be criticised for hindering policy innovation. However, the primary purpose of this study is to set a practical and achievable pathway for the optimisation of Western Australia's participation in the lithium-ion battery supply chain. The window of opportunity for Western Australia to establish and entrench its position in this rapidly evolving industry means that there is limited time for changes in law, renegotiation of agreements, or protracted public policy debate that will inevitably be associated with any major shift in policy norms. This is discussed further in the following subsections.

8.1.1. Recommendations Must be Legal

Any policy that requires changes to the Australian Constitution, could only be given effect through a successful referendum of the Australian electorate. The parliamentary process, public communications exercise and ballot administration that is associated with a referendum is a time consuming and expensive task that is vanishingly unlikely to be undertaken by a government to enable policy that benefits a single emerging new industry. Furthermore, given only eight of the 44 referendums held in Australia since 1901 have been successful, there is a significant likelihood that it would fail.

Similarly, renegotiation of terms of trade agreements is a time consuming and expensive task that is unlikely to be undertaken by a government to advance the interests of a single emerging sector of the economy. Many of the counterparties to existing trade agreements are home to existing or aspiring downstream lithium-ion battery manufacturing sectors (see Table 48), and are unlikely to provide Australia with concessions that undermine the competitiveness of their own domestic industry. Furthermore, in most circumstance these agreements harmonise trade arrangements in the relevant goods, leaving little further benefit to be achieved.

8.1.2. Recommendations Must be Aligned with Australian Policy Norms and Practices

The requirement of being consistent with the economic, social and political norms and practices that, generally speaking, underpin Australian policy frameworks is also grounded in practicality. If the policy recommendations in this report are to be implemented and effective, they must be able to rapidly negotiate and achieve an implementable solution from the policy debate process, must be broadly accepted by the electorate and must be sustained over time, meaning they must survive the electoral cycle.

8.1.3. Policy Focus of this Study

Most importantly, the policy recommendations made by this report must be consistent with the analysis in this report (see Section 7). Within the parameters discussed above, the recommendations must seek to optimally protect Western Australia's competitive advantage in the global lithium-ion battery supply chain, and where there is a *prima facie* case for Western Australia to develop new, globally competitive industry, ensure that the policy framework creates every opportunity for that new industry to attain and sustain meaningful market share.

To this end, the focus of the policy recommendations in this study are to:

- Ensure that Western Australia's competitive advantage as a supplier of relatively large volumes of high quality battery minerals to the global lithium-ion battery supply chain in entrenched and sustained;

- Ensure that the domestic lithium and nickel conversion plants that are the subject of domestic investment and FDI, as well as aspiring chemical conversion plants for these battery minerals and others, are given every opportunity to establish a sustainable competitive position in the downstream lithium-ion battery supply chain; and

- Delineate a clear pathway for Western Australian industry and/or FDI in the establishment of cathode active material precursor chemical manufacture in Western Australia.

8.1.4. Comments on other Policy Proposals

A large number of general and very specific policy recommendations have been made by other commentators over the recent period proposing ways to advance Western Australia's (and Australia's) prospects in the lithium-ion battery supply chain. For reasons associated with either the analysis in this report (see Section 7) or the parameters established in this Section 8.1, this study does not support many of those third-party recommendations. The general policy themes that have been promoted by other commentators that are not supported by this study are discussed in the following subsections.

Establishment of Free Trade Zones

Some have proposed that concessional geographical zones be established to support the development of lithium-ion battery industries in Western Australia.

Free Trade Zones, Specialised Industrial Precincts, Special Administrative Regions and other 'enclave' type zones that revolve around preferential taxation and regulatory treatment are more commonly a feature of developing economies, where the loss of revenue capture and administrative oversight is balanced by the critical need to accelerate economic development. The establishment of special zones of this type would represent unprecedented policy in Australia.

While there are numerous such zones across the globe, their track record in generating growth and, most critically, economically sustainable industry, has been mixed. Furthermore, while there is always scope for improvement, there is no evidence that extractive industries or downstream processors that would otherwise purportedly operate within Western Australia view existing applicable customs, quarantine and development/environmental approvals regulations in force as the main barrier to establishing operations within the State.

Arguably, such a proposal would also expose the Commonwealth Government to legal risk, with legislation specifically favouring businesses operating in an area within a State endangered by the Constitutional bar on discriminating via taxation policy against States or parts of States.[351] Special trade regulation treatment also risks Australia contravening its obligations under its various bilateral and multilateral trade agreements.

At a reduced scope, there is certainly a case for better organising industrial parks so that they can deliver optimal efficiencies. As discussed in Section 8.4.2, this would involve optimising head works and installed infrastructure such that it is fit-for-purpose, streamlining approvals processes and seeking reasonable ways optimising productivity for operations located in those parks. Nevertheless, the existence of organised industrial parks should not unduly restrict location options available to commercial operators, as project proponents are best equipped to determine the most suitable location for their production facilities.

State Participation in and Subsidisation of Industry

Significant state participation in industry through equity arrangements and subsidisation have also been proposed as policy instruments designed to drive growth in Western Australia's lithium-ion battery industry. Other than in the area of research and development, there is no evidence whatsoever of market failure in capital markets in this regard.

In any event, caution should be taken in providing government subsidy to emerging industry. Battery chemistries are in a state of flux, with new materials replacing old. Private industry, with its clarity of direct and singular fiduciary interests and responsibilities to shareholders, is adequately agile to navigate changing industry circumstance. Government is less likely to be able to do so.

While subsidies can address instances of market failure and encourage investment to kick-start industry, the global experience has been that the flow-through effects can differ drastically, and potentially result in inefficiencies, graft, entrenched monopoly interests and discourage innovation. As noted in Section 6, the global experience has been that governments have decidedly mixed success in 'picking winners' in the lithium-ion battery industry.

Proposals that go further and advocate for direct government investment into business are particularly problematic. In the particular context, the experiences of 'WA Inc' deservedly cast a long shadow over direct, first-hand government involvement and investment in industry. A number of self-evident sovereign risk and conflict of interest issues are also raised by proposals of this nature, together with extreme reputational risk.

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[351] *Australian Constitution*, s51(ii)

Any financial concessions offered to industry should only be designed to incentive investment in areas where competitive advantage can feasibly be established and maintained, and in any event should be time-bound.

Market Oriented Intervention

Policies designed to encourage industry development via manipulating market demand for final products carries many risks and is unlikely to produce positive results.

For example, there are clearly environmental policy drivers to incentivise increased adoption of electric vehicles in Australia. However, because Australia does not have an automobile manufacturing industry or downstream battery industry (nor is it likely to in the foreseeable future), additional vehicles required to meet increased demand and their batteries will be imported, offering little benefit to Western Australian industry.

Alterations to GST Policy

Proposals to modify the GST allocation policy to benefit a single industry undermines the fundamental premise of horizontal fiscal equalisation and one of the key principles on which the GST policy framework is based, namely policy neutrality. It is very unlikely that the Commonwealth, let alone other States, would consider any such proposal.

Battery Minerals as a 'Strategic' or Protected Resource

Some commentators have suggested that greater restrictions should be placed on ownership of battery mineral resource assets and exports of battery minerals from Australia.

A designation of a mineral as 'strategic' presently has little formal meaning in Australia, and hence this would require novel and extensive engagement with the Commonwealth government and potentially all other States to define terms and agree on and implement appropriate policy.

In relation to foreign investment and control of battery mineral resources, the existing 'national interest' test applied by the Foreign Investment Review Board is quite broad, taking into account factors such as the impact on the economy, competition policy, and national security. It is difficult to envisage what other criteria would be applied to battery mineral resource assets.

More broadly, proposals to develop strategic domestic reserves of battery minerals presents several issues:

- In order to sell to domestic markets those markets must actually exist. There is currently no domestic market for battery minerals and as the analysis in this study indicates, nor is there likely to be for the foreseeable future. If a reservation policy demands that a percentage of production be sold domestically at market prices, and no demand exists for that product, proponents would be obliged to accept such low prices on a proportion of their output as to potentially render the entire project uneconomic. Further, while domestic subsidised metals may create some new domestic industry where none presently exists, there is a risk that those new businesses would be economic only at those low, effectively subsidised prices and unable to compete if prices ever normalised. Creating stockpiles of battery minerals would seem pointless.

- Western Australia competes in a global market. While Western Australia reserves of battery metals are substantial, Western Australian production is frequently not at the lower end of cost curve. To an extent, this disadvantage is offset by generally higher ore grades and a better economic and socio-political climate. Imposing new market distortions may have adverse effects on attracting new industry, if proponents are aware that they will be required to set aside a significant proportion of production for sale to an uncertain, immature and unknown domestic market. With significant reserves elsewhere in the world, production and extraction may be driven offshore.

- The current global 'new energy' metals market is characterised by strong and increasing vertical integration. Security of supply is critical, and has led to downstream investment by battery materials producers, notably Tianqi and Jiangxi Ganfeng Lithium Co, locking up supply for their overseas production plants. If Western Australia was to impose domestic market reservations at this early and nascent stage of the industry development, it may endanger those export-focused investments already proposed or under consideration. Similarly, altering the policies of the Foreign Investment Review Board may endanger the carefully cultivated 'open for business' reputation of Australia and Western Australia when the only significant investment in Western Australian-based downstream battery metals beneficiation has come from multinationals and joint ventures with significant foreign interests.

8.2. Set the Right Strategy and Narrative

For the purpose of ensuring that the supporting policy framework is appropriately guided, its purpose adequately communicated and its performance evaluated, it is critically important that the policy framework is grounded in and designed to support a realistic and achievable Western Australian lithium-ion battery industry development strategy. It is also important that the narrative used by government(s) to promote the industry is consistent with the pillars of this strategy.

8.2.1. An Achievable Western Australian Battery Minerals Strategy

RECOMMENDATION 1: The Western Australian Government and participants in the Western Australian lithium-ion battery supply chain should work together to establish a clear strategy designed to allow Western Australia and Western Australian industry to optimally capitalise on its competitive advantage in the global lithium-ion supply chain and sustain that competitive advantage.

The strategy should be developed according to several principles, namely, the strategy should:

- Be evidence based and underpinned by fundamental economic principles, particularly with respect to comparative advantage and international trade;
- Be consistent with and implementable within Western Australia's (and Australia's) rules based open economy and political norms and practices;
- Seek to remove any unnecessary or inefficient regulatory obstacles to the development of Western Australian industry;
- Recognise that industry is best placed to make commercial decisions with respect to how it participates in the lithium-ion battery supply chain and the framework should provide for flexibility and diversity in this regard;
- Ensure that any taxation and economic incentives both encourage development and deliver an equitable return to Western Australia and the nation; and
- Guide research and development investment toward areas that sustain and enhance Western Australia's competitive advantage in the lithium-ion battery industry.

It is noted that the development of a Western Australian lithium-ion battery industry strategy is currently the focus of the Western Australian Government's Lithium Taskforce.

8.2.2. A Realistic and Positive Narrative

Recommendation 2: Government and industry leadership should use an agreed narrative to promote Western Australia's prospects in the lithium-ion battery supply chain. This narrative should be evidence-based, realistically achievable, clearly linked to the strategy, and very importantly recognise the importance of Western Australia's mining and emerging chemical processing industries as the fundamental source of Western Australia's competitive advantage in the lithium-ion battery supply chain, supporting their social licence to operate.

Public policy debate is always healthy and is a fundamental aspect of policy development in a democracy such as Australia. However, new industry development also requires strong multi-sector leadership. The promotion of economically unsustainable development strategies and associated policy frameworks risks confusion, poor allocation of scarce industry and fiscal resources, does not benefit industry or the community in the long run, and when unsuccessful, erodes government political capital.

The narrative that is used to promote Western Australia's prospects with respect to the lithium-ion battery supply chain by industry and government leadership should be evidence-based, based on strong economic fundamentals and clearly linked to the strategy discussed in Section 8.1.1.

Very importantly, it should recognise the fundamental importance of Western Australia's mining industry as the source of Western Australia's competitive advantage in the global lithium-ion supply chain. It should also recognise that Western Australia's downstream progression in the lithium-ion value chain will revolve around the growth of its emerging domestic environmentally sustainable chemical processing industry. Supporting these critical industry's social licence to operate will be a key function of the narrative that is used by government and industry.

Both the narrative and the strategy on which it is based, should also be used to promote the industry and its products globally by national agencies such as Austrade.

8.2.3. Strategy and Action

The strategy should link to very clear policy initiatives in the areas of:

- Supporting the development of strong international trade relationships for Western Australian participants in the lithium-ion supply chain;
- Optimising project investment certainty and operational productivity;
- Incentivising new industry development;
- Ensuring research and development outcomes support and enhance Western Australia's competitive advantage; and
- Maintain the industries social license to operate.

8.3. Build on Existing Trade Relationships

Recommendation 3 – Western Australian Trade Commissions, Austrade and the Commonwealth Department of Foreign Affairs and Trade should work with the various nations with which Western Australia and Australia already have extensive trade relationships and existing or prospective facilitative trade agreements, to optimise Western Australian supply of upstream products to the global lithium-ion battery supply chain and to attract FDI that builds upstream production capacity in Western Australia.

8.3.1. Western Australia's Established Relationships

Australia is an open economy that conducts international trade that in 2016-17 totalled approximately A$545 billion. East Asian countries are by far Australia's largest trading partners, collectively accounting for approximately 50 percent of Australian international trade, with the PRC accounting for 28 percent in its own right. Australia's next largest trading partner is the United States which accounts for approximately 7.0 percent of Australia's international trade.

The PRC accounts for between 22 percent of 25 percent of international trade undertaken by the states and territories, with the exception of the Australian Capital Territory in which it is negligible, and Western Australia, where the PRC accounts for approximately 40 percent of its international trade. With respect to wider East Asia, with the exception of the Australian Capital Territory where East Asia accounts for only 4 percent of international trade, East Asian nations account for between 43 percent in the case of Tasmania, and 69 percent in the case of Western Australia.

Western Australia, and primarily its resources industry, is critically dependent on its trade relationships with East Asia and accounts for a significant portion of the Nation's trade with East Asia. Table 47[352] below, summarises Western Australia's trade relationships with individual nations and its share of total Australian trade with each of those nations in 2016-17.

