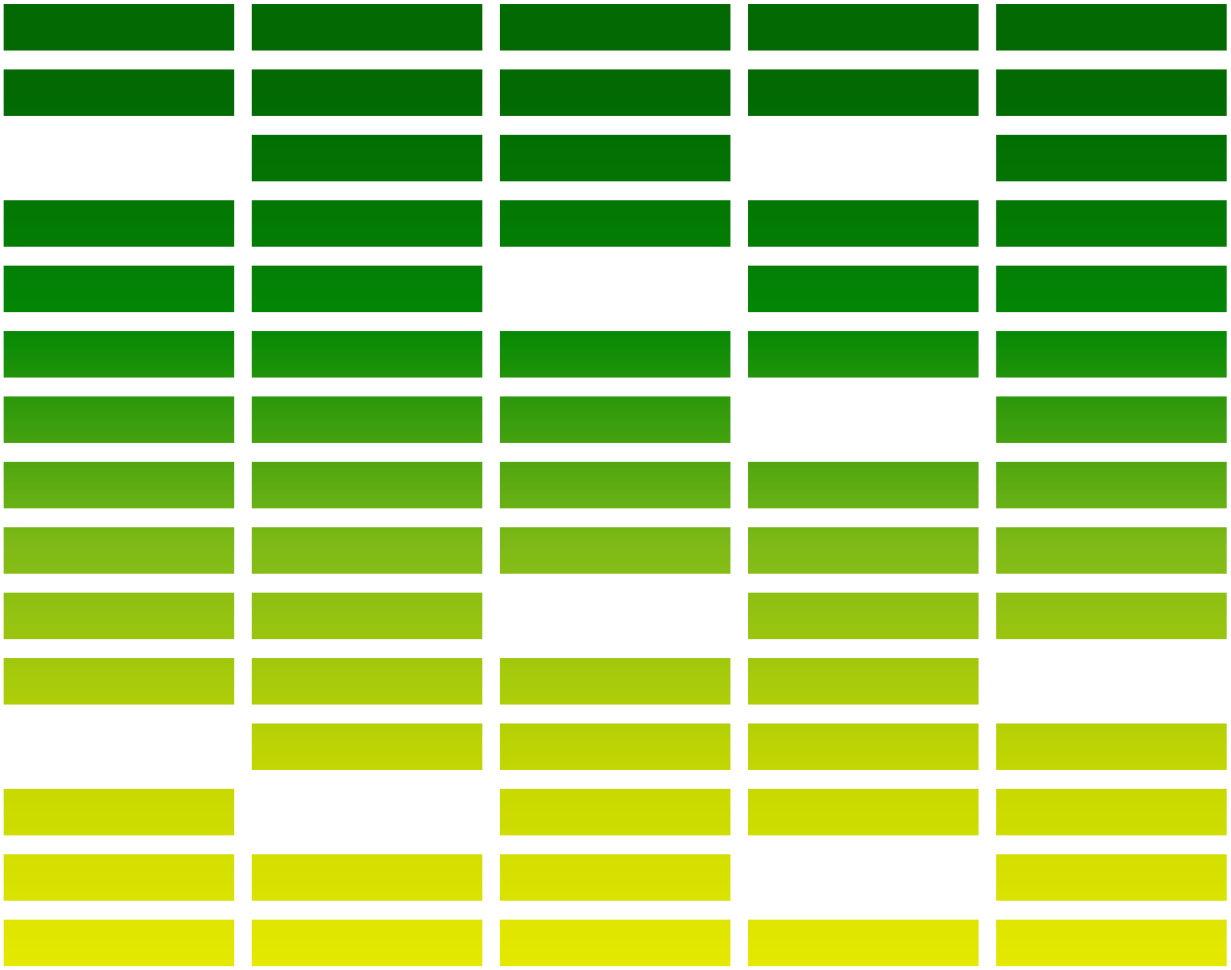
FUTURE BATTERY INDUSTRIES CRC

Australian Government
Department of Industry, Science, Energy and Resources

Business Cooperative Research Centres Program

State of Play

AUSTRALIA'S BATTERY INDUSTRIES



Produced for the Future Battery Industries CRC

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CSIRO

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Table of Contents

Executive Summary

Australia is well-endowed with battery minerals.

Australia is well endowed with all the raw materials for the manufacture of batteries. While graphite and cobalt reserves lag those of the world's major exporters of these materials, Australia still has significant resources to exploit and add value to. For all the other commodities required in various battery value chains, including lithium, nickel, vanadium, manganese, and alumina, Australia has world-class resources and significant reserves. However, these raw materials go through more complex purification and manufacturing steps before becoming batteries.

No commercial production of battery-grade chemicals yet.

Technology exists in several Australian companies.

The authors followed the value chain for the major battery-related commodities, from reserves and resources through all stages of processing. At the time of writing, there was found to be **no commercial production of battery-grade chemicals in Australia but the technology required exists in Australia**. One Australian company had piloted its process and is in a construction phase to make battery-grade nickel sulphate, and other Australian companies have technologies ready to deploy, or be piloted.

No commercial production of battery precursors yet.

It may be no surprise then, that **no battery precursor (anode or cathode active) materials were found to be commercially produced in Australia** at the present time. Several Australian research institutions and companies could produce laboratory or pilot-sized batches for testing. A consortium of Australian companies plans to produce NMC cathode precursors on a pilot scale in 2021.

Importantly, one company has built and piloted a process for the manufacture of a key cathode material, $LiFePO_4$. Several companies are on track to produce both graphite-based and lithium titanate-based anode active materials.

No cell manufacture but an active battery assembly industry.

Cell manufacture does not occur in Australia at the present time, although there are two cell manufacturing plants proposed. Cell manufacturing in Australia will not be cost competitive with Chinese-produced cells on the world market, but Australia may choose to manufacture cells for its local market and niche applications. **The battery manufacturing industry, using imported cells, is growing.** A number of companies are assembling cells into purpose-built power-delivery devices ("batteries") with relevant power management systems, sometimes on very large scales. These companies are generally addressing niche markets where high reliability and safety override price considerations.

Cell manufacture in Australia will most likely fill niche applications based on regional and strategic needs.

Significant capital investment is required to bring large scale cell manufacturing to Australia. Labour costs associated with manufacturing cells is not excessive due to the high degree of automation. However, Australia is not the lowest cost jurisdiction in the region regarding energy, transport, regulation, and taxation. The authors suggest that manufacturing in Australia will most likely fill niche applications based on geographic (hot climate) and strategic (defence) uses.

Recycling industry is relatively basic.

Recycling in Australia seems to consist largely of disassembly then homogenisation of cathode/anode materials. Mixed metal-containing products are exported overseas for full processing. Australia has a very low rate of battery recycling (except for lead-acid batteries). This should change soon with the introduction of a battery stewardship scheme. However, the scheme will not necessarily lead to recycling fully within Australia unless it is cost competitive vs. export to e.g. South Korea.

High level of capability in research institutions and in engineering companies.

There is no shortage of technical expertise in Australia to assist in establishing battery industries. The research sector in Australia is well advanced and, in many areas, world-leading. QUT has pilot cathode production facilities and lithium ion battery fabrication facilities. Deakin, CSIRO, UWA, and UTS have significant facilities for trialling a range of battery components and electrochemical testing. Closer to the beginning of the value chain, Australian universities, research institutions such as ANSTO and CSIRO, and a range of privately-owned companies, have significant expertise in mineral extraction and refining that can be turned towards manufacture of battery chemicals and precursors. Engineering, construction and service companies are becoming active in the area, growing with competence and confidence as the battery materials industry grows.

High level of capability in research institutions and in engineering companies.

Australia appears to be on the cusp of developing significant capability and capacity in industry to move further along the battery value chain. The already mentioned endowment in minerals, and industry trajectory moving towards value-adding, and deep technical competence, bode well. In the short term however, lithium suppliers are under considerable financial pressure and the required investment to capture future market opportunities may not be made in time to fully benefit.

Cathode and Anode precursor manufacture is a significant value-add step that could occur.

The present generation of **battery anode and cathode chemistries could be reproduced in Australia** using locally sourced materials. Whereas battery-grade chemicals are merely purified versions of commodities, precursor materials are the first significant engineered products in the manufacture of batteries. End-user (cell manufacturer) quality acceptance will be a critical step. The reward, however, is a many-fold increase in value (Austrade suggests up to 10x, the authors estimate 5 to 6-fold), from commodity-grade chemicals to finished precursor.

Policy settings in Australia rarely favour a battery industry.

Although Australia generally has a good reputation as a low-risk investment for mining, this does not necessarily translate to preference for Australia for investors, while large and high value orebodies exist overseas. Policies which encourage investment could change this. **At present, there is a lack of battery-specific initiatives in Australia.** There are, for the most part, no policies designed specifically to facilitate the growth of the battery industry. Only four policies/funding pools are directly focused on opportunities in the battery value chain, three of these being WA State Government initiatives.

Policy settings in other emerging battery producing countries are quite focused.

It becomes clear, when examining promotional material for European battery manufacturing that in the EU, local and federal government support is strong. Advantageous local property and taxation schemes are generous. Investment is available through government-supported bodies such as the European Investment Bank. This is a comparative advantage when compared with the current situation in Australia.

INTENT

The intent of this work is to provide a snapshot of the industry in Australia circa 2019. The intent is not to shine the best possible light on what the industry might be, but to show a baseline from where the industry can grow, and possibly to identify future opportunities. This includes a measurable baseline against which progress over the life of CRC can be assessed. It encompasses assets, expertise, capability and policy settings.

SCOPE

The scope of this work spans battery materials, cell manufacture, battery manufacture, battery engineering, and recycling markets and its objectives are to identify:

I. companies that are currently performing value-added business in Australia which includes companies that have proven and documented their potential to enter the market, even though they may not be conducting that business at present;

II. any significant repositories of proven battery-associated technology in Australia that could be applied to value-adding in the above sectors;

III. proven capability in industry, government-supported research institutions, and universities, that can be applied to R&D and support for the above sectors and;

IV. the policy settings at national and key state level in terms of critical minerals, battery industry strategies, value adding and trade policies, and energy transition.

NOT INVESTMENT ADVICE

Having regard for the intent, the report attempts to describe the business and prospective business of companies as accurately as possible with no attempt to forecast except to interpret independent observations of market trends. The content of this report does not represent investment advice. The Authors are not competent nor licenced to give such advice.

CONFLICTS OF INTEREST

The Authors have no shareholdings, nor hold positions with any of the companies mentioned in this report. However, in the normal course of their business the Authors have performed research work for some of the companies mentioned herein. The Authors are employees of CSIRO. The FBI CRC commissioned CSIRO to write the current report, for which CSIRO received payment at customary commercial rates.

ACKNOWLEDGEMENTS

The Authors would like to acknowledge the generous inputs of Jen Baird, Anna Tao, and Dr Joanne Loh (CSIRO), Andreas Seidel (Austrade, Frankfurt), and review by Professor Peter Talbot (QUT), Russell Barnett (Australian Venture Consultants), and Associate Professor Jo Staines (U. Melb).

Methodology

The Authors sought to establish the baseline activity in the battery industries in Australia: as a snapshot of the sophistication and volume of the industry as of March 2020; as more or less a directory of the main actors in Australia, for the reference of others in the industry; as a tool for the identification of gaps and opportunities in the industry.

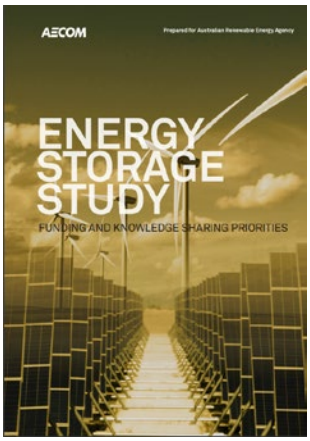
A broad range of data sources were considered in assembling this report. Searching ASX reports for company data is flawed in that many companies may be missed by an individual. However, Standard and Poors (S&P) maintains a reasonably complete and well-researched database of exploration, mining and mineral processing data for any publicly listed company. This was used extensively. The deficit in this database is that only publicly listed companies are analysed, but it was reasoned that few, if any non-listed companies operate in these areas. Beyond mining and processing, another S&P offering, CapitalIQ was used.

The Authors also used their own networks and understanding of the business. A number of companies were identified through commercial contact and earlier research activity, and other companies via contacts in the CRC.

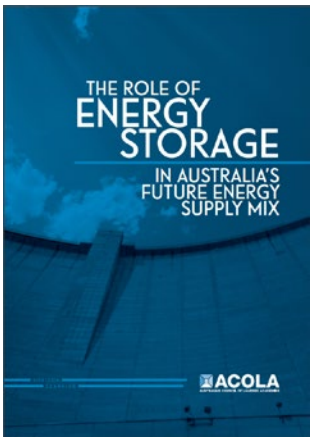
Some reliance is also made on data collected by the United States Geological Survey data, published as annual reviews, and cross-referenced with other publications, for example Australian national and state geological surveys, company literature, and in some cases telephone interviews.

Those who have gone before

The past four or so years have seen significant activity in analysing the battery minerals market and opportunities and associated energy topics. Each of the previous reports has had a different purpose, but we have borrowed, on occasion, from the Austrade (2018) and WA State Government (2019) reports, and acknowledge the diagrams and data reproduced from those reports.

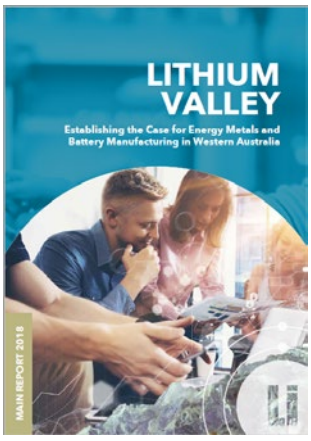


AREA/AECOM 2015

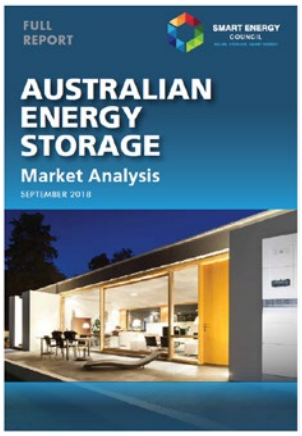


ACOLA 2017

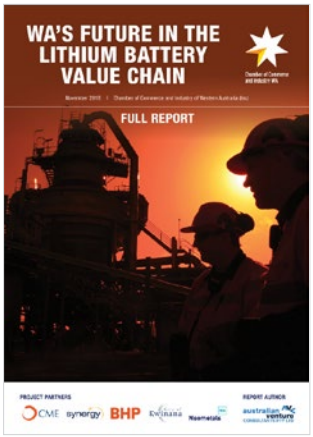
AMEC 2018



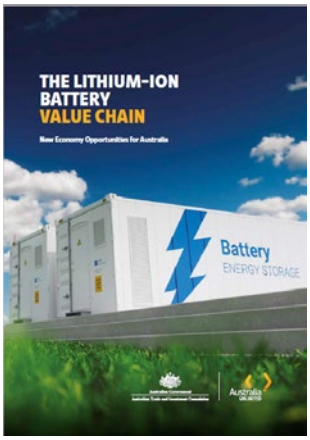
Regional Development Australia 2018



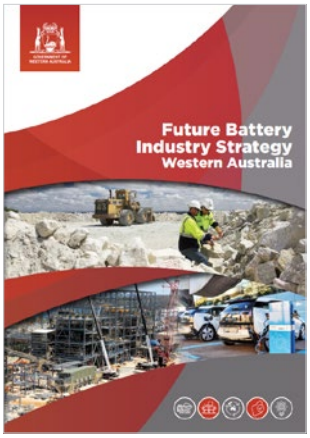
Smart Energy Council 2018



CCIWA 2018



Austrade 2018



WA Govt 2019

AREA 2015	https://arena.gov.au/assets/2015/07/AECOM-Energy-Storage-Study.pdf
ACOLA 2017	https://acola.org/hs1-energy-storage-australia/
AMEC 2018	https://secureservercdn.net/198.71.233.51/0h5.0cf.myftpupload.com/wp-content/uploads/2020/01/A_Path_Forward.pdf
RDA 2018	https://www.rdaperth.org/wp-content/uploads/2018/05/RDA4491-LITHIUM-REPORT-2018_LOWRES.pdf
SEC 2018	https://www.smartenergy.org.au/sites/default/files/uploaded-content/field_f_content_file/australian_energy_storage_market_analysis_report_sep18_final.pdf
CCIWA 2018	https://lithium.cciwa.com/
Austrade 2018	https://www.austrade.gov.au/ArticleDocuments/5572/Lithium-Ion%20Battery%20Value%20Chain%20report.pdf.aspx
WA Govt 2019	https://www.jtsi.wa.gov.au/docs/default-source/default-document-library/future-battery-industry-strategy-wa-0119.pdf?sfvrsn=ccc7731c_4

Acronyms and Definitions

AEMO	Australian Energy Market Operator. AEMO performs an array of gas and electricity market, operational, development and planning functions. It manages the National Electricity Market, the Wholesale Electricity Market.
Anode	The electrode where oxidation occurs. In a battery that is discharging, the anode is the electrode from which electrons flow out towards the external part of the circuit (negative).
ANSTO	Australian Nuclear Scientific Technology Organisation. ANSTO has a Minerals group located at Lucas Heights NSW and in recent years has shifted focus from its original remit (uranium; radioactive ores), to Rare Earths, and now to battery metal processing.
Battery materials	Basic chemicals and physical components required to manufacture batteries. These are chiefly chemicals that have been refined to high purity levels.
Battery	Any assembly of cells designed to produce standard and useful voltages and currents, also comprising practical connectors and potentially inbuilt monitoring systems.
BESS	Battery Energy Storage System
Bayer Process	A process where soluble aluminium phases are extracted and purified using reprecipitation from sodium hydroxide, then calcined to form Smelting Grade Alumina (SGA).
Cathode	The electrode where reduction occurs. In a battery that is discharging, the cathode is the electrode into which electrons flow from the external part of the circuit (positive).
Cell	A basic single current-producing unit of a battery, consisting of an anode and a cathode.
Concentrate	Also known as "con", this is a generic term for upgraded ore. This may be achieved by one or a combination of unit operations such as flotation, gravity separation, and smelting.
CRC	Cooperative Research Centre. Established under the Department of Industry. The Cooperative Research Centres (CRC) Program supports Australian industries' ability to compete and produce.
CRC-P	CRC Project grants support up to three years' worth of industry-led collaborative research. The grants cover up to $3 million in co-funding. Projects must include a minimum of 2 Australian businesses (with at least 1 small and medium-sized enterprise), and 1 research organisation.
CSIRO	Commonwealth Scientific Industrial Research Organisation
DSO	Direct Shipped Ore. Literally, shipped without further processing.
Ferromanganese	A manganese-iron alloy produced through smelting, capturing manganese in a form suitable for steelmaking.
Ferronickel	A nickel-iron alloy produced through smelting, capturing nickel in a form suitable for steelmaking.
Ferrovanadium	A vanadium-iron alloy produced through smelting, capturing vanadium in a form suitable for steelmaking.
GA	Geoscience Australia

Hard Rock Lithium	As opposed to *salar* or brine lithium, lithium that is contained in pegmatite formations, particularly as Spodumene.
HPA	High Purity Alumina, used in electronic components such as LEDs, and as separators in batteries. HPA comes in several purity grades, 4N ("4 nines", 99.99%) being the most common. 5N and 6N are other recognised grades.
JORC	The Joint Ore Reserves Committee Code provides a mandatory system for the classification of minerals Exploration Results, Mineral Resources and Ore Reserves according to the levels of confidence in geological knowledge and technical and economic considerations in Public Reports.
Kaolin	A clay mineral containing aluminium and silica. Clays can be used as a feedstock to make alumina *via* an acid route. This is a more expensive route for producing alumina than the Bayer process, but can deliver higher purity alumina.
kt	Thousand tonnes.
ktpa	Thousand tonnes per annum.
LCE	Lithium Carbonate Equivalent. 1000 kg Li_2CO_3 = 188 kg Li as metal = 1135 kg LiOH
LED	Light Emitting Diode
LIB or Li-ion	Lithium Ion Battery
LieNA™	Hydrometallurgical technology developed by Lithium Australia to recover lithium from fine spodumene.
LME	London Metals Exchange. The LME facilitates standards for metals such as aluminium, nickel and cobalt; brokers trade in those metals, and hold physical stocks. The LME is considered the least desirable customer, paying no premium for higher quality.
Matte	An intermediate phase in smelting consisting of unreduced (or partially reduced) metal sulphides.
MHP	Mixed Hydroxide Precipitate. A commonly traded nickel-cobalt hydroxide intermediate, produced via acid leaching of lateritic ores. The cobalt to nickel ratio is dependent on a number of factors.
MSP	Mixed Sulphide Precipitate. A commonly traded nickel-cobalt sulphide intermediate, produced via acid leaching of lateritic ores. The cobalt to nickel ratio is dependent on a number of factors.
NEM	National Electricity Market
Precursor	Functional compounds and structures that can be used to construct a functioning cell. Usually the compounds that cathodes, anodes or separators are made from, but not yet in the physical engineered form.
PHES	Pumped Hydro Energy Storage
Pyrometallurgy	The use of heat and either oxidants or reductants to separate metals from their ores. Also see *Smelting*.
QUT	Queensland University of Technology
Reserves	Mineral occurrences that are valuable and economically, and technically feasible to extract.
Resources	Mineral occurrences that are potentially valuable, and for which reasonable prospects exist for eventual economic extraction.