	WA Trade	National Trade	WA % of National Trade
PRC	64.0	152.0	42.1%
Japan	19.9	60.6	32.8%
ROK	11.2	34.0	32.9%
Hong Kong SAR	9.7	12.9	75.2%
United Kingdom	5.3	16.8	31.5%
Singapore	4.4	12.6	34.9%
United States	4.0	39.4	10.2%
Indonesia	3.6	9.9	36.4%
Papua New Guinea	3.5	5.1	68.6%
Malaysia	3.4	14.3	23.8%
UAE	2.9	2.9	100.0%
Thailand	2.7	16.8	16.1%
Germany	2.5	16.1	15.5%
Taiwan	2.1	12.3	17.1%
India	2.1	18.0	11.7%
Philippines	1.3	1.3	100.0%
Vietnam	1.2	8.4	14.3%
New Zealand	1.0	13.2	7.6%
Bahrain	0.8	0.8	100.0%
South Africa	0.6	0.6	100.0%

Table 47 – Western Australia's International Trade Relationships (2016-17)

As a result of these significant and long-standing trade relationships, Western Australia has deep industry and national and sub-national government relationships with many of the countries that host substantial downstream lithium-ion battery supply chain industry including

352 Department of Foreign Affairs and Trade (2018), *Australia's Trade by State and Territory: 2016-17*, Australian Government, Canberra

particularly PRC, Japan and ROK, as well as other important downstream markets such as United Kingdom, United States, Malaysia and Germany.

8.3.2. Australian Trade Agreements

Australia is also party to trade agreements with a number of its trading partners. As summarised in Table 48 below, many of these facilitate 'free-trade' in key minerals and upstream intermediate battery products.

Counterparty	Implications for Battery Supply Chain Participation
	Trade Agreements in Force
ASEAN Nations and New Zealand	ASEAN-Australia-New Zealand Free Trade Agreement - gradated reduction in tariffs for all primary battery chemistries resulting in zero tariff from 2016 onwards. No tariffs on identified battery precursors, some remaining on battery metals and components (eg. copper cathodes, polymer sheets).
Chile	Australia-Chile Free Trade Agreement - all goods meeting rules of origin requirements except sugar are exempt from tariffs.
Japan	Japan-Australia Economic Partnership Agreement - elimination of tariffs on all primary battery chemistries and most precursor chemicals. Gradated reduction of tariffs on some battery metals to zero by 2021, including nickel and some forms of aluminium.
Malaysia	Malaysia-Australia Free Trade Agreement - elimination of remaining tariffs under AANZFTA relating to selected battery components.
PRC	China-Australia Free Trade Agreement - wide-ranging FTA that covers a range of non-tariff measures (NTMs – internal licensing, procedures, regulations etc) that may otherwise prove a barrier to export. Aspects of this are discussed further in Chapter 6. Immediate elimination of most tariffs on battery metals, gradated reduction to zero by 2019 on most battery chemistries and precursors.
ROK	Korea-Australia Free Trade Agreement - elimination of tariffs on most battery chemistries, precursors and metals, gradated reduction of remainder (eg nickel) to 2021. Case-by-case forum for elimination of selected NTMs.
Singapore	Singapore-Australia Free Trade Agreement - elimination of all tariffs remaining under AANZFTA.
Thailand	Thailand-Australia Free Trade Agreement - gradated elimination of remaining tariffs under AANZFTA by 2020. Varying commitments to reduce NTMs and ease business access.
United States	Australia-United States Free Trade Agreement - all tariffs on goods from US entering Australia removed. Tariffs on Australian exported batteries, precursors and components gradated reduction to zero tariff by 2014.
	Trade Agreements Concluded but not in Force
Indonesia	Indonesia-Australia Comprehensive Economic Partnership Agreement - elimination of most remaining tariffs under AANZFTA relating to battery components, partial lifting of industry controls relating to ESS and power generation.
Peru	Peru-Australia Free Trade Agreement - elimination of all tariffs on batteries, precursors, components and chemicals. Aims to increase outbound Australian investment in minerals and energy sector, streamlining approvals.
Pacific Islands	Pacific Agreement on Closer Economic Relations - Australia and New Zealand committed to zero tariffs from entry into force. Progressive gradated reduction of tariffs imposed on Australian exports by PI States, with commitment to provide MFN status.

TABLE 48 – AUSTRALIAN TRADE AGREEMENTS

Trade Agreements between Australia and the European Union, Gulf States, Hong Kong SAR, India and other nations are also currently under negotiation.

8.4. Project Investment and Operational Certainty

Recommendation 4: The primary mechanisms for optimising project investment and operational certainty for the upstream lithium-ion battery industry in Western Australia should be in the form of improvements to the Strategic Industrial Area policy framework and the implementation of a time-bound machinery of government mechanism that facilitates all advance lithium-ion battery supply chain projects under the existing Lead Agency framework.

Ensuring that projects along the supply chain have clarity and certainty with respect to development pathways and operational regulation is critical to ensuring that Western Australia is an attractive investment destination and that its industry is optimally competitive in the global lithium-ion battery supply chain.

The three main mechanisms that the Western Australian Government uses to facilitate a higher level of project investment and operational certainty are the State Agreement, Strategic Industrial Areas and Lead Agency frameworks. Each of these frameworks is discussed in sections 8.4.1, 8.4.2 and 8.4.3 respectively. Section 8.4.4 describes the rationale for this recommendation

8.4.1. The State Agreement Policy Framework

State Agreements have been used by the Western Australian Government for over 50 years to provide investment and operational certainty for large, primarily resources industry, projects.

A State Agreement is a contract between the executive government of a sovereign state and a private entity (or entities) that sets out the rights and obligations of the parties to that agreement with respect to a project (and related projects) that are to be developed and operated within the jurisdiction of that sovereign state.

State Agreements provide large, long-term projects and their investors with the certainty they require to achieve final investment decision, and the State with long-term certainty over the benefits the government and local communities will receive from those projects over their life-time. They also provide the State and the project proponents with a mechanism for considered, predictable and transparent changes to terms that, provided the process is managed responsibly, can occur to meet changing needs and expectations without creating perceptions of sovereign risk.

Contrary to popular belief, the terms of State Agreements are actually onerous on both the State and the counterparties, typically placing long-term obligations on both parties that are beyond those that exist under the normal legislative framework that pertains to commercial operations. These obligations recognise the scale and long term interaction of the project with the community, prescribing obligations on project proponents with respect to the community, and on the government with respect to providing a transparent and predictable operating environment for the proponents and their investors.

The Western Australian State Agreement Framework

For over 50 years State Agreements have been the preferred framework for the development of large, primarily resources projects in Western Australia for project proponents and the State alike. State Agreements provide the proponents of large projects with important assurances that their projects can be developed to optimum specification and free from undue interference from third parties. The development of a project that is the subject of a State Agreement that has been ratified by the Western Australian parliament (see next subsection) also sends a clear statement to the proponent company's investors, joint venture partners in the project and the project's long-term customers, that the government supports the project and that there is a degree of bipartisan or 'democratic' support for the project. This provides these stakeholders, whose support is critical to the success of the project, with confidence in the capacity of the project proponent to implement the project over the long-term. This is particularly important for the multi-generational projects that are characteristic of certain resources sectors of the Western Australian economy such as iron ore, natural gas and bauxite-alumina.

Resources projects that are the subject of state agreements operate under a framework that is defined by the interoperability of the *Mining Act 1978* (WA) and the State Agreement that is specific to that project. While, to the extent that there are any inconsistencies, the provisions of the State Agreement takes precedence over the *Mining Act 1978* (WA), many provisions of State Agreements (as they stand amended today) either make reference to the *Mining Act 1978* (WA) or its associated *Mining Regulations 1981* (WA), or replicate specific terms therein, including with respect to the royalty charge that applies to the project.

The *Government Agreements Act 1979* (WA) applies to any agreement that is scheduled to, incorporated in or appearing in an act of parliament, the administration of which is vested in the Governor of Western Australia or a Minister of the Western Australian Government. *The Government Agreements Act 1979* (WA) also applies to any agreement that is scheduled to, incorporated in or appearing in an act and proclaimed to be a Government Agreement. Pursuant to Section 3 of the *Government Agreements Act 1979* (WA), the provisions of such agreements operate and take effect according to its terms notwithstanding any other State act or law.

The actual terms and conditions of individual state agreements are specific to what is required by the proponent and the State with respect to the particular project. However, generally speaking they provide project specific detail as to the rights and obligations of the government and project proponent with respect to project approvals processes, land tenure, development and operation of infrastructure that supports the project, taxes and charges that apply to the project (including royalty charges), community development and local employment and contracting requirements.

While there is considerable commonality across the terms of State Agreements, particularly with respect to the principles under which the terms and conditions pertaining to the issues discussed above are established, certain criteria will be considered with respect to the appropriateness of specific terms and conditions, including:

- Lifespan of the project;
- Requirement for long-term certainty for the proponents;
- Existence of extensive or complex land tenure issues; and
- Remoteness and infrastructure requirements of the project.

Ratification of Western Australian State Agreements

In Western Australia, state agreements go further than a simple contractual arrangement between a project proponent(s) and the State. State Agreements in Western Australia are ratified by the proclamation of an act of parliament specific to the individual State Agreement. This parliamentary ratification can adopt one of two forms:

- **'As if enacted' State Agreements**
  Where the terms of that State Agreement become a schedule to the ratifying act of parliament, referenced 'as if enacted', the project the subject of that State Agreement can proceed according to the terms of that State Agreement and the terms of that State Agreement will take precedence over other State law, where there is a direct conflict between other State law and the terms of the ratified State Agreement. [353] Ratified 'as enacted' State Agreements establish a framework that, to the extent there are direct conflicts between the terms of the State Agreement and any other State law, the state Agreement has the force of law for the development of large, long term projects. This provides the State and the project proponent long-term assurance and certainty of the 'ground-rules' by which the project will be established and operate, often over the course of several generations of Western Australians.

- **'Approved' State Agreements**
  A State Agreement can also be ratified as simply 'approved' whereby it takes effect notwithstanding any other state act or law. However, the State Agreement terms are governed by the common law of contract and Section 3 of the *Government Agreements Act (WA) 1979.*[354]

The key difference between state agreements that are ratified '*as if enacted'* and those which are '*approved'*, is that parties to '*as if enacted'* agreements have legislative remedies for breaches, whereas parties to state agreements that are simply *approved,* may only seek contractual remedies. Where a State Agreement is ratified '*as enacted'*, the remedies for non-performance are prescribed by the ratifying act and typically include specific performance, forfeiture of rights, higher taxes and charges or a prescribed process of arbitration. For State Agreements that are ratified as *approved,* remedies for non-performance are the subject of the common law of contract, the *Government Agreements Act 1979* (WA) and other Australian legislation that forms the law of contract within the jurisdiction of Western Australia.

Parliamentary ratification of State Agreements does not imply that terms of State Agreements cannot be changed to respond to evolving requirements of the project, industry structure or expectations of society, as they often are. However, the negotiation process that is required and the fact that changes to terms of a ratified state agreement require an act of parliament for those changes to take effect, means changes that might be required over time are relatively predictable and transparent to the parties to the state agreement, and to society more widely.

The ratification of a State Agreement is an important aspect of the State Agreement process because:

- It provides transparency and a highly visible level of 'democratic' support for the project on terms and conditions set out in the agreement, providing both the project proponent(s) and the State a degree of certainty in 'social license to operate' with respect to the project that might not otherwise exist; and
- By giving the State Agreement the force of law (to the extent there is a direct conflict between a term of the State Agreement and other State law), ratification provides a degree of sovereign risk mitigation that would otherwise not exist.

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353 Hillman, R. (2006), 'The future role for State Agreements in Western Australia', *ARELJ,* (25), pp.293-329

354 Brown, N. (2014), 'State agreements and the regulation of water resources', *The Centre for Mining, Energy, and Natural Resources Law,* University of Western Australia, Perth

Three key legal doctrines restrict the ability of ratified State Agreements to eliminate sovereign risk and provide flexibility for future governments:

- **McCawley's Principle**
  The McCawley Principle (derived from the precedence of *McCawley v. The King, 1920*) states that Acts of Parliament cannot fetter or bind subsequent acts - legislation that is proclaimed later in time prevails over that enacted previously to the extent of any inconsistencies, provided those inconsistencies are clear and apparent.[355]

- **Agreements are unable to bind a parliament**
  A parliament is not permanently bound to any terms of a State Agreement in that a unilateral amendment to a state agreement that is given effect by the proclamation of legislation is not a breach of that agreement. In such circumstances, the counterparty does not have contractual remedy.

- **Doctrine of Executive Necessity**
  The doctrine of executive necessity is a public interest based concept whereby contracts and agreements are not enforceable if they fetter statutory executive government discretions and powers. Broadly speaking the law permits a government to fulfil the fundamental purposes for which it was created, even though this may interfere with contractual rights. It is similar in principle to McCawley's Principle, in that a duly elected government cannot be prevented from making changes to policy, albeit in the case of a State Agreement that has been ratified by an Act of parliament, this change must be effected by legislation.

While the above doctrines do limit the ability of State Agreement to completely mitigate sovereign risk through State Agreements, two other factors, at least in theory, dilute the practical ability of these doctrines to undermine a State Agreement's sovereign risk mitigation benefits:

- **Bipartisan 'Agreement' not to Unilaterally Vary State Agreements**
  Since 1996 there has been a bipartisan supported Western Australian parliamentary convention that parliaments will not unilaterally vary state agreements. This has underpinned the sensible consultation and negotiation process that has led to changes in state agreements.

- **State Agreement can Prescribe a Parliamentary Process**
  The *manner and form* provisions pursuant to Section 6 of the *Australia Act 1986* (Cth), which are binding on State parliaments, require laws respecting the constitution, as well as powers or procedure of a State parliament to be made in such a manner and form as required by a law of the Parliament.[356] State Agreements can impose additional processes on a parliament that are required before an act prescribing a unilateral change can be passed. However, the ability of Section 6 of the *Australia Act 1986* (Cth) to prevent the operation of the legal doctrine discussed above has never actually been tested in a court.