Salar	Traditionally, a salt-encrusted lake. The definition has been expanded to operations where brine is withdrawn from beneath the surface and placed in dams where evaporation causes crystallization of the contained salts.
SGA	Smelting Grade Alumina. A mixture of Al_2O_3 phases with specific particle size characteristics and ~99.7% purity.
Smelting	Smelting uses heat and combinations of oxidants and reductants to decompose an ore, driving off other elements as gases or slag and leaving the metal base behind. Depending on the ore being treated, smelting can be used to separate metals into the slag phase, metallic phase or a matte.
Spodumene	The chief "hard rock" source of lithium. $LiAl(SiO_3)_2$ Pure spodumene is 8% by weight Li_2O. The commercially traded concentrate is usually 6%.
SX	Solvent Extraction
tpa	Tonnes per annum.
USGS	United States Geological Survey.
UTS	University of Technology, Sydney.
UWA	The University of Western Australia.
Vanadium Pentoxide	V_2O_5. 1,000 kg V metal = 1,786 kg V_2O_5.
V Flow Battery	Vanadium Redox Flow Battery
W	Watt is a unit of power; defined as capacity multiplied by voltage.
Wh	Watt-hour is a measure of electrical energy equivalent to a power consumption of one watt for one hour.
Zn Br Flow	Zinc Bromine Redox Flow Battery.
18650	A standard lithium ion battery format, 18 mm in diameter and 65 mm in height, slightly larger than a common AA.

Australia has a great deal of potential.

We have perhaps a once in a generation opportunity.

Can we act quickly enough?

How far should we go?

Will we get the investment that we require?

The turmoil in the oil sector caused by the COVID-19 pandemic gives governments the perfect opportunity to embrace green energy as a source of jobs that also serves climate goals.

Fatih Birol, Executive Director, International Energy Agency (IEA)

The Battery Value Chain

The value chain commences with the extraction of ores, brines or secondary sources (recycling), followed by the refining of those metals to a high purity chemical grade, combination into engineered precursor materials, assembly into electrochemically active cells and finally, assembly into battery packs that can deliver a useful voltage and current over a sustained lifetime. Figure 1 shows the value chain for lithium ion batteries, and also rare earth magnets.

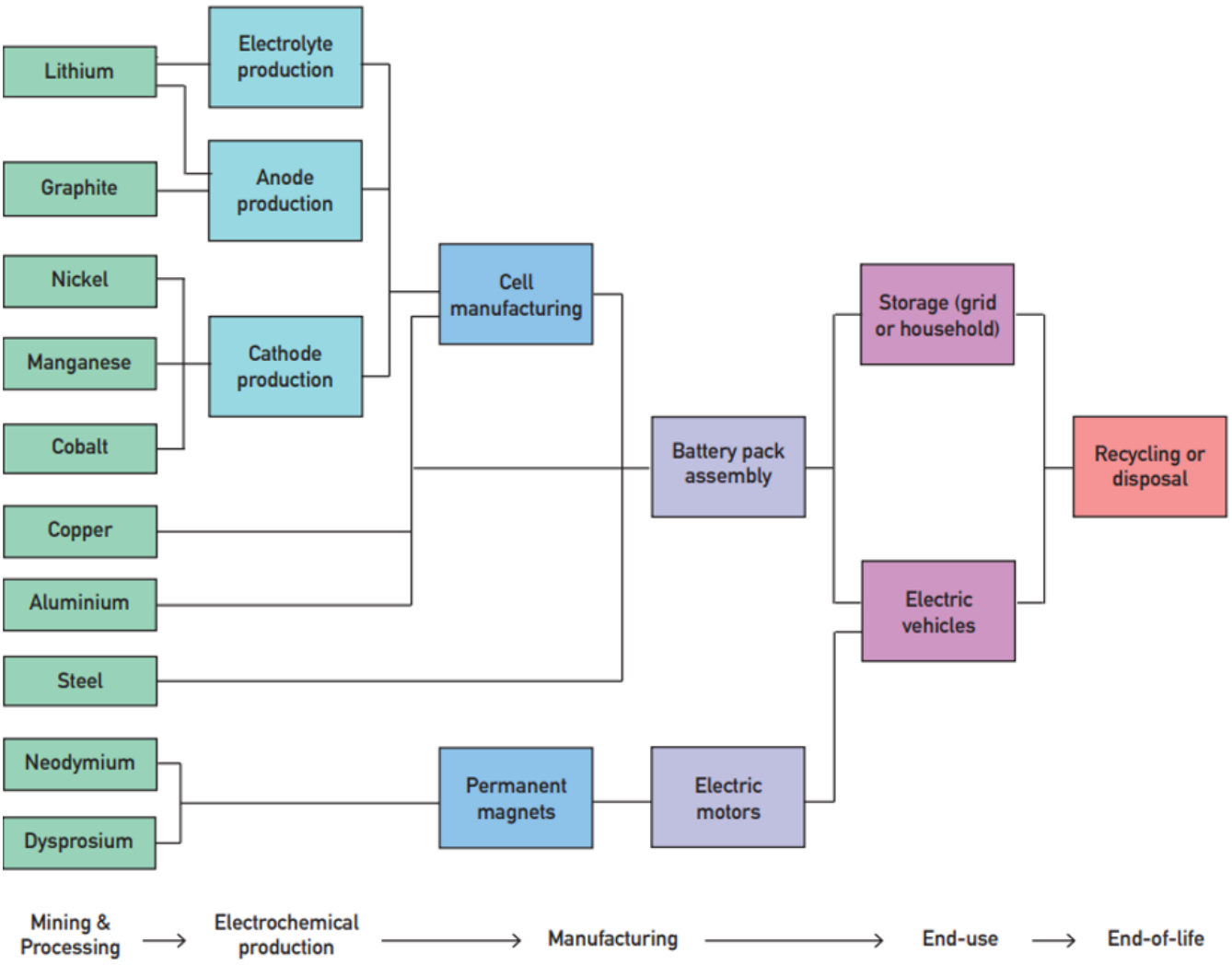
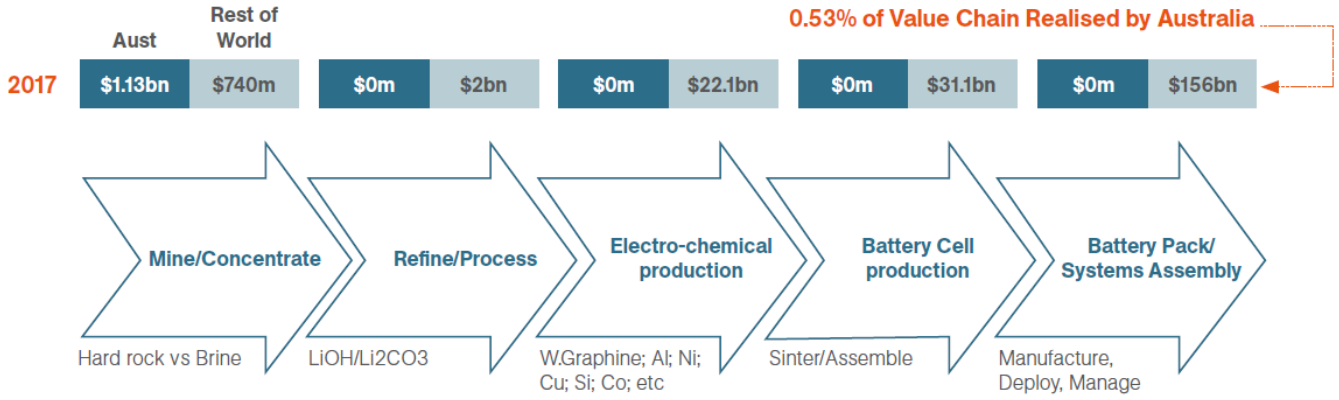


Figure 1. Value chain for lithium ion batteries and rare earth metals. (Dominish, E., Florin, N. and Teske, S., 2019, Responsible Minerals Sourcing for Renewable Energy. Report prepared for Earthworks by the Institute for Sustainable Futures, University of Technology Sydney. https://www.uts.edu.au/sites/default/files/2019-04/ISFEarthworks_Responsible%20minerals%20sourcing%20for%20renewable%20energy_Report.pdf)

The term "battery metals" is often used loosely, particularly when attempting to distinguish one base metal mining project from another. Nickel, cobalt, manganese etc. in the ground may become battery metals through processing, but *no ore deposit is inherently a battery metal deposit.* A mining project becomes a battery metals project only when the associated plant can purify the metals to *battery grade*.

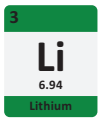
Austrade (2018) used the following diagram to demonstrate that very little of the value incorporated into lithium ion batteries is retained in Australia. The values are Australian dollars and only relate to the lithium content. Nonetheless, the diagram demonstrates that little value-add currently occurs in Australia, and that major value-adding steps occur at and beyond Electro-chemical production (production of cathode and anode precursor materials).



Source: Future Smart Strategies (2018)

Figure 2. Lithium value chain and market value (for Australia and the rest of the world). (Austrade, 2018, "The Lithium ion battery value chain", https://www.austrade.gov.au/ArticleDocuments/5572/Lithium-Ion%20Battery%20Value%20Chain%20report.pdf.aspx)

Austrade's 2018 report is reflective of what the current authors found – that Australia is proficient at exploiting its mineral wealth but conducts very little value-add. That is, mining is our strength, but manufacturing is a weakness. However, the Austrade report did not acknowledge the activity that does occur in the battery pack and systems assembly part of the value chain – albeit using imported cells.



Essential ingredients – Lithium

The literature and various reports, especially media releases, use different units when expressing lithium output and consumption. Lithium Carbonate Equivalent (LCE) is popular because lithium carbonate was one of the first major bulk-traded lithium products[1]. But often, equivalent lithium metal, and equivalent lithium hydroxide are quoted. The following conversions apply.

1.000 tonne Li = 6.043 tonne $LiOH.H_2O$ = 5.323 tonne Li_2CO_3.

0.165 tonne Li = 1.000 tonne $LiOH.H_2O$ = 0.881 tonne Li_2CO_3.

0.188 tonne Li = 1.135 tonne $LiOH.H_2O$ = 1.000 tonne Li_2CO_3 (LCE).

Ore grades are often quoted as % Li_2O. 1 tonne Li_2O = 2.472 tonnes LCE.

In this document, when quantities of Lithium are quoted, it is the metal equivalent unless otherwise stated.

Lithium is the core ingredient in modern rechargeable battery chemistries due to its high charge to weight ratio, its ability to transfer quickly through electrolytes, and intercalate into anodes and cathodes.

The top two sources of lithium are the mineral spodumene, which occurs widely throughout Western Australia, and lithium-enriched[2] brines in Bolivia-Argentina-Chile[3,4]. Other sources such as lithium micas (e.g. lepidolite) exist but are not widely exploited at this time.

Lithium is considered "critical" by a number of manufacturing nations, but this is not apparent at the present time, after higher prices piqued interest in exploration, and vast deposits were discovered in Australia and overseas. However, the projected, seemingly insatiable demand of the EV industry would exhaust all of the world's known reserves[5] by 2040 (Figure 3 and Figure 4). There is no doubt that more economic reserves will be discovered, but to suggest that today's known reserves, if exploited completely as demand rises, would only last[6] 20 years is a sobering thought (Figure 5). However, longer term shortages of lithium may drive the battery industry towards alternative chemistries in the future.

1 The preferred recovery method from brines involves adding sodium carbonate to the lithium-rich concentrated brine. Both sodium and potassium carbonate are soluble. Lithium carbonate is not.
2 Lithium enrichment is relative. Salar brines were not exploited for lithium, but potassium, prior to the late 1990s. Salar brines contain 5 to 20 g/L potassium, compared to 0.2 to 1.4 g/L lithium.
3 Both brine and spodumene resources occur throughout the world, but Australian and South American occurrences combined account for 86% of world supply.
4 https://pubs.usgs.gov/periodicals/mcs2020/mcs2020-lithium.pdf
5 USGS known reserves in 2019 were 17 million tonnes (metal basis). Projected consumption by 2040 is approximately 18 million tonnes.
6 Many lithium deposits have mine lives of 30 or so years, but the 20 year statistic is intended to reflect that the world will require all of the discovered lithium, in the next 20 years.

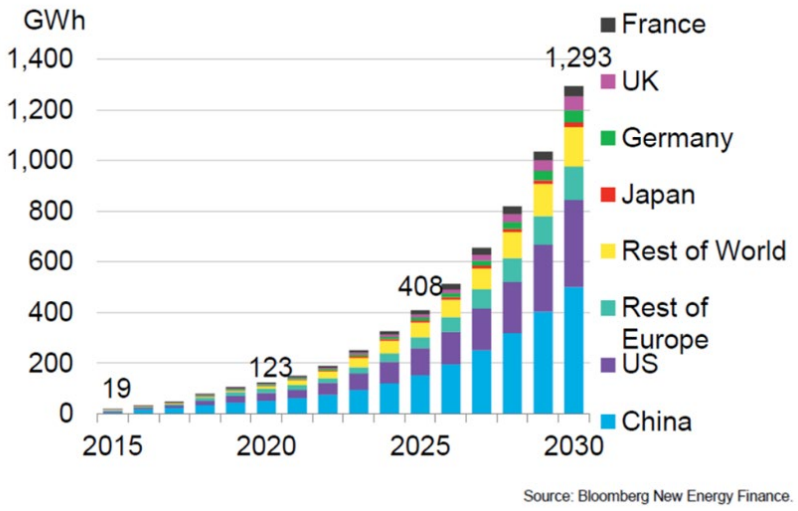


Figure 3. Demand for lithium ion battery storage capacity in the electric vehicle market, predicted by Bloomberg. Assuming 2 kg LCE required per kWh of battery storage[7], in 2030, lithium demand for EVs (alone) can be predicted to be 2.6 million tonnes LCE (500 kt metal basis).

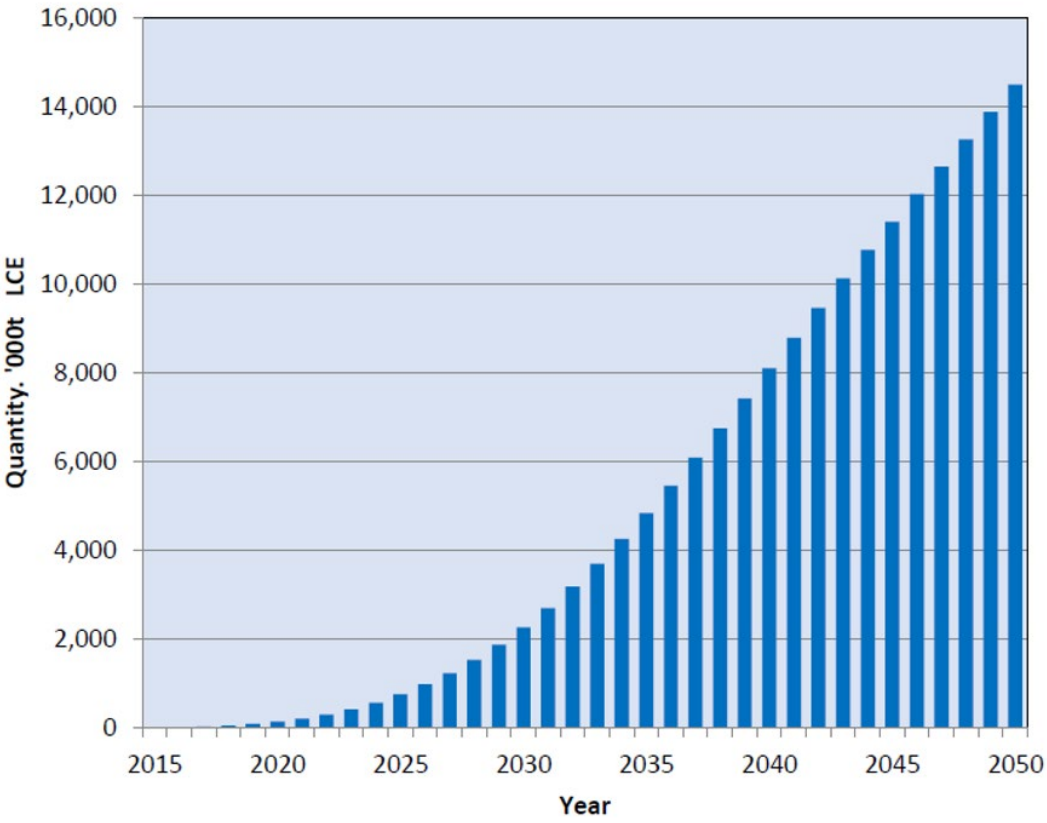


Figure 4. Demand for lithium ion battery storage capacity in the electric vehicle market, predicted by Hunwick[8]. This prediction at 2030 is 2.26 million tonnes LCE, or 425,000 tonnes on a metal basis. This broadly agrees with the prediction derived from Bloomberg/Tahil (which is higher by at least 18%).

7 https://ecotricity.co.nz/wp-content/uploads/2016/11/How_Much_Lithium_Per_Battery.pdf
8 Richard Hunwick, Hunwick Consultants, personal communication.

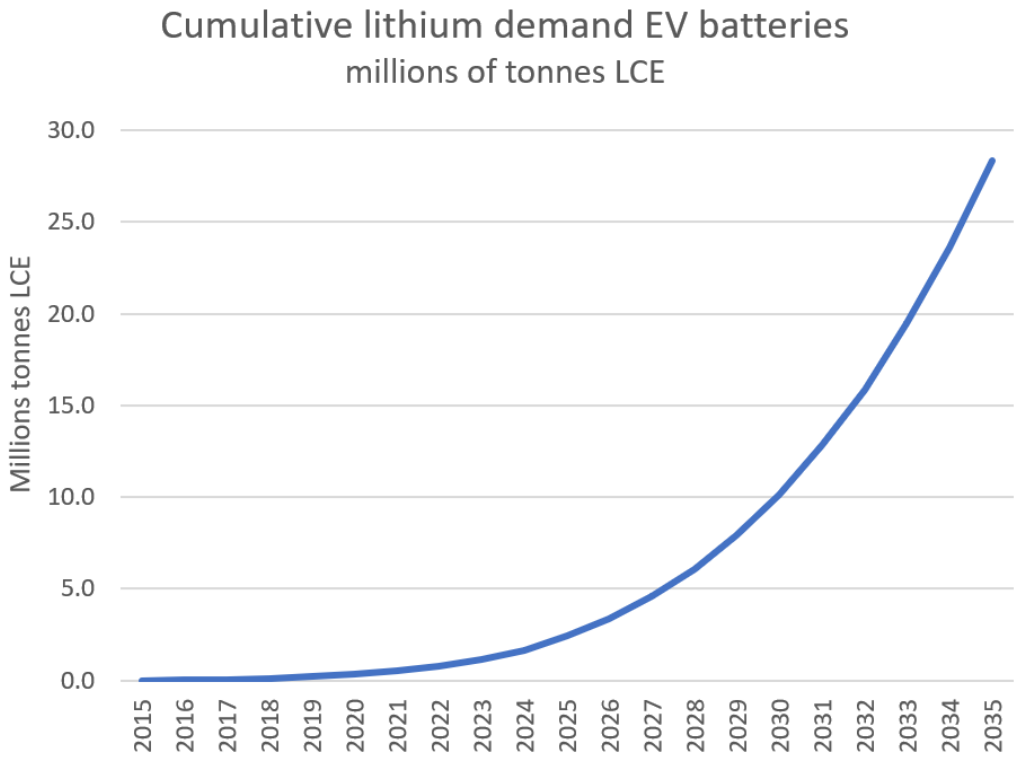


Figure 5. From Figure 4, the cumulative lithium demand can be plotted. Note that less than perhaps 5 million tonnes (LCE) has been mined in all of history. In the next 8 years the world will need to produce more lithium than in all of history just to keep pace with EV LIB demand.