The Western Australian State Agreement Landscape

Some contemporary analysis observes that the use of agreements between governments and project proponents is relatively scarce among OECD nations, and limited primarily to

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[355] Carney, G., 'An overview of manner and form', *Queensland University of Technology Law Journal*

[356] Hillman, R. (2006), 'The future role for State Agreements in Western Australia', *ARELJ,* (25), pp.293-329

developing nations.[357] Agreements between the government and project proponents have most certainly been used in other Australian jurisdictions including the Northern Territory (e.g. *Tanami Exploration Agreement Ratification Act 2004* (NT), Tasmania (e.g. *Copper Mines of Tasmania Pty Ltd (Agreement) Act 1999 (TAS*) and Queensland (e.g. *Century Zinc Project Act 1997* (QLD)). They are also used to facilitate projects in several Canadian provinces that demonstrate similar development contexts to resources projects in Western Australia in that they require large up-front investment, are located in remote, infrastructure starved areas, interact with small local communities and have long operating lives.

Certainly the extent to which State Agreements are used to facilitate development in Western Australia seems globally anomalous. However, the criteria by which government – private sector project development agreements become necessary to drive and sustain economic development is not one of the developed versus developing world, or volatile government versus stable democracy, but one which is defined by the project investment context. For these reasons, in Western Australia, State Agreements remain fundamentally important to supporting sustainable economic development.

State Agreements have been used by consecutive Liberal, Liberal coalition and Australian Labor Party governments in Western Australia since the 1950s as an important policy tool in the facilitation of projects that have driven state development. There are currently 61 state agreements in force in Western Australia. These cover a wide range of minerals, petroleum, forestry and industrial projects, with over a third of the agreements pertaining to the iron ore sector or infrastructure projects associated with that sector. The distribution of state agreements across sectors of the Western Australian economy is illustrated in Figure 47 below.

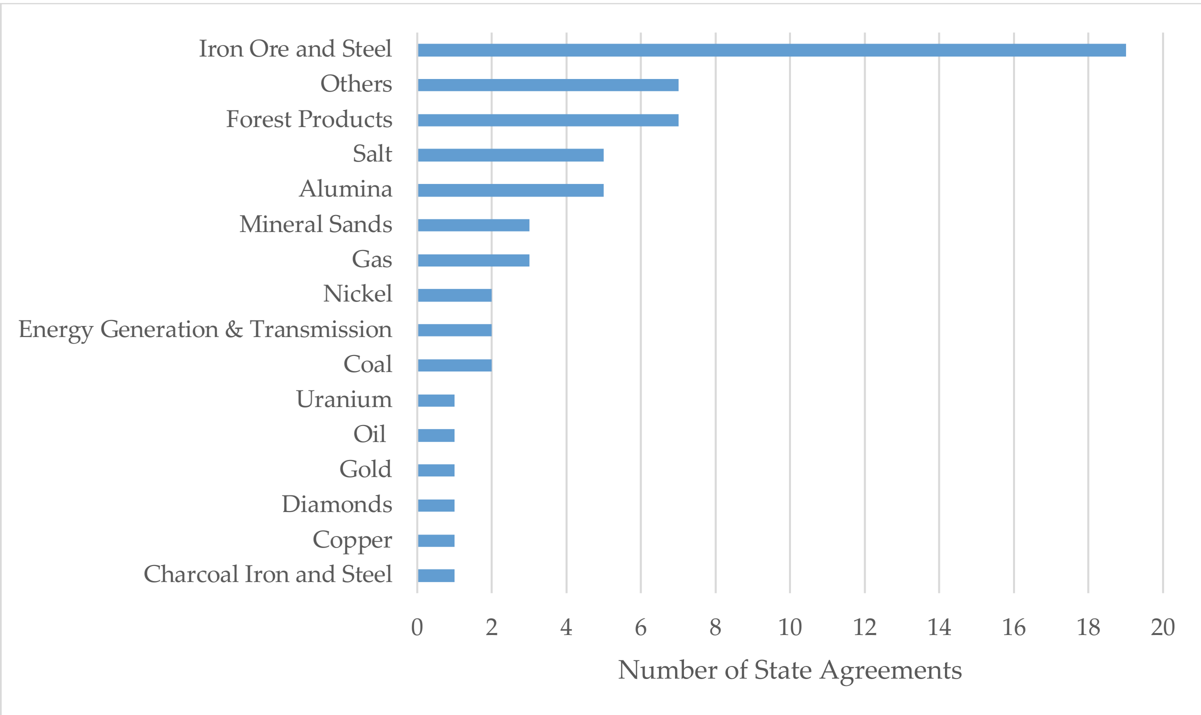

FIGURE 47 – DISTRIBUTION OF STATE AGREEMENTS ACROSS SECTOR OF THE WESTERN AUSTRALIAN ECONOMY

[357] Hillman, R. (2006), 'The future role for State Agreements in Western Australia', *ARELJ,* (25), pp.293-329

State Agreements have been proclaimed by governments in every decade since the 1920s, with the exception of the 1930s. However, most of the agreements proclaimed prior to 1960 are no longer in effect. As illustrated in Figure 48 below, while most of the current State Agreements were proclaimed in the 1960s and 1970s, they have been a consistently used policy tool since this time. Indeed in the case of the iron ore sector, where the use of State Agreements has been most prolific, at least one new State Agreement has been proclaimed each decade since 1960.

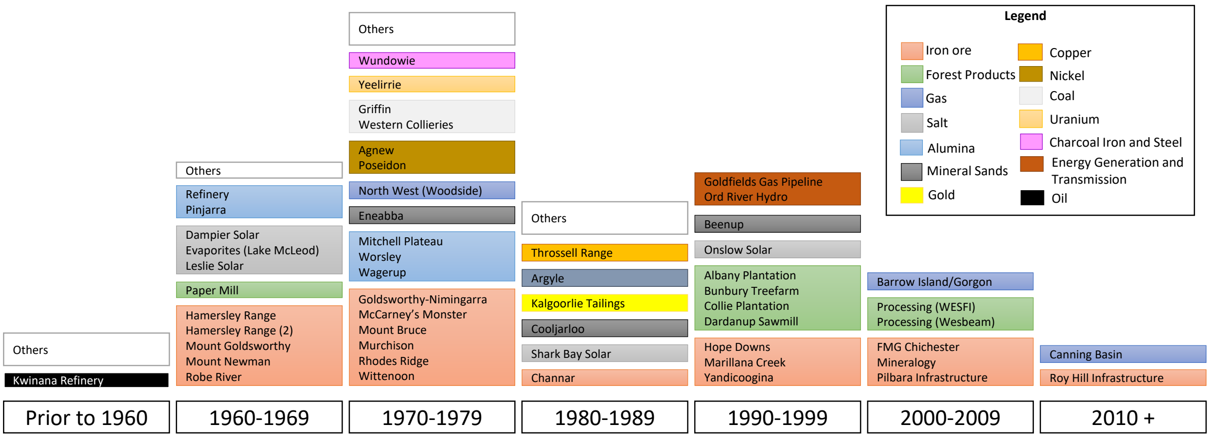

FIGURE 48 – WESTERN AUSTRALIAN STATE AGREEMENT TIMELINE – DATE OF PROCLAMATION

8.4.2. Strategic Industrial Area Policy Framework

The Strategic Industrial Area policy framework was developed by the Western Australian Government partly as a land planning and management framework, and partly to offer project proponents some of the certainty that is provided by the State Agreement framework (see Section 8.4.1) without the significant obligations that the State Agreement places on proponents and the State.

Strategic Industrial Areas (SIA) are areas of land in strategic locations that are set aside, or 'quarantined', for industrial use in order to attract investment in downstream processing, heavy industry and other industrial activity associated with the State's main upstream primary industries. This is given effect through a coordinated, 'whole-of-government' approach to planning for SIA areas.

SIA's are delivered through LandCorp, with some project communication activity coordinated through the relevant Regional Development Commission, but with the Department of Jobs, Tourism, Science and Innovation performing a lead agency role. The land that is the subject of an SIA is either held freehold by LandCorp and leased to a tenant, or is Crownland that converts to freehold land and is vested in LandCorp, once a tenant is prepared to enter into a lease. Most SIAs form part of state regional planning strategies and are appropriately zoned within the relevant local government area jurisdiction.

There are currently 12 SIAs operating or under development. The approximate location of the current SIA's is illustrated in Figure 49 below and Appendix 7 contains information on specific location, form and status of tenure, status of planning, infrastructure access, target industries and current project proponents of each of these SIAs.

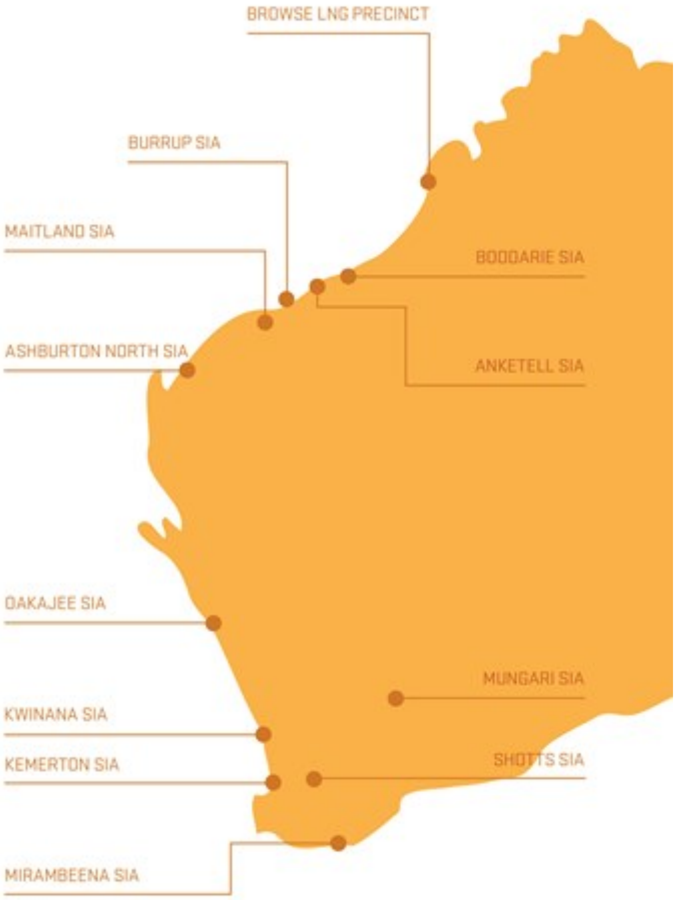

Figure 49 – Western Australian Strategic Industrial Areas

The SIAs are located in close proximity to key upstream Western Australian natural resources industries and are connected (or intended to be connected) to important infrastructure such as road, rail or ports. SIAs are, in effect, planned and protected industry hubs, designed to facilitate the downstream processing of natural resources (minerals, petroleum and agriculture) that are located in proximity to the specific SIA. They are also generally located close to local workforce and town site amenities, and are protected by planning buffer zones that provide some long-term comfort as to the viability of the area as an industrial site, regardless of other long term developments in the area.

Proponents interested in establishing facilities on a SIA are required to submit a business case the Department of Jobs, Tourism, Science and Innovation that articulates details of the project and the project's strategic alignment with the specific SIA. The Department of Jobs, Tourism, Science and Innovation then acts as the lead agency to assist the applicant in determining whether their proposal is suitable for the intended purpose of the SIA and if so, navigating the issuing of lease and the development of the project more generally.

Some SIAs are in close proximity to industrial infrastructure associated with projects that are the subject of State Agreements. However, SIA's are not State Agreements and do not replicate the purpose of State Agreements discussed in 8.4.1 above. SIAs are however, a demonstrated and important mechanism for reducing development risk associated with stand-alone or smaller industrial projects. Policy platforms similar to SIAs are commonplace globally.

The one lithium conversion plant under construction and another navigating the approvals process, as well as the nickel sulphate plant currently under construction are all located in SIAs, namely Kwinana and Kemerton, with some future plants planned for non-SIA areas.

While clearly preferential to a greenfields development site, SIAs are not competitive with 'turn-key' industrial sites that are offered to downstream battery supply-chain operators in many other jurisdictions. As has recently been demonstrated, projects can still encounter significant uncertainty and delays in project approvals and require significant investment in head-works and other infrastructure, a situation that does not typically arise in 'turn-key' industrial estates globally.

The Western Australian Government should explore mechanisms to improve the competitiveness of SIAs as industrial sites for battery mineral and chemical processing.

8.4.3. Lead Agency Framework

Significant development projects can be designated by the Western Australian Government as a *Major Proposal* or State *Significant Proposal*, whereby it will be assigned a lead agency of the Western Australian Government to assist with efficient planning and navigation of various statutory approvals. A *Major Proposal* is one that is deemed by the lead agency to meet criteria to warrant more intensive case management. A *State Significant Proposal* is one that is deemed by the Cabinet of the Western Australian Government to be critical to the advancement of the State of Western Australia or the Nation based on environmental, social, economic or heritage considerations.

Once a project is designed as a Major Proposal, or State Significant Proposal, the Department of Jobs, Tourism, Science and Innovation will be appointed as the *Lead Agency* for that project. In this role, the Lead Agency is responsible for:

- Providing proponents with information on statutory requirements through agency guidelines and referrals
- Case managing and coordinating approvals applications across government for proposals
- Assisting proponents to identify the potential impacts of the proposal on matters such as infrastructure, the environment and regional communities as well as the social considerations that arise from the proposal.

The categories of projects that qualify for this status are summarised in Table 49[358] below.

Project Level	Description	Status	Lead Agency Role
1	Project that is moderate in scale and capable of being accommodated through existing environmental, social and economic processes.	Major Project	Provide initial advice and support through an appointed project officer. Services include referral and introduction to relevant departments.
2	The project is a new proposal or expansion of an existing project where the proposed investment is significant or of strategic importance.	Major Project	A project manager will be assigned to assist with Government related aspects of proposal definition, infrastructure, industrial land, regional issues, coordination and interaction with agencies in relation to key statutory approvals.
3	The project is a proposal that is very large and/or complex with particular strategic importance to the State Government.	Project of State Significance	A senior project coordination team is appointed to assist with Government related aspects of proposal definition, infrastructure, industrial land, regional issues, coordination of key statutory approvals and if requested by Government, negotiation of a State Agreement.