World lithium production (Figure 6) was stable through the first half of the decade, averaging 34,300 tonnes annually for the world, and 13,100 tonnes annually from Australia. 2016 sparked the most recent "lithium boom" when prices reached US$74,000 per tonne (contained metal basis). The predicted increase in lithium demand fuelled the increase in production; world production doubled rapidly soon after, with much of this new capacity being associated with the Talison's Greenbushes mine[9] in Western Australia. Production peaked at 95,000 (world total) / 58,000 (Australia) tonnes before a falling price (currently US$39,000/t) driven by oversupply, caused a decrease in production. In 2019 the USGS recorded world production as 77,000 tonnes, and Australian production as 42,000 tonnes. At present the vast majority of Australian lithium concentrate is exported to China where it is refined into Lithium Carbonate (for the lithium chemicals market) or Lithium Hydroxide (for the battery market).

The Authors thought it important to make comment on lithium extracted from salars, and lithium extracted from hard rock sources (principally spodumene). The former is cited as being produced at lower cost than the latter, and this is true. However, production of lithium hydroxide from hard rock can be a direct route to battery-grade chemical, whereas lithium carbonate precipitated using soda ash from brine concentrates, requires further purification before it becomes a battery-grade chemical. The cost differential is therefore less important than is often stated.

9 The Greenbushes lithium mine ownership is 51% Tianqi Lithium (China), 49% Albemarle (USA) although Tianqi is seeking to divest itself of at least some of its stake.

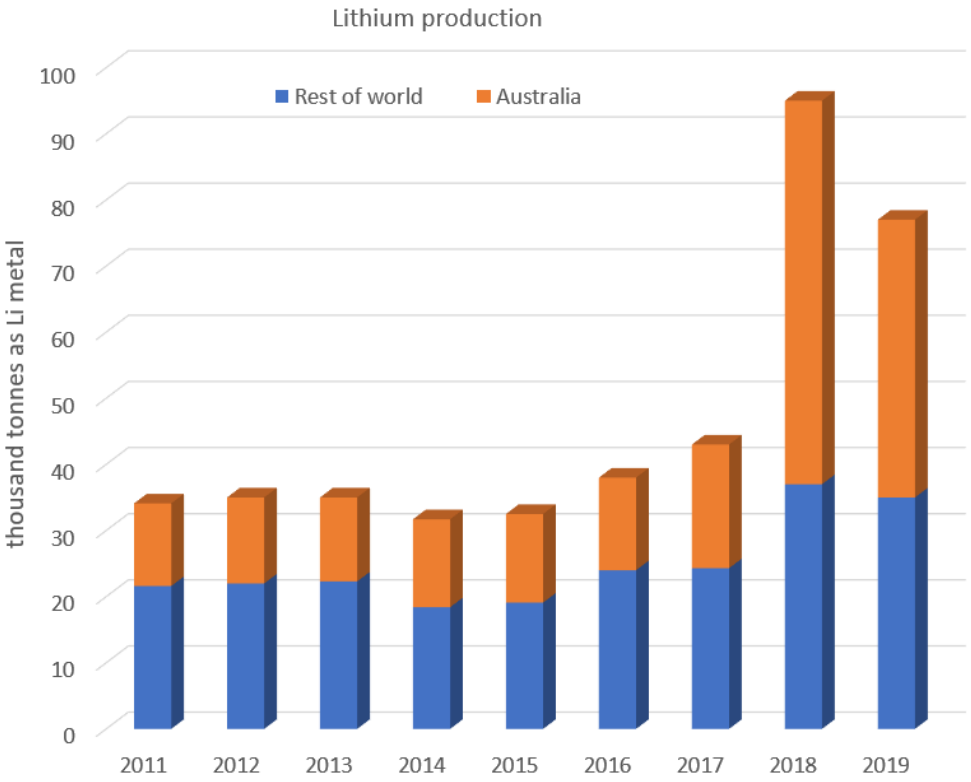


Figure 6. Lithium production for Australia and the rest of the world (USGS).

Future predicted increased demand for lithium for *EV batteries alone* is staggering, with a predicted doubling from approximately 12,500 tonnes[10] in 2018, to 25,000 tonnes in 2020, to 150,000 tonnes in 2025, to 425,000 tonnes in 2030 with a linear increase of an additional 100,000 tonnes per year, *every year* until 2050. This growth will, of course, be compounded by additional growth in the demand for batteries associated with consumer goods and for household and utility grid storage (Figure 7).

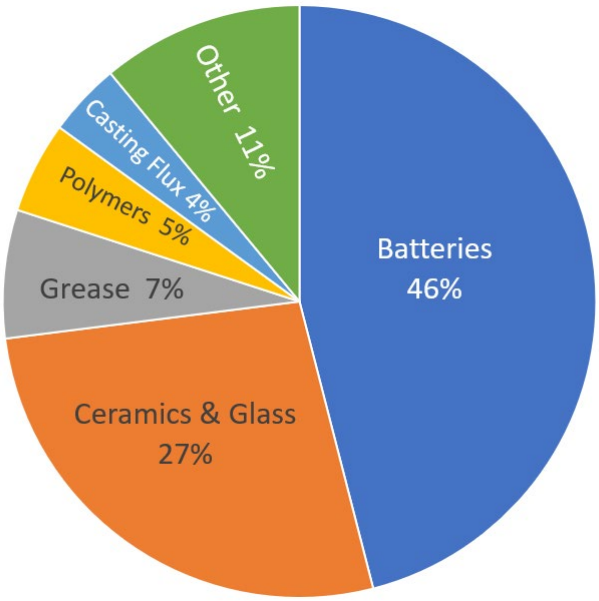


Figure 7. 2016 USGS data[11] suggested that only 46% of all mined lithium (~20 kt in 2017) entered the battery value chain, most other uses being in ceramics, glass and greases. Nearly all the forecast growth in the lithium market is in the battery industry. As of late 2019, it is thought[12] that up to 60% of annual production is made into batteries.

10 This does not concur with the 20,000 tonnes derived in Figure 1. However, 20,000 tonnes would apply to the whole battery market. These predictions are for the EV market only.
11 This estimation of percentage for different uses is not regularly published. The 2016 Yearbook is the last estimation made.
12 Russell Barnett, personal communication.

Although pure Spodumene is about 8% Li_2O by weight, the Greenbushes (Western Australia) deposit grades range between 1.2%[13] and 2.8%[14]. It is upgraded by gravity, heavy media, flotation and magnetic processes, into a range of lithium concentrates, before shipping to market. Some other mines have produced "direct ship ore" (DSO) at a few percent lithium content, and do not upgrade[15].

By mid-2019 there was only one lithium (hydroxide) refinery in Australia, built and owned by Tianqi (China) and located at Kwinana, WA. At that time the refinery was being commissioned and as of January 2020 it had not reached[16] nameplate capacity of 48,000 tonnes lithium hydroxide (42,300 tonnes LCE). Other refineries have been planned at various times in Western Australia, by Albemarle (USA), Covalent Lithium (SQM, Chile; Wesfarmers, Aust.), Pilbara Lithium, and Neometals.

At the time of writing no battery grade lithium chemicals are produced in Australia (Figure 8).

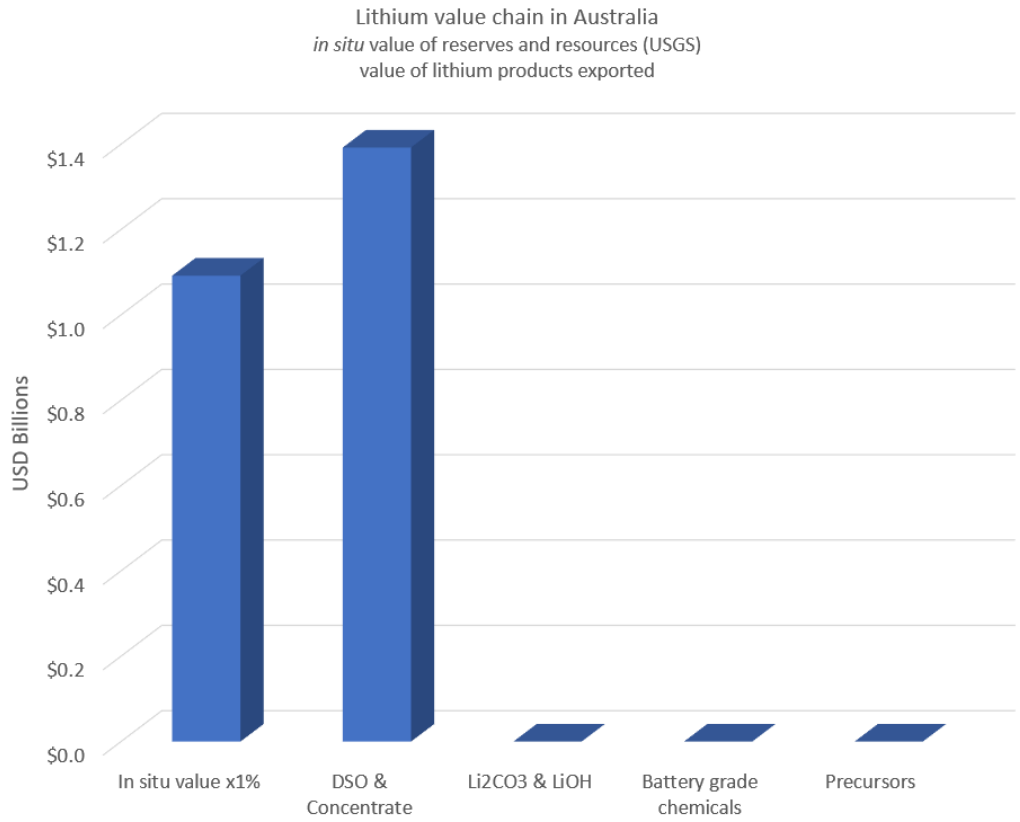


Figure 8. In situ value of Australia's reserves (represented as 1% to maintain readability) and the value of other exports along the value chain. The value chain in Australia at the time of the commencement of the FBI CRC stopped with the export of Spodumene concentrate and ore.