TABLE 49 – MAJOR PROJECT OR PROJECT OF STATE SIGNIFICANCE DESIGNATION

8.4.4. Rationale for the Recommendation

State Agreements are Not the Right Framework

For the following reasons, the State Agreement framework is not a suitable mechanism for providing investment and operational certainty for current or foreseeable Western Australian projects associated with the lithium-ion battery supply chain:

- **Not a Cost Effective Solution**
  The negotiation, communications, parliamentary process and administration associated with State Agreements is too costly an exercise for the State or the proponents given the scale that is typical of projects operating in the lithium-ion battery supply chain. While, it is feasible that the State Agreement framework could be applicable to a much larger, vertically integrated multi-entity project, no such project is currently being proposed for Western Australia.

- **Many Proponents will not be Able to Carry the Obligations**
  For many of the current Western Australian project proponents, the obligations that State Agreements typically confer on proponents will be too significant for those proponents to commit to the agreement.

- **The Projects can be Regulated Adequately by the Existing Legislative Framework**
  The current and anticipated lithium-ion battery supply chain projects in Western Australia are not characterised by attributes such as unique infrastructure that isn't or can't be regulated by the existing regulatory framework.

358 Department of Premier and Cabinet, *Lead Agency Framework,* Government of Western Australia, Perth

- **The Strategic Industrial Area and Lead Agency Framework can Provide Many of the Same Benefits**
  A significant portion of the certainty that is provided by the State Agreement Framework can be provided by the SIA and Lead Agency Frameworks.

Strategic Industrial Areas are Useful, But Need Some Work

The one lithium conversion plant under construction and another navigating the approvals process, as well as the nickel sulphate plant currently under construction are all located in SIAs, namely Kwinana and Kemerton, with some future plants planned for non-SIA areas (see Section 5.3).

As discussed in Section 8.4.2, SIAs, primarily by virtue of their zoning and the zoning of lands around them, provide project with a degree of investment and operational certainty and through the existence of some infrastructure, improved productivity.

However, while clearly preferable to a greenfields development site in this regard, they are generally not competitive with other 'turn-key' style industrial estates that are offered to downstream battery supply chain operators in many other jurisdictions. As has recently been demonstrated, projects can still encounter significant uncertainty and delays in project approvals and require significant investment in head-works and other infrastructure, a situation that does not typically arise in 'turn-key' industrial estates globally.

Given the chemical industry intensive nature of immediate downstream processing that is likely to occur in Western Australia, SIAs that are the subject of current investment by operators in the lithium-ion battery supply chain (Kwinana and Kemerton SIAs), or in close proximity to advanced upstream projects (Burrup, Maitland, Ashburton North, Boodarie, Anketell and Mungari SIAs) should be the subject of a study designed to optimise their competitiveness with industrial estates elsewhere. The terms of reference for such a study should be developed collaboratively with industry, but should address at least the following:

- In consultation with industry, determine which SIAs are likely to be attractive with respect to hosting downstream lithium-ion battery supply chain capacity, and the nature of that capacity
- Development of a pathway to reduce environmental approvals process risk for projects seeking to establish operations in those specific SIAs
- Undertake a local industry symbiosis study to inform the optimisation of operations that includes all aspects of input sourcing, workforce access, logistics and waste management
- Ensure that infrastructure and headworks are optimised for the purposes of downstream facilities
- Explore opportunities to reduce industry costs such as an alternative electricity pricing framework for industrial facilities that create significant daytime load, allowing increased deployment of renewable energy across the State's networks.[359]

For purposes of clarification, such a policy should not restrict industry from establishing production facilities outside of an SIA.

A Lead Agency Taskforce

The major lithium-ion battery supply chain projects will qualify for Major Project Status (Level 1 or 2) described in Table 49 above. However, if Western Australia is to fully capitalise on the

[359] Such a policy will need to create whole-of-system capacity and be open to all generators.

opportunity to create a competitively sustainable chemical conversion and precursor manufacturing industry, it is likely that a more coordinated and strategic approach across the industry will be required.

Using the Lead Agency and SIA frameworks as the tools, and in recognition of the strategic importance of the opportunity and its time bound nature, it is recommended that a time bound (five year) special working group (taskforce) be established within the Lead Agency, and in accordance with the general Lead Agency framework, that assists all lithium-ion battery supply chain projects that have definitive feasibility study as though they were Level 1 or 2 projects.

This working group should seek direction from the Strategic Plan discussed in Section 8.2.1, oversee the study designed to optimise the competitiveness of SIAs as a location for investment in downstream lithium-ion battery competitiveness, and generally seek to optimise the competitiveness of Western Australian industry in the global lithium-ion battery supply chain.

Once it is deemed that conditions have stabilised the taskforce would be dissolved. Such a model could be used for other sectors as deemed appropriate.

8.5. New Industry Development Incentives

Other than by providing direct grants or concessional loans, the main mechanisms through which the Western Australian Government can incentivise projects in the lithium-ion battery supply chain are, where the project involves primary production, the minerals royalty regime, or in all cases, more efficient state taxes generally, particularly with respect to payroll tax. These mechanisms are discussed in subsection 8.5.1 and 8.5.2 respectively. The recommendation is that these mechanisms should be used collectively, to establish a Western Australian chemical processing industry. This is discussed in Section 8.5.3.

8.5.1. The Minerals Royalty Regime

Currently, all entities investing or proposing to invest in downstream lithium-ion battery supply chain capacity in Western Australia also operate or are proposing to operate upstream operations that do or will mine battery minerals. As discussed below, one of the principles of the Western Australian minerals royalty regime is to progressively discount the royalty rate that applies to output, subject to the extent to which primary ore is further processed (i.e. as a proponent adds value to the primary ore, the applicable royalty rate should decrease). Therefore, it is reasonable to propose that lower royalty rates could be offered to incentives companies with battery mineral mining interests to invest in downstream lithium-ion battery processing infrastructure.

However, there are a number of other aspects of the Western Australian minerals royalty regime that must be understood when contemplating such a proposal.

The Taxation of Mineral Resources

Changes to the taxation of mineral and petroleum resources has received considerable public policy attention in Australia over the past decade, albeit little has changed. The resulting stability of Australia's resources industry taxation framework has been a major contributor to Australia's international reputation as a resources industry investment destination. There are several principles that underpin a competent resources industry taxation system, from an industry and government perspective. Table 50 below summarises key principles that underpin a competent resources taxation system from industry and government perspectives.

Public Sector Economics Literature[360] TAXATION GENERALLY	Henry Taxation Review Report[361] TAXATION GENERALLY	Minerals Council of Australia[362] MINERALS TAXATION	Western Australian Government[363] MINERALS ROYALTIES
Economic Efficiency An economically efficient taxation system is one that does not interfere with the efficient allocation of resources.	**Equity** The taxation system should be equitable in its relative treatment of different tax payers, including current and future tax payers.	**Prospective** Changes in taxation and royalties should not undermine the basis upon which long-run investment decisions have been made, nor compromise the principles of equity and efficiency.	**Equity** The royalty system should return fair and appropriate compensation to the community for the loss of its resources, and treat producers equitably so that similar projects are required to make similar royalty payments
Administrative Simplicity The administration of the taxation system from the Government and taxed entities perspective should be simple and relatively inexpensive.	**Low Costs from Economic Inefficiencies caused by the Tax System** An economically efficient taxation system is one that does not interfere with the efficient allocation of resources.	**Internationally Competitive** The total taxation burden should be internationally benchmarked and be competitive against other global investment destinations, recognising the mobility of capital.	**Efficiency** The royalty system should not reduce the productive capacity of the economy, or unduly deter or distort employment and investment decisions.
Flexibility The taxation system should be able to respond to changes in economic circumstances easily, or even automatically in some instances.	**Low Costs of Operating the Tax System** The administration of the taxation system from the Government and taxed entities perspective should be simple and relatively inexpensive.	**Differentiated** Capital investment and financial return characteristics differ significantly among minerals commodities and taxation rates should recognise this.	**Adequacy** The royalty system should return sufficient revenue to support Government spending on services and investment.
Political Responsibility The taxation system should be designed such that the tax payer can ascertain what they are paying and evaluate how accurately the system reflects their preferences.	**Institutional Sustainability** Relating to low costs of operating the tax system, the system should ensure that the tax payer and the beneficiary of that tax are sustainable.	**Mineral Resource Based** Minerals resources taxation and royalties should be levied on the primary resource value only, and not on the value added in downstream transport logistics and processing.	**Stability and Predictability** The royalty system should provide stable and predictable revenue to allow Government to plan and deliver services sustainably, and to provide proponents with stable and competitive royalty framework when planning projects.
Fairness The taxation system should be equitable in its relative treatment of different tax payers.	**Environmental Sustainability** Related to economic efficiency, the efficient allocation of resources requires that environmental costs imposed on others should be internalised through taxes/prices or regulation.	**Equitable and Efficient** Genuine reform of taxation and royalty arrangements should promote economic activity and improve the efficiency, simplicity and fairness of the system without compromising neutrality and seek to minimise deadweight loss to the economy of taxation and royalty collection.	**Transparency and Simplicity** The royalty system should be simple for Government to administer, and for proponents to comply with and understand.
	Provision of Sustainable Revenue to Fund Government The system should provide resources to sustain government programs and to redistribute income and wealth.		

TABLE 50 - COMPARISON OF PERCEPTIONS OF CHARACTERISTICS OF A BEST PRACTICE TAXATION-ROYALTIES SYSTEM: TAXATION GENERALLY, MINERALS INDUSTRY TAXATION AND MINERALS ROYALTIES

360 Stiglitz, J. (2000), *Economics of the Public Sector,* 3rd Ed., Norton, New York

361 ACIL Tasman (2009), *Selected Mining Royalty and Taxation Issues Arising from the Henry Tax Review: Royalty-Tax Systems, Assignment and Revenue Redistribution,* CMEWA, NSWMC, QRC and SACOME

362 Minerals Council of Australia submission to the Henry Tax Review

363 Western Australian Department of Treasury

> *'Across the globe, no type of tax on mining causes as much controversy as royalty tax'*
>
> - World Bank (2006)

Royalties are a tax that is unique to the natural resources sector and is one that has manifested itself in a wide variety of forms globally. While the base that royalties tax can be profit margin oriented, they are typically charged against either a quantity of natural resource that is extracted and sold (specific royalty) or the value the natural resource that is extracted and sold (*ad valorem* royalty). Given that it is generally not good public policy practice to tax industry out of existence, all royalty policies must give consideration to profitability.

With at least 110 nations having replaced or made significant amendments to their mining legislation over the past 30 years, royalty systems across the globe are also evolving as nations try to achieve the right balance of attracting investment in the development of their natural resources, and ensuring they appropriate an optimal return, from particularly non-renewable resources such as minerals.[364]

Principals Underpinning the Western Australian Royalties Regime

In assessments of the royalty regime and in advocacy designed to change it, industry has had a tendency to treat royalties the same as any other tax. It is true that to the extent that a royalty is a legislated government impost levied against income generated by industry and payable by industry, royalties are a tax. However, from the government's perspective royalties are at least philosophically a little different. In the case of Australia, historical circumstances surrounding Federation and the Australian Constitution, has tended to result in State's adopting a very proprietary position over royalties that extends beyond just a philosophical position.

Like all other Australian states, the Western Australian Government has a Constitutional right to receive a return on *in situ* mineral resources that occur within the boundaries of the State. This Constitutional right has its roots in circumstances prior to Australia becoming a federation, is consistent with the Australian Constitution, and has been reinforced by multiple constitutional conventions.

These circumstances are as follows:

- When Britain proclaimed Western Australia as a penal settlement in 1827, beneficial ownership of all lands vested with the Crown, with control exercised by the British Government in accordance with British law at the time.
- Under British common law, ownership of land includes rights to coal and minerals (except gold and silver) within the boundaries of that land. Therefore, when land grants are made by the Crown, surface rights as well as rights to minerals pass to grantees or purchasers.
- Between settlement and the mid-1800's the Western Australian colonial administration progressively sought control of the 'waste lands of the Crown'.
- In the mid-1800s, the British Parliament ratified a constitution conferring powers on the colonial legislatures (including that of Western Australia) pertaining to land and minerals that allowed the Western Australian legislature to reserve all coal and mineral (except construction materials) for the Crown when making Crown grants of land.

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[364] Otto, J., Andrews, C., Cawood, F. Doggett, M., Guj, P., Stermole, F. and Tilton, J. (2006), *Mining Royalties: A Global Study of their Impact on Investors, Government and Civil Society*, World Bank

- In 1901, the Constitution of the Commonwealth of Australia was proclaimed and Section 51 which identifies the head of power under which the Federal Parliament may make laws does not identify minerals as an area in which the Federal Parliament has jurisdiction and therefore minerals remain under the jurisdiction of the State legislatures.

The resultant vesting of ownership of *in–situ* minerals within state boundaries with states, combined with their constitutional right to make laws pertaining to those minerals, provides states with both the right and the legal mechanism to charge a fee to third parties wishing to extract and commercialise those minerals. In this sense, a royalty is a price paid to the state for the 'license' to extract and commercialise, in this case, a non-renewable, natural resource.

It is on this basis that the Western Australian government differentiates royalties from other types of taxes, determining them to be more akin to a 'price' paid for a license to commercialise resources owned by the State, than a 'tax'. In the case of Western Australia, the importance of this proprietorship is exacerbated by the fiscal importance of royalty receipts, whereby they account for approximately 25 percent of Western Australian Government revenue.

Tiered Rating Based on a Netback to a Benchmark Return

In 1981, the Western Australian Government determined that the State's minerals royalty regime should return to the State an amount 'in order of' 10 percent of the value of the ore 'ex mine'[365] as compensation for the exploitation of State owned resources. This benchmark was reinforced by the 2015 Royalty Review[366], and is one of several mechanisms used by the Western Australian Government to determine whether a particular royalty rate or the royalty regime overall is equitable.[367]

The value of ore 'ex-mine' was also determined to be the value of the ore at the mine-head, which is considered to be the ROM stockpile, as this generally the first 'ex-mine' point in the minerals production process at which the value of ore can be reasonably determined.

There is limited information available as to how the benchmark rate of 10 percent was determined. The two most commonly espoused views are:

- The tender process for the first Western Australian iron ore mine, Goldsworthy, indicated that a rate of 7.5 percent of mine revenue was the maximum government charge that the market could bare at the time, and the Government arbitrarily determined that the cost of crushing and screening was equivalent to 2.5 percent of the market value, resulting in a benchmark rate of10 percent of mine-head value; and/or
- 10 percent of the wellhead value was the traditional royalty levied against petroleum production and this was simply translated across to minerals royalty policy[368].

365 Minister for Mines (1981), IN: Department of State Development and Department of Mines (2015), *Mineral Royalty Rate Analysis – Final Report,* Western Australian Government, Perth

366 Department of State Development and Department of Mines (2015), *Mineral Royalty Rate Analysis – Final Report,* Western Australian Government, Perth

367 Department of Mines and Petroleum (2015), *Mineral Royalty Rate Analysis – Final Report,* Western Australian Government, Perth

368 Guj, P. (2013), *Western Australian Royalty Review: Some Key Policy and Administration Considerations,* Centre for Exploration Targeting

Despite a lack of clarity as to the historical foundations of the 10 percent benchmark, the 2015 Review of the minerals royalty regime[369] by the Western Australian Government further reinforced its relevance:

- In a tiered ad valorem system, the main benefit of a benchmark is to enable comparison of royalties within and between industries at a point in time, and over time. Other considerations, such as economic conditions and level of processing, should also be taken into account.
- The benchmark also gives the community a readily understood gauge of the return it makes on the sale of the State's mineral resources.
- That the 10 percent benchmark and *ad valorem* rates in Western Australia strike a reasonable balance between equity, efficiency, a fair return to the community, and competitiveness.

Consistent with the first espoused view, the royalty rate that should apply to a mineral commodity is generally charged at one of three rates, depending on the amount of downstream processing that is undertaken by the operator within Western Australia. Because no operations in Western Australia sell ore directly from the ROM stockpile (i.e. even in the case of DSO, there is a crushing and/or milling process), no mineral commodities in Western Australia are charged a royalty rate of 10 percent. The rate that applies is discounted according to a three stage scale to reflect the additional cost associated with different levels of downstream processing.

Table 51 below lists the in-principle rates that apply mine output that has been the subject to different stages of downstream processing from the mine-head.

Stage	In Principle Rate
Benchmark Return: Mine-head (ROM Stockpile)	10.0%
Bulk material (Crushed and Screened)	7.5%
Mineral concentrates	5.0%
Minerals in metallic form	2.5%

TABLE 51 – IN PRINCIPLE MINERAL ROYALTY RATES

Legislative Instruments for Prescribing Royalty Rates

Generally speaking, there are three objectives of the Western Australian Government's minerals policy:

1. Encourage the development of the State's mineral resources to generate economic benefits;
2. Control development of the State's mineral resources to ensure that development of those resources is consistent with State policies that are designed to address societal expectations with respect to social, environmental and other economic issues; and
3. Optimise the economic rent collected by the government for the third party use of the non-renewable resources that are owned by the State.

[369] Department of State Development and Department of Mines (2015), *Mineral Royalty Rate Analysis – Final Report,* Western Australian Government, Perth

While there is a wide range of local, state and commonwealth government regulation that affects the mining industry, the industry's activities, including its royalty obligations, are governed primarily by the following mechanisms:

- **The *Mining Act 1978* (WA) and associated *Mining Regulations 1981* (WA)**
  The *Mining Act 1978* (WA) provides the government with a legislative mechanism to charge royalties on minerals production and its' associated *Mining Regulations 1981* (WA) prescribe rates to specific categories of production of specific minerals. With the exception of a limited number of minerals (e.g. salt and building materials), these rates reflect the netback principles discussed above. They can be modified by the Minister for Mines with subsequent ratification by Parliament.

- **State Agreements**
  Projects that are the subject of State Agreements (see Section 8.4.1) either have a specific royalty rate that is prescribed by the State Agreement or make reference to the *Mining Regulations (WA)* 1981 for royalty rate determination. Where the rate is prescribed by the State Agreement, that rate may be the same as the regulations (e.g. iron ore State Agreements), or concessional (e.g. alumina and diamonds).

Case Precedence for Discounted Royalty Rates

There is case precedence for the Western Australian Government providing royalty rates under both State Agreements and the powers afforded to it under the *Mining Act 1978* (WA) that are discounted from the general netback principle. Such concessional rates have typically been afforded to reflect:

- An unusually large investment that the project will make in local social and physical infrastructure that might be required to support the project at a particular site;
- Unusually high capital start-up costs associated with the project;
- High costs associated with transitioning a mine from open pit to underground operations; and/or
- The importance of the project to the local community, including with respect to creating employment opportunity for local communities.

The historical and contemporary examples where Western Australian Governments have prescribed royalty rates that in the context of the netback principle, are *prima facie* concessional are summarised in the following Table 52 and the policy rationale for the concessions discussed in detail in Appendix 8.

Sector	Theoretically Applicable Rate	Concessional Rate	Primary Policy Rationale	Instrument
Gold	2.5%	Various concessions over time including full exemption, partial exemption and concessional rates	Strategic mineral (historical importance of gold reserves) and financial hardship	Mining Regulations
Alumina	2.5%	1.65%	Scale of investment, financial hardship and significant employer	State Agreements
Diamonds	7.5%	5.0%	Financial hardship and significant employer	State Agreements
Iron ore fines	7.5%	5.625%	New market development	State Agreements
Magnetite	5.0%	12 month 50% concession	Financial hardship	Ministerial
Iron ore juniors	7.5%	Repayable 50% rebate	Financial hardship	Ministerial
Salt	n.a.	n.a.	Renewable resource	State Agreements

TABLE 52 – HISTORICAL AND CONTEMPORARY ROYALTY CONCESSIONS

The Royalty Regime as the Policy Instrument

The royalty rate that applies to lithium production is currently the subject of review by the Western Australian Government. The current end-product of lithium mining in Western Australia is a spodumene (lithium) concentrate with an approximate 6 percent lithium content. In accordance with the netback principle, this product attracts a royalty rate under the *Mining Regulations 1981* (WA) of 5.0 percent.

The further processing of this concentrate to a lithium hydroxide product produces a compound that has a much higher lithium content of approximately 30 percent. However, according to the current netback principle, to attract the lower rate of 2.5 percent, the product would theoretically need to be a lithium metal of around 98 percent plus lithium content. Given that in current market conditions and strategic context, the production of lithium hydroxide is a desirable industry for Western Australia, a new tier of royalty rate that applies to higher grade concentrates should be implemented with a rate that is between 5.0 percent and 2.5 percent, recognising the additional value-adding investment. Obviously, this should only be considered if the product prices that determine the tax base differential is such that the lower rate does indeed provide an incentive.

The limits of the netback principle are further challenged in the case of the production of nickel or cobalt sulphide. The feedstock to these processes is a metal product that already attracts the theoretical lowest royalty rate of 2.5 percent. The conversion of these metal products to technical grade chemicals in the current market conditions and strategic context is most certainly value-adding and therefore, could be subject to a further discounted rate. However, applying this approach has two obstacles that need be addressed:

- The primary purpose of the Western Australian royalty regime is to provide a return to the State for the third party commercialisation of its non-renewable resources. As such, there is likely to be limited political appetite for providing a mechanism whereby proponents pay a negligible royalty rate, irrespective of the degree to which they value-add to the resource.

- Such an incentive only benefits mining company downstream expansion. It is likely that if Western Australia is to establish a robust presence of the upper mid stream lithium-ion battery supply chain, it will need to provide incentives for non-mining interests to invest as well.

For these reasons, it is likely that some demarcation of mining and chemical processing policy is required. This is discussed in Section 8.5.3.

8.5.2. Other Taxes

Another major Western Australian tax impost on industry is payroll tax. Pursuant to the *Pay-roll Tax Assessment Act 2002* (WA), all companies with a payroll totalling $850,000 must pay a pay-roll tax to the Western Australian Government. The payroll tax liability and how it is calculated is tiered based on total payroll. This is summarised in Table 53 below.

Applicable Rate	Threshold	Basis of Liability Calculation
5.5%	$0.85 million to $7.5 million	WA Taxable Wages – Deductable Amount X Applicable Rate
5.5%	$7.5 million to $100 million	WA Taxable Wages X Applicable Rate
6.0%	$100 million to $1.5 billion	WA Taxable Wages X Applicable Rate
6.5%	More than $1.5 billion	WA Taxable Wages X Applicable Rate

Table 53 – Western Australian Payroll Tax and Thresholds

Payroll Tax is a significant source of revenue for the Western Australian Government. In 2016-17, the Western Australian Government collected an estimated $3.5 billion in payroll tax.[370] However, payroll tax also serves to add to the cost of employment, which as discussed in Section 7.8 is a major source of competitive disadvantage for Western Australian industry. A more efficient Western Australian taxation system designed to improve the competitiveness of Western Australian industry more generally should give consideration to payroll tax reform.

8.5.3. Toward a Western Australian Battery Chemicals Industry Policy

As discussed in Section 6, while the effectiveness of policy frameworks designed to incentivise investment in domestic downstream lithium-ion battery supply chain has had variable success internationally, the absence of any such policy in Australia (and Western Australia) is somewhat of an anomaly.

The development of lithium-ion battery supply-chain capacity in Western Australia, at least in the first instance, requires investment in the establishment of a chemical manufacturing industry. As discussed in the previous sections 8.5.1 and 8.5.2, the main levers that the Western

370 Department of Treasury (2018), *Overview of State Taxes and Royalties*, Western Australian Government, Perth

Australian Government can use to incentive this investment are, where a mining company is involved, the royalties regime, and in all cases, more efficient state taxes generally, particularly payroll tax.

It is proposed that any inventive package revolving around these mechanisms should be based on the following principles:

- Manufacture of high principle constitute chemicals (such as lithium hydroxide) directly from mineral concentrates should attract a new netback rate that is between 5.0 percent and 2.5 percent, provided product prices are such that the resulting tax base differential does indeed provide an incentive.
- Any additional concessions should be targeted at encouraging investment in capacity downstream from that which is already taking place (i.e. downstream from chemical conversion)
- Any additional concessions could be time-bound
- The concession package should both encourage mining operations to invest in further downstream processing associated with the lithium-ion battery supply chain and for non-mining interests to invest in that capacity.

Recommendation 5: To incentivise investment in conversion plants and upstream lithium-ion supply chain chemical manufacturing in Western Australia, the Western Australian Government should give consideration to the following:

- **In accordance with the net-back principle that applies to the design of Western Australia's minerals royalty regime, operations that convert a mineral concentrate directly to a marketable chemical that has a higher primary constituent content should be charged a prescribed royalty rate that is between the current netback principle based mineral concentrate rate (5.0 percent) and the metal rate (2.5 percent), provided product prices are such that the resulting tax base differential does indeed provide an incentive.**

- **Conduct further analysis and modelling to determine if there is an economic case for using the royalty regime to incentivise investment in Western Australian battery chemical precursor production capacity.**

- **As is always the case, consideration should be given to ensuring that Western Australia's overall taxation framework optimises the productivity of all Western Australian industry, particularly with respect to payroll tax.**

This proposal has the following benefits:

- It provides a clear demarcation between the minerals policy framework and an emerging framework designed to incentivise the development of a downstream chemical processing industry in Western Australia, while recognising the natural link between the two sectors in Western Australia
- It provides incentive for both mining companies to invest downstream, as well as downstream operations that are not vertically integrated
- It provides financial leverage for domestic mining operations to enter into partnership with downstream processors in developing downstream capacity in Western Australia
- It maintains the ability of the royalty regime to provide a return to the State for the commercialisation of its non-renewable resources, while providing short-term incentive for investment in an important strategic industry.

8.6. Research and Development

As with all industry, sustained investment in research and development that improves productivity will be essential to ensuring that Western Australia's competitive position in the lithium-ion battery supply chain is maintained. The two principle mechanisms that will support this in the immediate term are the proposed Future Battery Industries Cooperative Research Centre (if successful) and the R&D Tax Credit program. These are discussed in the following subsections 8.6.1and 8.6.2.

8.6.1. Future Battery Industries Cooperative Research Centre

The Cooperative Research Centre (CRC) Program supports industry led collaborations between industry, researchers and the community. Its objectives are to:

- Improve the competitiveness, productivity and sustainability of Australian industries, especially where Australia has a competitive strength and in line with government priorities;
- Foster high quality research to solve industry-identified problems through industry-led and outcome focused collaborative research partnerships between industry entities and research organisations; and
- Encourage and facilitate small and medium enterprise (SME) participation in collaborative research.

CRC grants provide successful applicants with grant funding for up to 10 years for collaborations from industry, research and community sectors to solve industry problems and improve the competitiveness, productivity and sustainability of Australian industries. There are currently 31 active CRCs in Australia.

A number of operations in the Australian lithium-ion battery supply chain, together with research organisations across Australia are currently mounting a bid to have a Future Battery Industries Cooperative Research Centre established with its headquarters in Western Australia.

This presents a significant opportunity to focus Australian research resources on challenges and opportunities pertaining to Western Australia's competitive advantage in the lithium-ion supply chain. As such, the majority of the proposed CRC research portfolio should focus on issues such as:

- Leveraging Australia's significant expertise in extractive metallurgy to identify systems for extracting lithium and other battery minerals from alternative host mineralisations that currently present technical and/or economic challenges.
- Optimising the interface between extracted concentrates and metal products and the production of technical grade chemicals.
- Improving the productivity of chemical conversion across a range of battery minerals that are produced in Australia.
- Developing social science that allows the emerging Australian (Western Australian) chemical conversion industry to proactively engage with the community, ensuring its social license to operate.
- Exploration of niche applications of lithium-ion and other battery technologies where Australian industry may be able to establish competitive advantage.

Recommendation 6: While there may be discrete areas of battery technology innovation where Australian science is at the cutting-edge, the proposed Future Battery Industries Cooperative Research Centre should carefully ensure that the vast majority of its resources are targeted at underpinning and expanding Australia's (primarily Western Australia's) competitive advantage in the lithium-ion battery supply chain.

8.6.2. R&D Tax Incentive

The Commonwealth Government R&D Taxation Incentive program is a major stimulus for R&D investment by Australian business. Additional credits that encourage larger companies to be rewarded for R&D investment of up to $150 million are welcome in this regard. However, the capping of cash refunds for smaller companies at $4 million may serve to stifle important innovation in the emerging Western Australian lithium-ion battery sector.

Recommendation 7: The Commonwealth Government give consideration to revoking the recently imposed $4 million cap on cash rebates under the R&D Tax Incentive Program.