13 https://en.wikipedia.org/wiki/Greenbushes_mine
14 https://www.nsenergybusiness.com/projects/greenbushes-lithium-mine/
15 For example, Mineral Resources' Wodgina mine commenced shipping ore with only 1.5% Li in 2017. Operations were suspended in 2019 due to a weak lithium price. Albemarle bought a controlling stake in the mine on the day it was mothballed. https://www.afr.com/companies/mining/minres-reaps-us1-3-billion-for-stake-in-mothballed-lithium-mine-20191101-p536h2
16 There is in fact some doubt when this nameplate capacity will be reached. Tianqi has revealed that it was delaying commissioning of the plant because of an *adverse liquidity situation.* https://www.afr.com/street-talk/china-s-tianqi-offers-stake-in-giant-aussie-lithium-project-20200413-p54jcw

Table 1. Lithium capacity in Australia

COMPANY	LOCATION	EXPORTED FORM	2019 PRODUCTION KT/Y LCE	POTENTIAL CAPACITY KT/Y LCE
ALLIANCE MINERALS AND TAWANA JV	Bald Hill, WA	6% Concentrate[17]	0	23
ALTURA MINING	Pilgangoora, WA	6% Concentrate	33	67
GALAXY RESOURCES	Mt Cattlin, WA	6% Concentrate[18]	14.8[19]	?
MINERAL RESOURCES AND JIANGXI GANFENG LITHIUM JV	Mt Marion, WA	6% Concentrate and DSO	0	67[20]
MINERAL RESOURCES LTD / ALBEMARLE	Wodgina, WA	Wet 6% concentrate and DSO	6	111[21]
MINERAL RESOURCES LTD AND JIANGXI GANFENG LITHIUM	Mt Marion, WA	Wet 6% concentrate	50	50
PILBARA MINERALS	Pilgangoora, WA	6% Concentrate	3.8[22]	19.8
COVALENT (SQM AND WESFARMERS JV)	Mt Holland, WA	Intention to build LiOH refinery	0	51
TALISON LITHIUM (ASX:TSL)	Greenbushes, WA	6% Concentrate	100	200[23]
		TOTAL LCE EQUIVALENT	207.6	603.6
		TOTAL LI METAL EQUIVALENT	39.0	113.4

Comment: The estimates in the above table for current production in Australia are comparable to USGS data for 2019 (38.8 vs 42 kt as Li). Missing data and inconsistencies in achieving 6% Li_2O will account for this. Something to note is the *potential capacity* in Australia, which is 3x current world consumption. The Hunwick data (Figure 4) and Bloomberg data (Figure 3) suggest that Australian supply could meet all of world demand, with our existing full capacity, out to 2023 or 2024.

17 Under Administration.
18 Reportedly closing in 2022.
19 Capacity in 2020 from https://www.asx.com.au/asxpdf/20200316/pdf/44g2qt8j3xnqsy.pdf indicates approximately 100,000https://www.asx.com.au/asxpdf/20200316/pdf/44g2qt8j3xnqsy.pdf indicates approximately 100,000 tonnes at 6% Li2O. Capacity in 2020 from https://www.asx.com.au/asxpdf/20200316/pdf/44g2qt8j3xnqsy.pdf indicates approximately 100,000 tonnes at 6% Li2O.
20 Upgrade project under way to increase capacity to 450,000 tpa at 6% Li_2O.
21 Upgrade project was under way to increase capacity to 750,000 tpa at 6% Li_2O, but currently in care and maintenance.
22 Both Mineral Resources and Pilbara minerals have chosen to moderate output due to low lithium price. Pilbara is not mining but working through stockpiles.
23 Upgrade to 1.34 mt @ 6% has been postponed.

28
Ni
58.6934
Nickel

Essential ingredients – Nickel

The battery value chain for Nickel commences with the mining of nickel-bearing ores. In Australia these are primarily either sulphide-based or lateritic oxides. Cobalt is commonly hosted in lateritic Ni ores (rule of thumb, in about a 1:10 ratio) but will be discussed later. The basic process chemistry will not be discussed in detail here as there are many variations depending on ore characteristics, other metals being recovered, and closeness to power and markets. The next stages beyond mining may include beneficiation, smelting, high pressure digestion in acid, and the production of a value-added high-nickel materials. To achieve battery grade requires further purification steps.

According to S&P Global data, Australia has approximately 27 nickel-producing properties with approximately 8.5 million contained tonnes of nickel and there are over 250 properties[24] at the exploration, prefeasibility and feasibility stages, with total additional contained nickel of at least 33 million tonnes. The more conservative USGS estimate is JORC-compliant reserves of 5.4 million tonnes, with a total resource of 20 million tonnes.

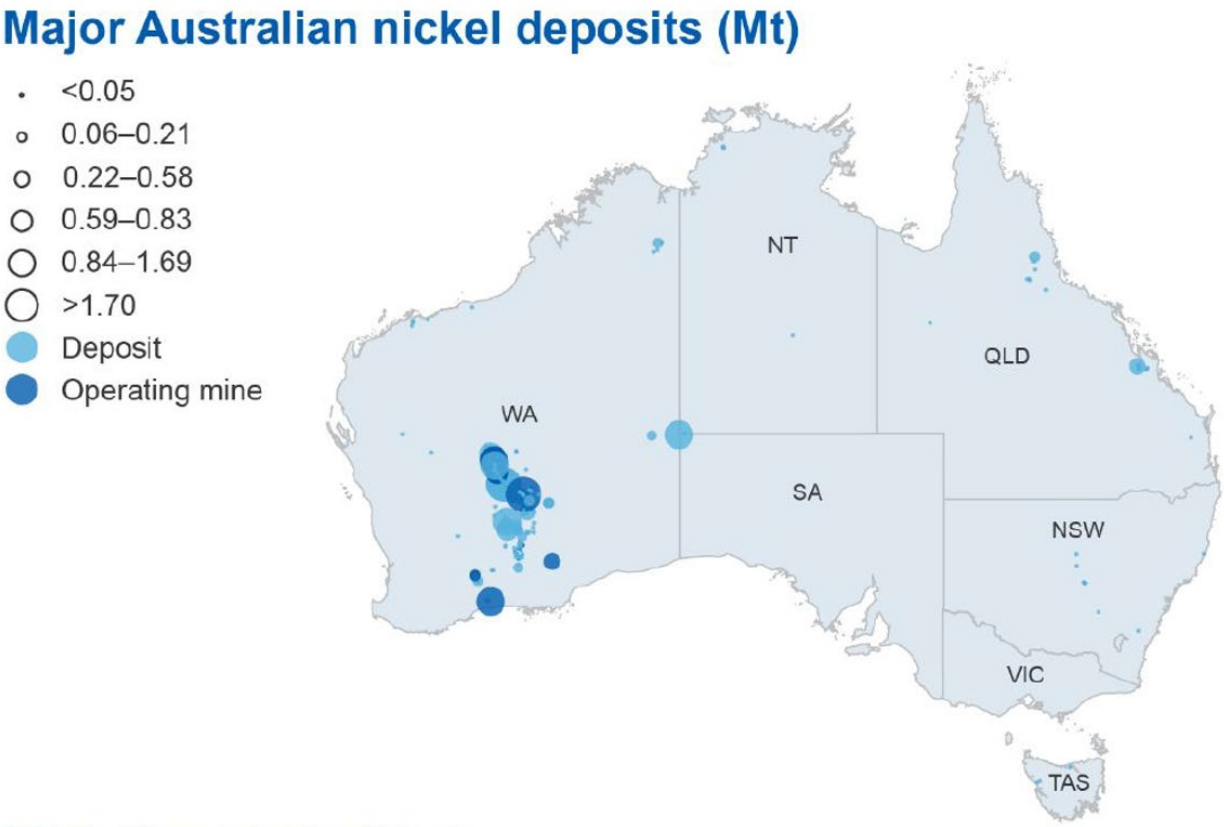


Figure 9. Location of Australia's major nickel deposits (Resources and Energy Quarterly, June 2017, Department of Industry).

Geoscience Australia recorded total mine output as 178,853 tonnes in 2017. Since then the nickel price has fallen and some capacity has been put into care and maintenance. Table 2 lists the operational nickel mines in Australia. The present authors estimate 2019 output to have been 160,000 tonnes.

24 Australia's prospective and developing nickel deposits and operations are so numerous that they have been listed in the Appendix rather than in the body of the report.

Nickel West (BHP, Kwinana) has the capacity to produce 75,000 annual tonnes of nickel metal at 99.8% purity; currently as much as 75% of which is exported as powder and briquettes to overseas customers who process it to battery grade nickel sulphate[25] and the balance is exported as LME grade briquettes. Nickel West typically also exports additional nickel units in the form of matte due to nickel-in-matte production exceeding the capacity of the Kwinana Refinery. Glencore's Murrin Murrin operation produces approximately 40,000 tpa of LME grade briquettes. Both refineries have offtake agreements with other miners, and do not source all of their nickel from their own mining operations. Not all of Australia's nickel is refined, and a number of miners have offtake agreements with overseas refiners. Prior to its closure in 2016, Queensland Nickel ("Palmer Nickel and Cobalt Refinery", Townsville) exported briquettes for the stainless-steel industry, produced in Townsville from New Caledonian laterite ore, and from MHP from First Quantum's Ravensthorpe operations. Prior to being placed on care and maintenance in 2017, First Quantum's mine and refinery was expected to produce mixed hydroxide precipitate (MHP) equivalent to 28,000 annual tonnes of nickel. That facility is due to re-start in 2020. All of Australia's current nickel metal, cobalt metal, and nickel-cobalt co-precipitate exports originate at the **refineries** listed in Table 3.