Appendix 1: Case Study: The Australian Steel Industry

The contemporary Australian steel industry was first established in Lithgow, followed by Newcastle and Port Kembla at the turn of the 20th century, and the domestic steel industry fully met domestic demand for steel for well over 80 years.

What these three locations had in common was proximity to inputs, easy access to markets, availability of labour, and relatively low transport costs. However, the geographic locations of these production centres were not the only factor that catalysed investment in the establishment of the domestic iron and steel production in Australia.

Strong government intervention was a theme throughout the history of the Australian steel industry. Early on, bounty systems coupled with government driven domestic steel allocation helped to catalyse the development of the iron and steel industry. This government intervention resulted in the modernisation and expansion of existing domestic production capacity while also resulting in growth effects that manifested in the mining and supportive upstream industries.

Tariffs played a significant role in the establishment and growth of the steel industry and continued to play a significant role until the late 1970's, when they began to be slowly phased out. The Australian government often partnered with steel producers and the iron ore sector as a co-investor on infrastructure projects. Furthermore, the government implemented an export ban on iron ore from 1938 to 1960, and subsequently intervened in deciding whether the prices negotiated for ore exports were acceptable by granting export permits.

In the years between the 1960s and the 1980s, demand for steel increased significantly to facilitate infrastructure growth, however during the 1980's the emergence of cheaper steel from south east Asian manufacturers resulted in significant restructuring of the Australian steel industry.

In 1996, the Western Australian government passed legislation in an attempt to foster downstream beneficiation by requiring major exporters of iron ore to engage in beneficiation beyond that of just iron ore concentration and palletisation. The two acts, the Iron Ore Beneficiation Agreement Act and the Iron Ore Direct Reduced Iron Agreement Act were passed by the state '*for the purpose of promoting employment opportunity and industrial development, and in particular the establishment of further processing facilities in Western Australia*'[371].

These agreements stipulated that, as a requirement to do business in Western Australia, companies must submit plans for and implement beneficiation projects. These acts resulted in the initiation of two beneficiation projects, the Boodarie hot briquetted iron plant using the FINMET process, and the Hismelt operation in Kwinana, projects undertaken by BHP and Rio

371 Iron Ore Beneficiation (BHP) Agreement Act 1996 (WA)

Tinto respectively. The processing technologies employed at both plants were new to the market at the time and had yet to be fully developed or widely adopted by the industry.

Neither project reached economic viability, thus prompting their respective closures, despite significant capital expenditures by the companies involved and the deployment of new, potentially more efficient production technologies.

As a result of the two beneficiation project failures, in 2011 the Western Australian government moved to repeal the beneficiation acts of 1996 and renegotiated its agreements with Rio Tinto and BHP regarding iron ore extraction. The new agreements removed the requirement for the implementation of beneficiation projects by the two producers, however included higher rates for royalties associated with extraction and export of iron ore.

Despite the apparent incentives for downstream processing and manufacturing, the Australian steel industry has continued to decline. At its peak in the early 1980s, Port Kembla Steelworks employed 22,000 employees, compared to less than 5,000 today.

In 2011, BlueScope Steel ceased exporting steel and closed blast furnace 6 at its Port Kembla Steelworks and reported a full year loss of approximately A$1 billion.

In 2015, the New South Wales government introduced a Steel Industry Protection Bill, the objective of which was to support the Australian steel manufacturing industry. The Bill requires that, as far as practicable, that all steel used in public works or infrastructure constructed by or on behalf of public authorities in New South Wales is manufactured in Australia.

However declining East-Asian Hot Rolled Coil prices and a global oversupply of steel production has resulted in BlueScope steel facing ongoing annual losses, threatening the economic viability of its remaining furnace.

The following figure illustrates the rapidly growing dominance of the steel industry of the People's Republic of China since the turn of the century.

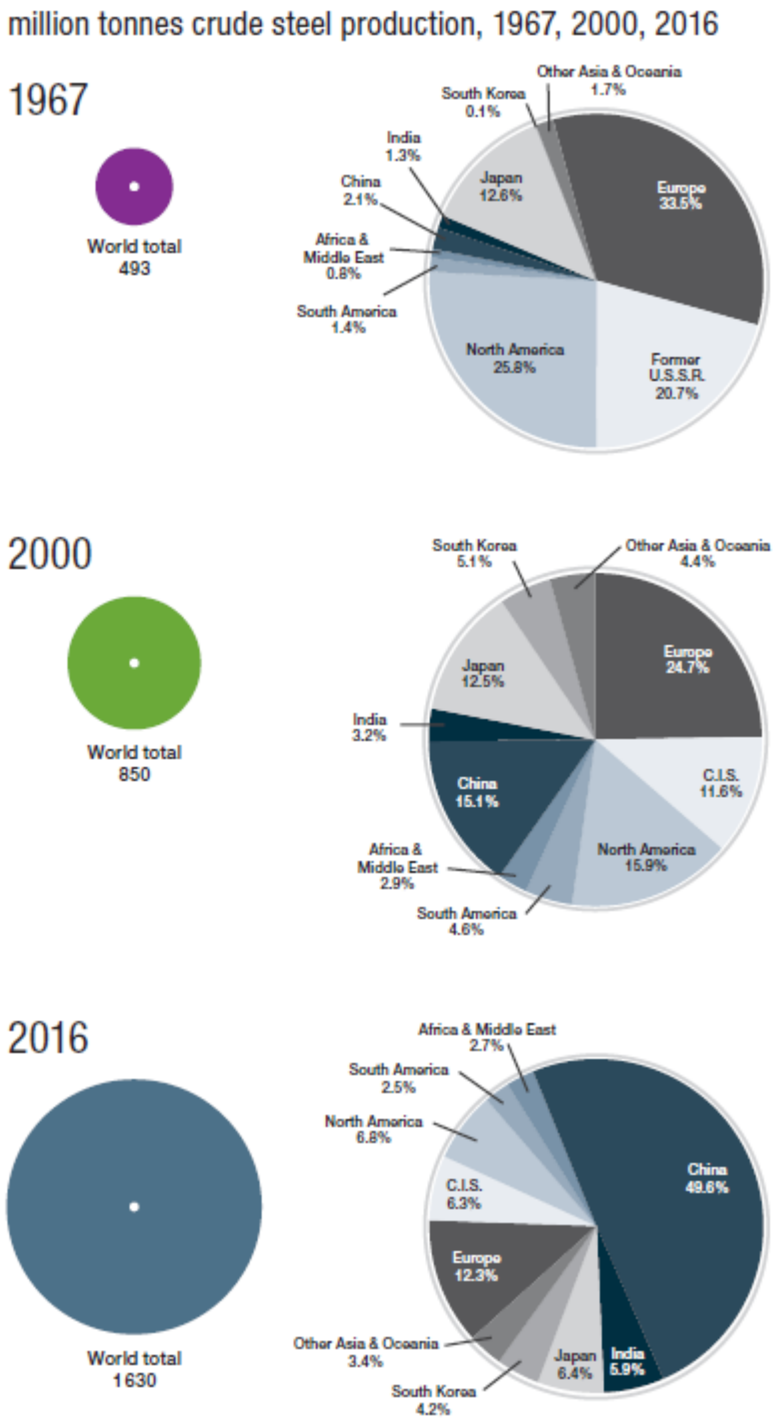

Figure 50: Global Crude Steel Production 1967, 2000, 2016

Appendix 2: Electric Vehicle Availability in Australia

Original Equipment Manufacturer	Vehicles in the Market	Market Status in Australia
Toyota	Prius (PH), Prius C (PH), Prius B (PH), Camry Hybrid (PH)	78,000 sold
Lexus	CT2000h (PH)	Available in Australia
Honda	Accord Hybrid	Available in Australia
BMW	I3(BEV), i8 (PHEV), ActiveHybrid 3 (PHEV), X5 (PHEV), 330e (PHEV), 225e	Available in Australia
Tesla	Model S (BEV), Model X SUV (BEV)	Available in Australia
Nissan	Leaf (BEV)	Available in Australia
Mitsubishi	i-Miev (BEV), Outlander (PHEV)	Available in Australia
Audi	A3 Tron (PHEV)	Available in Australia
Porsche	Panamera (PHEV) Cayenne (PHEV)	Available in Australia
GM Holden	Volt (PHEV)	No longer available in Australia
Mercedes	350e (PHEV)	Available in Australia
Volvo	XC90 T8	Soon available in Australia
Renault	Kangoo (BEV)	Not available in Australia
BYD	BYD E6	Soon available in Australia

Appendix 3: Western Australian Nickel Resources

Project	Proponents	JORC class	Mineralisation	Region	Production
BHP Nickel West	BHP Billiton Nickel West	N/A	N/A	WA	90.6kt nickel metal equivalent
Forrestania Nickel	Western Areas; Great Western Exploration	Resource	25.91Mt @ 1.7%	Kondinin	23.05kt NiS
Murrin Murrin	Glencore	Resource	268Mt @ 1.01%	Laverton	41.9kt NiS
Kalgoorlie Nickel Project	Ardea Resources	Resource	773Mt @ 0.7%	Kalgoorlie	
Pyke Hill	Admiralty Resources; Cougar Metals	Resource	14.69Mt @ 0.9%	Leonora	
Pardoo Highway	Arrow Minerals; Caeneus Minerals	Resource	44.7Mt @ 0.3%	Karratha	
Radio Hill	Artemis Resources	Resource	4.02Mt @ 0.5%	Karratha	
Carlingup - Nindilbillup	Australasian Mining; Phanerozoic Energy	Resource	16.01Mt @ 0.57%	Ravensthorpe	
Mt Thirsty Nickel	Barra Resources; Conico	Resource	31.94Mt @ 0.55%	Dundas	
Kurnalpi - Grey Dam	Carnavale Resources	Resource	14.5Mt @ 0.7%	Kalgoorlie	
Kambalda Nickel / RNC	Consolidated Minerals; Salt Lake Mining; Maverix Metals	Resource	15.8Mt @ 4.42%	Coolgardie	
Duketon Nickel	Duketon Mining	Resource	1.9Mt @ 1.7%	Laverton	
Ravensthorpe First Quantum	First Quantum Minerals	Reserve	124.3Mt @ 0.61%	Ravensthorpe	
Silver Swan/Black Swan	Indago Resources; Western Areas; Harmony Gold (Australia)	Resource	30.7Mt @ 0.58%	Kalgoorlie	
Nova-Bollinger	Independence Group; Free CI	Reserve	13.6Mt @ 2%	Dundas	

Project	Proponents	JORC class	Mineralisation	Region	Production
Kambalda-Independence	Independence Long; Maverix Metals	Reserve	0.4Mt @ 3.9%	Coolgardie	
Wingellina	Metals X; Samsung C&T	Resource	187Mt @ 1%	Warburton	
Mincor Nickel	Mincor Resources	Resource	2.7Mt @ 3.6%	Coolgardie	
Carnilya Hill	Mincor Resources; Celsius Coal	Resource	1.03Mt @ 2.8%	Coolgardie	
Scotia-Broad Arrow	Minotaur Exploration	Resource	1.05Mt @ 2%	Menzies	
Honeymoon Well	Norilsk Nickel Ojsc Mmc	Resource	173Mt @ 0.68%	Wiluna	
Lanfranchi Tramways	Panoramic Resources	Reserve	0.21Mt @ 2.03%	Kalgoorlie	
Savannah Nickel	Panoramic Resources	Reserve	8.21Mt @ 1.37%	Halls Creek	
Lake Johnston	Poseidon Nickel	Resource	3.5Mt @ 1.49%	Dundas	
Windarra	Poseidon Nickel	Reserve	1.719Mt @ 1.45%	Laverton	
Aztec Dome	Ramelius Resources	Reserve	3.37Mt @ 0.63%	Kalgoorlie	
Mt Fisher East	Rox Resources	Resource	2Mt @ 2.5%	Wiluna	
Thunderbox Nickel	Saracen Mineral Holdings; Norilsk Nickel Ojsc Mmc	Resource	0.69Mt @ 2.1%	Leonora	
Cosmos	Western Areas	Resource	10.4Mt @ 2.6%	Leonora	

Appendix 4: Aspiring Australian Cobalt Producers

Western Australian Projects

Project	Proponents	JORC class	Mineralisation	Region	Production
Goongarrie Nickel/Cobalt Project	Ardea Resources	Reserve	40.1Mt @ 0.09%	Kalgoorlie	$CoSO_4$ 5.5ktpa nameplate 'base case', expansion study to 10ktpa
Mt Thirsty Cobalt/Nickel	Barra Resources; Conico	Resource	31.94Mt @ 0.13%	Dundas	$CoSO_4$ 1.9ktpa nameplate
Ravensthorpe First Quantum	First Quantum Minerals	Reserve	124.3Mt @ 0.03%	Ravensthorpe	C&M Previously 600t $Co(OH)_2$
Murrin Murrin	Glencore	Resource	268Mt @ 0.07%	Leonora	$CoSO_4$ 3ktpa in 2017
Nova-Bollinger	Independence Group	Reserve	13.6Mt @ 0.07%	Dundas	$CoSO_4$ Est. 850t in 2018
Mulga Rock	Vimy Resources	Resource	34.1Mt @ 0.024%	Victoria Desert	Pre-feasibility

<u>Goongarrie Nickel/Cobalt</u>

Located within the larger Kalgoorlie Nickel Project, a series of tenements prospective for nickel/cobalt sulphides covering approximately 1,800km2 near Kalgoorlie in central WA, the Goongarrie Nickel/Cobalt Project, comprising approximately 5% of the overall area, is considered most strategically viable by current owner Ardea Resources. This high-grade ore-bearing subsection has been subject to multiple feasibility studies and mineralisation reports since 2004, identifying the largest known cobalt resource outside the Congo and high grades of cobalt ore[372].

As of March 2018, the results of a pre-feasibility study indicate a JORC-compliant total reserve of some 40.1Mt of high-grade cobalt, and support a 'base case' of a 1Mtpa ore processing operation, resulting in battery grade outputs of nickel sulphate at around 41.5ktpa and cobalt sulphate at approximately 5.5ktpa[373]. The company is understood to be progressing through a definitive feasibility study looking at increasing total ore throughput to 2.25Mtpa, which would result in a cobalt sulphate output of around 10ktpa[374], however also highlights that the project has significant potential to scale as further drilling defines the remaining 95% of the larger Kalgoorlie Nickel Project tenements.