Table 2. Operational nickel mines in Australia

COMPANY	LOCATION	PRODUCTS	Ni OUTPUT TONNES/Y	OTHER REPORTED
GLENCORE PLC	Murrin Murrin Mine	Ni, Co	39,700[a]	3,200 Co
BHP GROUP	Mt Keith	Ni/Co Concentrate	40,000	-
BHP GROUP	Leinster	Ni/Co Concentrate	27,000[b]	-
INDEPENDENCE GROUP NL (IGO)	Nova-Bollinger	Concentrate	30,708	13,700 Cu 1,100 Co
PANORAMIC RESOURCES LTD., ORA GOLD LTD.	Savannah	Ni/Cu/Co Concentrate[c]	8,000	4,500 Cu 600 Co
MINCOR RESOURCES NL	South Kambalda	Care and Maintenance		
FIRST QUANTUM MINERALS LTD.	Ravensthorpe	Ni/Co	0	
MINCOR RESOURCES NL	Mariners	Care & Maintenance	0	
WESTERN AREAS	Forrestania/ Cosmic Boy/Flying Fox/Spotted Quoll/ Cosmos	Concentrate[d]	15,800	

[a] Includes third-party ore feeds
[b] The Leinster concentrator has a capacity for more than 40,000 tonnes.
[c] Savannah concentrate is exported to the Jinchuan group in China.
[d] Offtake agreements with BHP and Jinchuan.

Table 3. Nickel refining capacity in Australia

COMPANY	LOCATION	PRODUCTS	Ni CAPACITY TONNES/Y	Co CAPACITY TONNES/Y	STATUS
BHP NICKEL WEST	Kwinana, WA	Nickel briquettes Nickel powder Cobalt precipitate	75,000	1,000*	Operating
GLENCORE	Murrin Murrin, WA	Ni briquettes Cobalt precipitate	40,000	4,000	Operating
QUEENSLAND NICKEL	Townsville, Qld	Nickel briquettes Cobalt precipitate	76,000	3,500	Care and Maintenance
FIRST QUANTUM	Ravensthorpe, WA	Mixed Hydroxide Product	28,000**	3,500	C&M Restarting 2020

*Estimated. **Feeds into Queensland Nickel's capacity.

25 Nickel West, personal communication.

There is a great deal of potential to create a significant battery-grade nickel industry in Australia. Nickel West's current exports of ~56,000 annual tonnes of nickel to overseas battery chemical processors is one example. Between the mothballed QNI and soon to restart Ravensthorpe operations, there is an additional 75,000 annual tonnes of metal theoretically available, although the majority of technologies under development to make battery grade nickel salts do not require the intermediate production of metal. Nickel West has announced that it will produce battery-grade nickel sulphate at its Kwinana refinery, after successful process development and piloting with CSIRO. Although, as mentioned, refining to metal is not necessary on the route to battery grade, Nickel West's ability to do so using established refining capability does confer an advantage in simplicity of impurity-removal processes.

It is known (ASX and press releases) that BHP's Nickel West has the purification technology required to produce battery grade nickel sulphate[26], as does WA's Alpha Fine Chemicals[27], Clean TeQ[28], and Qld's Pure Battery Technologies[29]. Queensland Pacific Metals, a subsidiary of Pure Minerals (ASX:PM1) has announced a strategy to process laterite ores in Townsville with the intention of developing the capability to produce at battery grade with the help of CSIRO[30].

No representation can be made in the present report as to the quality or success of these technologies as no commercial plant has yet been commissioned based on any of these technologies.

As of January 2020, there was as yet **no commercial scale production of battery grade nickel** in Australia, but a number of battery-grade projects in the pipeline for delivery in 2020 or 2021 (Figure 10).

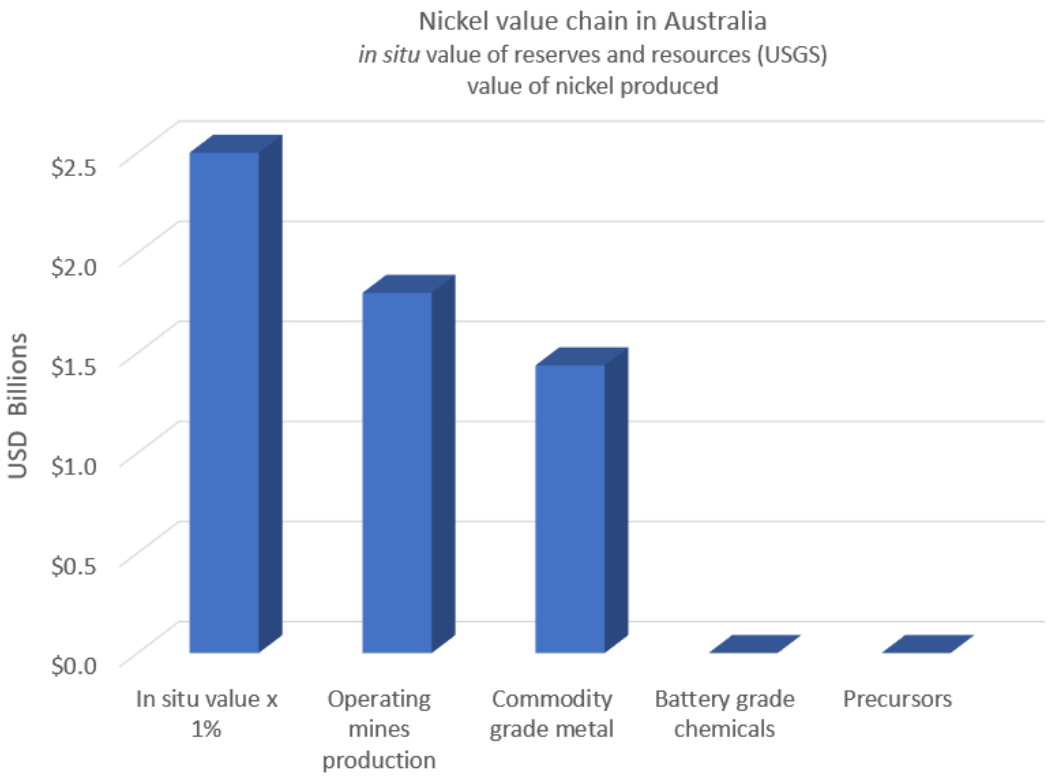
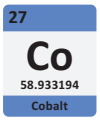


Figure 10. In situ value of Australia's nickel reserves (represented as 1% to maintain readability) and the value of other products along the value chain. The value chain in Australia at the time of the commencement of the FBI CRC stopped with the export of commodity grade nickel metal. Export value is calculated using average LME prices for nickel during 2019.

26 https://www.bhp.com/-/media/documents/media/reports-and-presentations/2018/20180608eduard-haegeldd2018final-ppt.pdf?
27 http://afchemicals.com.au/ Alpha claims to produce battery grade nickel and cobalt by extraction from pregnant leach solution (PLS).
28 https://www.cleanteq.com/lithium-ion-batteries/ The website claims that Clean TeQ will produce high quality battery grade nickel and cobalt sulphate. It is not stated explicitly, but this may be via their *All Russian Research Institute of Chemical Technology (ARRICT)* developed Clean iX technology.
29 https://purebatterytech.com/ claims to directly produce a battery grade mixed Ni/Co salt by direct extraction from PLS.
30 https://www.asx.com.au/asxpdf/20200131/pdf/44dnl9qg3z35bx.pdf

Essential ingredients – Cobalt



The battery value chain for Cobalt in Australia most often commences with the mining of nickel-bearing ores, primarily sulphide-based or lateritic oxides. Cobalt is commonly hosted in about a 1:10 ratio with nickel in lateritic ores, although the recovery of cobalt is not nearly as efficient as the recovery of nickel. Sulphide deposits generally have a lower Co:Ni ratio. However, 72% of the world's cobalt is a co-product of copper mining (the Democratic Republic of the Congo's cobalt is largely hosted this way). So far, there are no dedicated cobalt mines in operation in Australia. For this reason, it is a difficult task to tabulate Australia's actual reserves. They can however be estimated from the USGS 2020 publication, as 1.2 million tonnes (the same document estimates that the DRC has only 3.6 million tonnes). The USGS estimates Australia's current cobalt production to be 5,100 tonnes annually (GA estimate 4,971, SA Government estimate 3,900 tonnes), but all are likely to be an underestimate. BHP's Nickel West operation produces a mixed nickel-cobalt sulphide precipitate for sale (quantities unknown, of the order of 1,000 tonnes) and Glencore's Murrin Murrin operation claims to produce nearly 4,000 tonnes annually (form unknown, but not battery grade).

Prior to its closure, Queensland Nickel ("Palmer Nickel and Cobalt Refinery", Townsville) exported an unknown quantity of cobalt chemicals from its Townsville operations. These were likely not to have been battery grade. The tailings dam at Queensland Nickel has created some interest. Whether or not it can be economically processed, it is claimed that 69,000 tonnes of cobalt exist in the tailings[31].

Please refer to Table 3 for cobalt plants and exports from Australia (in each case, as a co-product with Ni). There are a number of other prospective Co producers at feasibility and prefeasibility stages with indicated resources totalling nearly 142,000 tonnes. Table 4 lists the most prospective Australian cobalt mining operations.

Table 4. The most prospective cobalt mining operation in Australia (in addition to the Ni/Co miners and refiners in Tables 2 and 3).

COMPANY	LOCATION	RESERVES AND RESOURCES TONNES
AUSTRALIAN MINES LTD.	Flemington	2,744
CONICO LTD., BARRA RESOURCES LTD.	Mt Thirsty	31,600
GALILEO MINING LTD.	Norseman	26,600
COBALT BLUE HOLDINGS LTD., BROKEN HILL PROSPECTING LTD.[32]	Thackaringa	79,500
FIRST QUANTUM MINERALS	Ravensthorpe	59,000
RESOLUTION MINERALS LTD.	Wollogorang	1,210

31 https://web.archive.org/web/20180815234024/https://www.australianmining.com.au/news/clive-palmer-targets-6bn-cobalt-queensland-tailings/
32 NB: This is not BHP (Broken Hill Proprietary Ltd.)

As of December 2019, there was **no commercial scale production of battery grade cobalt** in Australia, and no active cobalt mines where cobalt was not a co-product of nickel. However, there are a number of highly prospective projects in the pipeline (Figure 11).