While no offtake agreements have yet been secured, Ardea is understood to be seeking a minority strategic investor to finance development of the project, appointing KPMG as strategic advisors and having received a number of unsolicited enquiries from downstream processors, including battery cell manufacturers and carmakers[375]. This an IPO in late 2016 and initial ASX listing in February 2017, raising AUD $12.39 million[376].

Mt Thirsty Cobalt/Nickel

Near Norseman in Coolgardie, the Mt Thirsty project is a somewhat unusual highly oxidised nickel/cobalt/manganese deposit, with high-grade cobalt-bearing ores supporting a focused atmospheric leaching cobalt recovery process, resulting in lower processing capital costs compared to more typical pressurised acid leach[377]. As a result, approximately 80% of project revenue is expected to derive from cobalt[378].

The project is a 50/50 joint venture between Barra Resources and Conico, and is still at feasibility stage, with no offtake agreements yet concluded. Initial scoping studies completed in 2018 support a 21-year life of mine, scaling to approximately 1.9ktpa cobalt and 1.76ktpa nickel. A pre-feasibility study commended in May 2018 is expected to firm these results further[379].

Ravensthorpe First Quantum

Acquired by Canadian company First Quantum Minerals as a decommissioned nickel operation in 2010, the Ravensthorpe open-pit nickel laterite operation has been placed into care and maintenance as of October 2017 due to depressed global nickel prices. When operational, cobalt recovery from the project was at approximately 1.4% of the hydroxide

[372] *Quarterly Operations Report*, published Ardea Resources, 30 June 2018
[373] *Goongarrie – Highly-scalable, multi-decade project*, in *Advancing our Flagship, Multi-Decade Goongarrie Nickel Cobalt Project Towards Production*, presented Aredea Resources, Battery Material 2018, Shanghai, PRC, 18-19 April 2018
[374] *2.25Mtpa Goongarrie Nickel Cobalt Project Expansion Study Demonstrates Enhanced Project Economics,* published Ardea Resources, 24 July 2018
[375] *Ibid*; *Quarterly Operations Report*, published Ardea Resources, 30 June 2018;
[376] *ASX Market Release: Ardea Resources Limited*, published ASX, 7 February 2017
[377] *Mt Thirsty Cobalt-Nickel Project*, published Barra Resources, accessed 01/08/2018
[378] *Ibid*
[379] *Ibid*, *Conico and Barra hand out contracts for Mt Thirsty*, McKinnon, S published The West Australian, 31 May 2018; *Mt Thirsty PFS Contracts Awarded*, published Conico, 31 May 2018

precipitate produced (approximately 600 tonnes per annum)[380], reportedly sold at spot pricing to downstream processors in the PRC and not subject to long-term offtake agreements[381].

As at the date of this report, First Quantum has reported no short to medium-term plans to restart operations, and hence the Ravensthorpe project is unlikely to have a significant impact on WA cobalt production[382].

Mulga Rock

An extremely remote project located in the Great Victoria Desert, the Mulga Rock project proposes an open-cut mine focusing on uranium-bearing sandstone and lignite. With a JORC compliant resource of approximately 28,000 tonnes, the deposits are the second-largest uranium find in WA[383], and are 100% owned by Vimy Resources.

With uranium the definite focus of the project, an initial Definitive Feasibility Study released in January 2018 considered, but discounted, the prospect of a base metals plant targeting recovery of cobalt, nickel, copper and zinc from the uranium process tailings. With increasing demand and higher spot prices for battery metals worldwide, Vimy Resources announced in April[384] that a second feasibility study is in progress, with early results indicating that a tailings recovery process would be economic and could produce some 2.5kt of cobalt and 6.2kt of nickel over the life of the project. At this early stage, no offtake agreements have been yet.

Other Australian Aspiring Cobalt Producers

Project	Location	Stage	Outputs
Owendale	NSW	Feasibility Commenced	Scandium, Platinum, Nickel, Cobalt, Copper, Palladium
Syerston	NSW	Feasibility Commenced	Scandium, Nickel, Cobalt, Platinum, Palladium
SCONI	QLD	Feasibility Commenced	Cobalt, Nickel, Scandium, Iron Ore
White Range	QLD	Feasibility Completed	Copper, Cobalt, Gold, Silver, Molybdenum, Rhenium
Mount Gunson	SA	Feasibility	Copper, Cobalt, Silver, Gold, Iron Ore , Uranium
North Portia	SA	Feasibility Commenced	Copper, Gold, Molybdenum, Cobalt

380 *Ravensthorpe*, published First Quantum Minerals, accessed 01/08/2018; and derived statistics
381 *Cobalt (Advanced Release)* in *USGS 2014 Minerals Yearbook*, published United States Geological Survey, October 2016
382 *First Quantum Minerals Reports Second Quarter 2018 Results*, published First Quantum Minerals, 30 July 2018
383 *Mulga Rocks U prospects*, published Mindat.org, accessed 01/08/2018
384 *Battery Minerals provide upside for the Mulga Rock project*, published Vimy Resources, 12 April 2018

Appendix 5: Australian Graphite Projects

Western Australian Graphite Projects

Yalbra Graphite

Located approximately 300km due east of Carnarvon, the Yalbra Graphite project covers an area of approximately 40 square kilometres, with a further 400 square kilometres of surrounding prospective graphite zones (Coordewandy and Gum Creek Graphite Projects)[385]. With a JORC-compliant resource of 2.27 megatonnes at approximately 20.1% contained granite, the Yalbra project is claimed by 100% owner Buxton Resources to be the highest-grade graphite prospect in Australia.

Subject to extensive exploration throughout 2013 and 2014, and with Buxton resources buying out its minority partner Montezuma Mining in 2016, the progress on commercialising Yalbra nonetheless seems to have stalled, with the last mention of the project in company reporting in mid-2016[386] where Buxton was stated to be seeking a strategic partner to commercialise the project through investment and/or offtake. As such, the future likelihood of the project having a significant impact on WA graphite production under current ownership is in doubt, with Buxton appearing to devote most of their attention to the 'Double Magic' nickel/copper strike in the West Kimberley[387].

Munglinup Graphite

The graphite deposits near the town of Munglinup, approximately 70km east of Ravensthorpe, have been known and sporadically explored since the early 20th century, with repeated interest in its high-grade deposits failing to result in significant commercial exploitation[388]. Previous feasibility studies and exploration by the WA Government, Gwalia Consolidated and Battery Limits have established a JORC-compliant resource of 3.625 megatonnes at 15.3% graphite, with a commercially favourable flake size distribution of 67% greater than 150 micrometres and 35% 'Jumbo' (greater than 300 micrometres)[389].

Current tenement majority owner Mineral Commodities acquired a 51% controlling stake from Gold Terrace in 2017, with a farm-in agreement and term sheet establishing a pathway for Mineral Resources to secure 100% ownership upon commercialisation[390]. A feasibility scoping study and expanded drill programme over late 2017 and early 2018 have indicated an

[385] *Yalbra Project*, published Buxton Resources, accessed 01/08/2018

[386] *Quarterly Activities Report for period ending 31st March 2016*, Buxton Resources, published 30 April 2016

[387] *Quarterly Activities Reports* for periods 31 March 2016 – 30th June 2018, all Buxton Resources, accessed 01/08/2018

[388] *Munglinup Graphite deposits*, published Mindat.org, accessed 01/08/2018

[389] *Ibid*, *Munglinup Graphite Announcement*, published Mineral Commodities, 11 September 2017

[390] *Ibid*; *Mineral Commodities to acquire stake in Munglinup graphite project*, Masige, S, published Australian Mining, 11 September 2017

economic, low-cost project, with estimated production of 56ktpa over a mine life of nine years[391].

No offtake agreements are yet in place, however Mineral Commodities is understood to be in early stage discussions[392], and a pre-feasibility study released in May 2018 utilises an assumption that long-term offtake agreements will be in place by June 2019[393].

McIntosh Graphite

Approximately 190km north of Halls Creek, near the WA/NT border, the McIntosh graphite project combines some 11 tenements covering 330 square kilometres, with a JORC-compliant defined resource containing some 21.3 megatonnes of ore[394]. While this is of a lower grade compared to some other WA graphite prospects, at only 4.73% graphite, the graphite recovered is reportedly of an ore-type that supports easy purification through a proprietary low-cost process, resulting in a concentrate at between 99.9991 and 99.9998% purity – thus meeting '5N' standard and being suitable for a range of premium applications in nuclear physics, advanced electronics, synthetic diamonds and lithium batteries[395].

While most of the exploration work and initial studies have been done by Hexagon Resources, the project is now majority-owned by Mineral Resources in an earn-in 51/49 JV under which Mineral Resources is obliged to bring the project into commercial production – targeting a final decision to mine by 2020 and commercial production by 2021[396]. Hexagon has stated it is most concerned with enabling production from the mine to support its downstream processing ambitions utilising its proprietary graphite recovery process[397]. In particular, Hexagon seeks to develop its position a supplier for the lithium battery market, and reports that it has partnered with an as-yet-undisclosed 'highly credentialed advanced materials research company' to produce sample lithium ion cells utilising its McIntosh-sourced graphite[398].

Final estimated production figures are still to be determined, through a feasibility study due to be completed by late 2019[399], however present estimates are for approximately 100ktpa of

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391 *Munglinup Graphite Project scoping study results,* published Mineral Commodities, 27 November 2017; *Munglinup Metallurgical Testwork confirms premium flake graphite*, published Mineral Commodities, 8 February 2018; *Expandable graphite produced from Mineral Commodities' Munglinup ore*, Nicholas, L, published SmallCaps, 8 May 2018

392 *Race is on at Munglinup*, Washbourne, M, published Australia's Paydirt magazine, 1:259 (Apr 2018)

393 *MRC Munglinup graphite PFS confirms robust project*, published Mineral Commodities, 30 May 2018

394 *June 2018 Quarterly Activities & cash flow report*, published Hexagon Resources, 30 July 2018

395 *Hexagon achieves '5N' high purity graphite concentrate from McIntosh*, Karinja, F, published SmallCaps, 18 January 2018

396 *Mineral Resources takes reins to develop, build Hexagon's McIntosh graphite mine*, McKinnon, S, published The West Australian, 27 March 2018; *MinRes and Hexagon complete Stage 1 funding for McIntosh graphite JV*, Hosie, E, published Australian Mining, 27 March 2018

397 *June 2018 Quarterly Activities & cash flow report*, published Hexagon Resources, 30 July 2018

398 *Hexagon Reports Highly Encouraging Cell Cycling Results For McIntosh Graphite*, published Hexagon Resources, 17 July 2018

399 *HXG and MRL commence McIntosh Definitive Feasibility Study*, published Mineral Resources, 13 July 2018

graphite concentrate once Stage 1 is completed[400]. Hexagon reports that there is already early-stage interest in securing offtake rights from the project, with PRC-based China National Building Materials-General Technology Co entering into a non-binding MoU to purchase 30% of planned production from the project[401].

Other Australian Graphite Projects

Project	Location	Stage	Production
Mount Dromedary	QLD	Feasibility	up to 50000tpa
Uley	SA	Care & Maintenance	uo to 64000tpa
Campoona	SA	Prefeasibility	140000tpa
Oakdale	SA	Prefeasibility	94500tpa
Arno	SA	Prefeasibility	Unknown
Koppio-Kookaburry Gully	SA	Reserves Development	30-40000tpa
McIntosh	WA (Halls Creek)	Prefeasibility	Unknown

400 *Hexagon Resources Grabs $6m Graphite Options*, Rosenstreich, M, published The West Australian, 8 June 2018
401 *June 2018 Quarterly Activities & cash flow report*, published Hexagon Resources, 30 July 2018

Appendix 6: A Comparison of Military and Civilian Battery Requirements

While specific purposes and applications will result in different selection criteria, some general desired characteristics of batteries for defence purposes are noted in the following table[402], along with a brief comparison to the civilian sector.

Criterion	Defence weighting	Civilian weighting
Power density (W/kg)	Valued but variable. Most relevant for weapons systems (particularly directed energy or microwave), active defence systems and aircraft. Essentially unlimited appetite for peak power output – higher-energy chemistries enable new demand. Across all applications, interest in speed of recharge, which is improved by power density.	Variable. Lower overall requirements. Typical applications in power tools, EVs, drones. Generally, civilian sector seeks bare minimum power requirements for specific application. Interest in speed of recharge, but not at expense of other higher-priority requirements (typically economics and energy density).
Energy density (Wh/kg)	Valued across all applications. Virtually all defence purposes require combination of power and energy. Some applications may specifically value depth and duration of discharge, such as ground vehicles, ships/submarines, satellites, UAVs, and man-portable devices.	Variable by sector. In a typical optimisation schema, considered second after economics (once a given power output threshold has been met). Generally, considered means to reduce overall device size (keep same energy output in smaller footprint) rather than increase device life.
Safety	Critical. Typical batteries for defence purposes are designed with multiple redundancies, safeguards and shutoffs, and ruggedized to withstand combat trauma and harsh environmental conditions.	Highly valued. Typically safety features negatively affect device performance or economics, hence for most manufacturers the direct appetite is for compliance with legislated and industry standards. Safety is thus a concern but acts more as a threshold issue.

402 Commentary adapted from *Australia's Future Submarine: the great battery debate*, Greenfield, P, published *The Strategist/Australian Strategic Policy Institute*, 14 April 2016; *Custom power and energy solutions for demanding defence applications,* Saft Military Batteries, accessed 1 September 2018; *A French-led lithium revolution for Australia*, Senator Rex Patrick, published *Defence Connect Newsletter*, 22 May 2018; *The Design & Safety Challenges of a Lithium-ion Main Storage Battery for Conventional Submarines*, Depetro, A, presented Submarine Science, Technology and Engineering Conference 4, 16 November 2017; *TECHNICAL NOTE | Review of Battery Technologies for Military Land Vehicles*, Sims, B, Crase, S, published Department of Defence, Science and Technology, January 2017

		In some sectors this will be a higher consideration, for example EVs and medical devices.
Process maturity	Critical. Defence forces require technology, particularly mission-critical devices, to be well understood, highly reliable, and have an excellent service history. As an example, in some applications (such as submarines) lead-acid batteries are still utilised, predominantly because the full nuances of a century-old chemistry operating in that environment are mapped and understood in a way that lithium-ion chemistries are not.	Low importance. Economics is the primary motivator behind most civilian uses, with industry quick to adopt novel processes that meet threshold criteria at a lower cost. A lack of unique or novel device or environmental requirements means most batteries are commoditised and standardised, and therefore interchangeable, with few barriers to adopting new processes or returning to old if a problem is encountered.
Economics	Valued but secondary. Typically, procurement by government is well resourced.	Critical. Economics - $ per kWh - is the primary motivator behind most if not all civilian battery applications.
Security of supply	Critical. National security implications strongly favour selection of processes and chemistries which are less amenable to monopolisation or control by foreign governments. As an example, concerns have been raised regarding increasing control of rare earths, lithium metal and cobalt by the PRC.	Low importance. As noted above, batteries for civilian purposes are for the most part interchangeable. A lack of national security implications, and the large number of commercial suppliers at large scale, reduces the likelihood of commercially relevant process interruption. Most often considered in a futures context of securing supply at favourable prices.
Ethics of production	Valued but secondary. Where relevant, implemented as a function of policy considerations by the government of the day.	Highly valued. Increasingly, global consumers take ethical and environmental considerations into account when making purchase decisions. The degree to which this will outweigh economics, and hence the degree to which manufactures value a 'more ethical' product, varies by product, market and recent public awareness.

Appendix 7: Strategic Industrial Areas

Strategic Industrial Area	Tenure and Planning Status	Infrastructure Connections	Target Industries	Key Proponents/Proposals
Browse LNG Precinct (60kms north of Broome)	Project Area: 3,000ha Land Tenure: Sublease from LandCorp (the site is Crown land leased to LandCorp). The port area will be transferred to the Kimberley Ports Authority. Detailed planning and environmental approvals progressing The Browse LNG Precinct is located within the boundaries of the Shire of Broome and is currently subject to an Interim Development Order. The Western Australian Planning Commission has initiated an Improvement Plan over the precinct, which requires the preparation of an Improvement Scheme to control development. The Improvement Scheme is currently being prepared. DSD is currently seeking State and Federal environmental approvals for the Browse LNG Precinct. The Browse LNG Precinct is subject to the Browse LNG Precinct Project Agreement, which is the native title agreement for the area.	Planned common-user facilities such as roads, port, infrastructure corridors and worker's accommodation. The Browse LNG Precinct is a greenfield site and no services have so far been established at the Precinct.	Site for at least two gas processing facilities	No current proponents

Strategic Industrial Area	Tenure and Planning Status	Infrastructure Connections	Target Industries	Key Proponents/Proposals
Boodarie (10kms southwest of Port Hedland)	Project Area: 3,500ha Land Tenure: Sublease from LandCorp (Crown land that will be transferred to LandCorp in freehold). Planning approvals in place. The Native Title claimants over the Boodarie SIA are the Kariyarra people. Currently, 200ha within the Boodarie core is not subject to Native Title.	The estate is traversed by infrastructure such as APA pipeline, Northwest Coastal Highway, powerlines and Water Corporation infrastructure. However, the Boodarie SIA is largely undeveloped and unserviced, although a number of regional services	Downstream processing projects for iron ore, natural gas and salt.	Alinta gas fired power station; Sub 161 compressed natural gas facility
Anketell (30kms east of Karratha)	Project Area: 850ha Land Tenure: Lease from LandCorp (Crown land that will be transferred to LandCorp in freehold). The port area will be transferred to the Pilbara Port Authority. Planning approvals progressing. A Development Plan which provides further guidance and detail in relation to development within the Boodarie SIA is currently being prepared. Under the Town of Port Hedland Town Planning Scheme No. 5, the Boodarie core is zoned 'Strategic Industry' permitting the development of heavy / strategic industries. The Anketell Project area is the subject of the Native Title determination FCA 536 which held that the Ngarluma	Planned multi-user deep-water port. The Anketell SIA is a remote site with no current services.	Industries utilising the region's natural gas, iron ore, salt and other primary resources	No current proponents

Strategic Industrial Area	Tenure and Planning Status	Infrastructure Connections	Target Industries	Key Proponents/Proposals
	People hold non-exclusive native title over the area			
Burrup (20kms north west of Karratha)	Well established, project ready industrial estate with eight large sites. Land Tenure: Lease with LandCorp. The Burrup SIA is located within the City of Karratha. Under the City's Town Planning Scheme No.8, the SIA is zoned 'Strategic Industry'. In 1996 the Burrup Peninsula Land Use Plan and Management Strategy was prepared by the Burrup Peninsula Management Advisory Board for the purpose of allocating land for industry, conservation, heritage and recreation. With respect to Native Title, the Western Australian Government has entered into the Burrup and Maitland Industrial Estates Agreement (BMIEA). Future proponents will be required to comply with any BMIEA obligations relevant to the land as part of their lease.	Gas, power, potable water and desalinated water are located in close proximity to the Burrup SIA.	LNG and domestic gas processing, ammonia, urea, methanol, GTL and other downstream gas processing	NWS JV, Pluton LNG, Yara Pilbara Fertilisers, Yara Pilbara Nitrates
Maitland	Project Area: 3,000ha Land Tenure: Lease from LandCorp (Crown land that will be transferred to LandCorp in freehold). Project Ready. Under the City of Karratha Town Planning Scheme No. 8, the Maitland SIA	DBNGP transverses the estate and Northwest Coastal Highway runs along the southern boundary. The Maitland SIA is largely undeveloped and un-serviced.	Petroleum processing, power production, urea, ammonia and ammonium production	Energy Development Limited

Strategic Industrial Area	Tenure and Planning Status	Infrastructure Connections	Target Industries	Key Proponents/Proposals
	is zoned 'Strategic Industry' permitting the development of heavy / strategic industries. LandCorp and DSD are preparing an Improvement Plan / Improvement Scheme to guide development within the Maitland SIA and provide more certainty with regard to proponent project approvals. The Burrup and Maitland Industrial Estate's Native Title Agreement (BMIEA) provides native title approval for the Maitland SIA.			
Ashburton North (11kms south of Onslow)	Project Area: 8,000ha Tenure: Lease from LandCorp (Crown land that will be transferred to LandCorp in freehold). The port area will be transferred to the Pilbara Port Authority. Under the Shire of Ashburton Town Planning Scheme No. 7, the Ashburton North SIA is designated as a Special Control Area for strategic industry purposes. The determined native title holders for the area are the Buurabalayji Thalanyji Aboriginal Corporation (BTAC).	Connected to existing road and gas infrastructure and deep-water port under construction.	LNG and domestic gas processing, ammonia, urea, methanol, GTL and other downstream gas processing	Chevron Wheatstone LNG and BHP Billiton Macedon Domestic Gas Plant
Oakajee (23kms north of Geraldton)	Project Area: 1,134ha	Proximity to the North West Coastal Highway and future Deep-water port. Currently an un-serviced site.	Downstream processing of iron and gas.	No current proponents

Strategic Industrial Area	Tenure and Planning Status	Infrastructure Connections	Target Industries	Key Proponents/Proposals
	Tenure: Lease or sublease from Landcorp. The port area will be transferred to the Midwest Port Authority. Project ready estate. The majority of land within the Oakajee SIA has been cleared of Native Title.			
Mungari (26kms west of Kalgoorlie)	Project Area: 700ha Land Tenure: Lease from LandCorp (LandCorp owns freehold) Under the Shire of Coolgardie Town Planning Scheme No. 4 (TPS4), the Mungari core is zoned 'Special Use – Mungari Industrial Park'. Project ready. Land within the Mungari core has been cleared of Native Title.	Connected to existing road, rail, power and water infrastructure.	Chemical and resource processing of gold, nickel and other minerals, or related industries	No current proponents
Kwinana (30kms south of the Perth CBD)	Project Area: 270ha Tenure: Lease from Landcorp Project Ready	Natural gas, grid, rail and road access, deep-water bulk materials port	Chemical and resource based processing, power generation and other industrial activity	Alcoa, BHP Billiton Nickel West, BP Refinery, CBH Group, Cockburn Cement, Coogee Chemicals, CSBP Limited, Verve Energy, Tronox, BGC, Air Liquide, BOC
Kemerton (17kms east of Bunbury)	Project Area: 2,109ha	Connected to road, power, gas and power infrastructure. There are a	Industries processing natural resources in the region including	Simcoa Operations, Kemerton Silica Sand, Cristal,

Strategic Industrial Area	Tenure and Planning Status	Infrastructure Connections	Target Industries	Key Proponents/Proposals
	Tenure: Lease from LandCorp (LandCorp owns freehold) Project Ready	number of local ground and surface water sources.	silica sands and other heavy industry	Kemerton Power Station, Tesla Power Station
Shotts (8kms east of Collie)	Project Area: 235ha Tenure: Lease from Landcorp (LandCorp owns freehold) Project Ready. Under the Shire's Local Planning Scheme No. 5 (LPS5), the Shotts SIA is designated as 'Special Use Zone No. 11 – Shotts Industrial Park and Structure Plan Area – SPA No.1' for the purposes of activities associated with coal mining. A Native Title Agreement has been agreed which clears Native Title and allows development to occur within the Shotts SIA.	Connected to existing road, rail and power infrastructure	Coal related energy and downstream processing	Perdaman Chemicals and Fertilisers, Premier Coal
Mirambeena (15kms north of Albany)	Project Area: 80ha Tenure: Project Ready	Connected to existing road, power, water and deep-water port	Multiple including sandalwood processing, fertiliser distribution and grain processing	Plantation Energy, Albany Plantation Export Company

Appendix 8: Case Precedence for Concessional Royalty Rates

Gold Sector

The Western Australian gold industry almost exclusively produces gold metal and therefore, according to the netback principle, the gold sector should, in principle, pay a royalty rate of 2.5 percent. The gold sector has been the beneficiary of a range of concessions over the past thirty years and despite a recent attempt by the Western Australian Government to not only remove the concession but impose a substantially higher royalty rate on the sector, it continues to receive a concession.

When the Mining Regulations were introduced in 1981, gold production was exempted from paying royalties. In 1998, a rate of 1.25 percent was imposed on the sector and in 2000, this rate was increased to 2.5 percent on the caveat that the higher rate only applies if the average spot price for gold exceeds A$450 per ounce for a quarter. In 2005, the pricing trigger was removed and the full rate applied to all production except the first 2,500 ounces produced by each operation, which is deemed to be exempt from royalties.

It is not entirely clear what the policy rationale for this historical concessional treatment has been. However it is likely a mix of:

- Historical strategic importance of domestic gold production; and
- Importance of the gold industry to the Western Australia and regional economy and therefore, its relative political power.

In the August 2017 Western Australian Government budget, the Western Australian Government announced its intent to remove the 2,500 ounce exemption and increase the rate to 3.75 percent, effective from 1 January 2017. To date the Western Australian Government has not been able to achieve the necessary parliamentary support to make these changes.

Alumina Sector

The Western Australian alumina sector is comprised of two fully integrated mining and refining operations. In accordance with the netback principle, the alumina that is produced from these refineries should be subject to a royalty rate of 2.5 percent. While Darling Range bauxite is abundant, it is of particularly low grade rendering it historically uncompetitive in the direct shipping ore market. This means that it could only be realistically commercialised by refining it to alumina in country.

In the context of the small scale of the Western Australian economy at the time, the establishment of bauxite refinery capacity based on the Bayer process in Western Australia in the 1960s-70s represented a very significant capital investment and employment vector in close proximity to the Perth metropolitan area. Western Australia's relatively undeveloped status and remoteness at the time, meant energy and reagent costs were particularly high. As a result the project proponents were able to negotiate, through the State Agreement process, a 50 percent decrease in the applicable royalty rate to 1.65 percent.

Diamond Sector

The Western Australian diamond sector has, over the longer term and currently been comprised of a single operation located in the Kimberley Region. In recent history production from this single operation has been complemented by much smaller short-term production from a separate operation in the Kimberley Region.

In accordance with the net-back principle, a rate of 7.5 percent should apply to diamond production. However, both Argyle and the currently suspended Ellendale operation pay a concessional rate of 5.0 percent.

Facing high costs and potential closure, Argyle was able to negotiate with the Western Australian Government, through its State Agreement, a reduction in its rate to assist with financial hardship during the transition to an underground mine. In the face of escalating costs, it has managed to maintain this rate. At the same time, the concessional rate was also applied to Ellendale's production in the interests of sector equity.

Iron Ore Fines

According to the netback principle, the rate that should apply to all crushed and exported iron ore is 7.5 percent. Pursuant to separate State Agreements, BHP Billiton and Rio Tinto historically paid a concessional royalty rate on iron ore fines of 5.625 percent. This concession was granted in recognition of the historically lower value placed on fines in global iron ore markets ,and the investment that the companies were required to make to establish a market for Western Australian iron ore fines.

As demand for iron ore escalated over the past decade, the price of iron ore fines normalised with other iron ore products. Furthermore, new producers emerged in Western Australia, who as a result of not having state agreements, were not afforded the concession. As a result the Western Australian Government negotiated with BHP and Rio Tinto to progressively equalise the concessional rate with the rate that is prescribed by the *Mining Regulations 1981* (WA). As a result the rate applying to BHP and Rio Tinto fines production increased to 6.5 percent in 2012 and 7.5 percent in 2013. It should be noted that the amended rate prescribed by the state agreements does not reference the Mining Regulations for rate determination, but merely prescribes an equivalent rate.

Magnetite

In 2013, the Western Australian Government, under Ministerial discretion, offered aspiring magnetite producers the ability to apply for a 50 percent rebate on royalties for their first year of production. Applications were to be considered on a case-by-case basis. Following the 12 month concession period, the full royalty rate of 5 percent was to apply.

At the time the concession was offered, there were 29 magnetite projects at various stages of development located primarily in the Mid West Region of Western Australia. This represented a potentially substantial new industry in a region that had been depressed by a decline in its fishing industry. These projects had already been hampered by a recent decision by Mitsubishi not to proceed with the Oakajee Port and Rail project and were facing financial hardship as a result of lower iron ore prices.

Iron Ore Juniors

In recognition of the financial hardship incurred by junior iron ore producers when the iron ore price deceased dramatically in 2014, the Western Australian Government offered a 50 percent royalty rebate to junior iron ore producers for 12 months for so long as the iron ore price remained under A$90 per tonne. The rebate was repayable over the following 24 months.