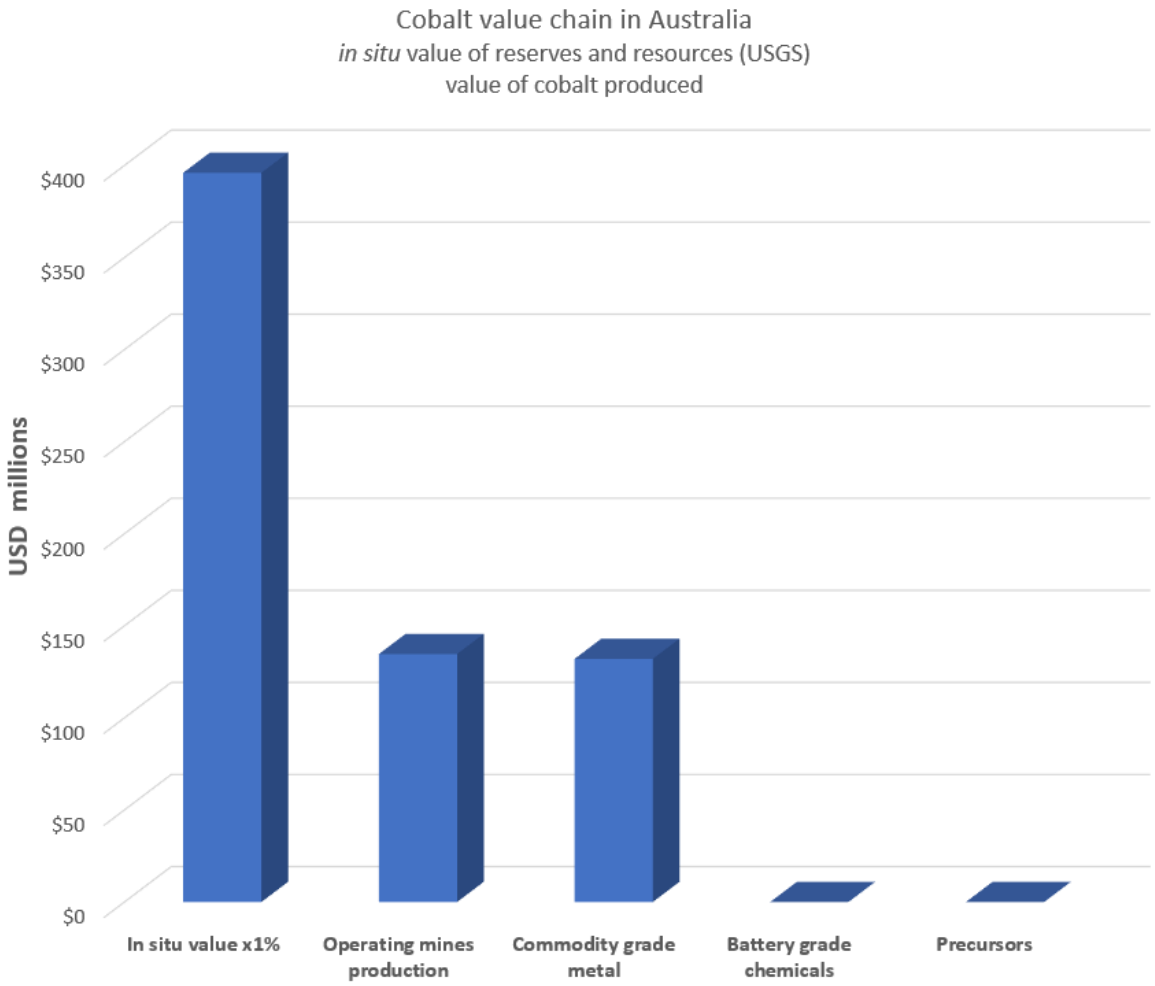
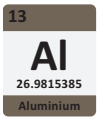


Figure 11. In situ value of Australia's cobalt reserves (represented as 1% to maintain readability) and the value of other products along the value chain. The value chain in Australia at the time of the commencement of the FBI CRC stopped with the export of commodity grade cobalt metal. Values are calculated using the average LME price for cobalt in 2019.

Essential ingredients – Aluminium and HPA



Until the last decade, Australia was by far the world's largest producer of alumina, before that production was matched, now exceeded, by China. Australia produces approximately 20 million tonnes of smelting grade alumina (SGA) annually *via* the Bayer process, to feed the world's aluminium smelters (export value approximately $8 billion). Standards for SGA are closely tied to surface area specifications and performance in electrolytic cells. Purity rarely exceeds (or rarely *needs* to exceed) 99.7% as Al_2O_3, with the major impurities being Na (always), and often Ca, Fe, Si and Ti. The High Purity Alumina (HPA) product required for electronics and battery separator manufacture cannot be produced via the Bayer process. Australia's standing in metallurgical alumina production does not confer any advantage in entering the HPA market[33], chiefly because the major impurity, Na, is not tolerated in electronics applications. The Bayer process is inherently limited to approximately 99.90% purity (and approximately 0.10% Na_2O) due to a surface equilibrium phenomenon that exists when precipitating gibbsite from pregnant liquor[34].

High Purity Alumina is increasingly important in battery architecture and in fact there is often more HPA in some battery designs than Ni or Co. HPA is typically >99.99% Al_2O_3 for the "4N" grade (there are 5N and 6N grades). The traditional process commences with high purity Al metal, dissolution and reprecipitation, often via an alkoxide. Due to the energy intensity required for the production of metal, this is a costly route. Companies such as Orbite[35] (now bankrupt) have proposed more direct production through acid extraction of bauxite, or even red mud, but their process was not robust at an industrial scale.

As previously stated, battery grade aluminas are not likely to be produced directly via the Bayer process. Bayer-produced SGA is also not suitable for economic purification to HPA because it has been calcined into insoluble phases. However, the crystalline gibbsite ($Al(OH)_3$, sometimes conveniently but incorrectly described as $Al_2O_3.3H_2O$, "trihydrate") produced as an intermediate step in the process, has been used as a starting point for the production of higher-purity alumina chemicals such as ultra-white fillers and water treatment chemicals[36], but the same could be said about any chemical-grade aluminium salt, or kaolin. On a cost basis it is probably more logical to commence the process with a feedstock other than one as complex as bauxite, such as clays which can occur in quite pure deposits. Any aluminium-based feedstock will suffice, if elimination of impurities is economically feasible. As a guide, SGA as commonly produced in Australia is valued around US$400 per tonne. 4N HPA is currently valued at between US$20,000 to $30,000 per tonne. Al_2O_3 can exist in seven different non-hydrated phases and in amorphous form even after high temperature calcination. The preferred phase for HPA appears to be α-Al_2O_3 (corundum) but the authors have not tested this in the market. As previously mentioned, LED and other ceramic uses of alumina are high volume consumers, but the whole market is expected[37] to grow by nearly 22% year on year until 2028.

Altech Chemicals is headquartered in Perth WA, and will manufacture 4N electronic and battery grade products at its facility in Malaysia. Its feedstock is reported to be kaolin, mined at Meckering WA.

There are no known producers of HPA in Australia at the present time. There are, however companies pursuing HPA production in Australia (Table 5).

Table 5. Prospective HPA activities in Australia.

COMPANY	LOCATION	STAGE
ALPHA HPA[38]	Gladstone, Qld	Pilot plant
FYI RESOURCES[39]	Kwinana, WA	Pilot plant
ANDROMEDA METALS	SA	Testwork
ALCHEMY RESOURCES	West Lynn, NSW	Testwork
LAVA BLUE[40]	Lava Plains, Qld	Mine operating. Pilot plant

33 The industries also operate on very different scales. World production of SGA is ~123,000,000 tonnes whereas the market for HPA is ~50,000 tonnes annually.
34 Vernon, C.; Loh, J.; Lau, D.; Stanley, A. in Essential Readings in Light Metals, Volume 1: Alumina and Bauxite DOI: 10.1007/978-3-319-48176-0_83
35 https://en.wikipedia.org/wiki/Orbite_Technologies#Orbite_process
36 https://www.coogee.com.au/Our-Businesses/Chemicals-Manufacturing/Chemicals/Alumina-Hydrated
37 https://www.alliedmarketresearch.com/high-purity-alumina-market
38 http://www.alphahpa.com.au/
39 https://www.fyiresources.com.au/
40 https://www.lavablue.com.au/hpa

Battery Grade Aluminium Salts

High purity aluminium sulphate is used in the precipitation of NCA (Lithium Nickel Cobalt Aluminium oxide) cathode precursors. As for all other components destined for battery use, aluminium salts must be purified of deleterious metals (in particular, requires very low Fe and Cu) to a purity of >99.95%. Coogee Chemicals produces aluminium sulphate (alum) suitable for water treatment in Australia and specifies[41] that the product has as little as 250 ppm of impurities (i.e. 99.975% purity). This sounds promising, but the impurities are chiefly Fe at 220 ppm, which would exceed allowable iron contamination by at least an order of magnitude[42]. Nowchem[43] also makes alum in Australia but no specification for the product can be found in the public domain.

It is unlikely that any company in Australia produces battery grade aluminium salts. It is not known whether any Australian companies currently aspire to do so.

Battery Grade Aluminium Foil

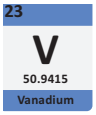
Aluminium foil is used as a current collector for cathode materials. A survey of 7 overseas suppliers of battery grade aluminium foil offered 99.9% purity at no more than US$2600 per tonne, which is not a large premium for rolling to the thickness of 16 µm (household aluminium foil can range from a nearly unusable 16 µm up to 200 µm depending on quality and use). LME aluminium ingots are available at less than US$1700 per tonne, with a minimum purity of 99.7% and presumably this minimum purity is often exceeded. Companies such as Hydro Aluminium offer high purity aluminium between 99.998% to 99.9999% but no companies offer bulk ingots of "battery grade" aluminium metal. Australia produces somewhere between 1,600,000[44] and 1,960,000[45] tonnes of aluminium metal annually, which is only 2.5% of world production.

It is not known whether any of Australia's 4 smelters produce aluminium metal of significantly higher specification.

The authors could not find any Australian manufacturers of aluminium foil. However, this seems like an industry that Australia could easily develop for a niche market such as battery foil.

41 https://www.coogee.com.au/files/files/797_Coogee_PIS_Aluminium_Sulphate_Solid.PDF
42 For example, allowable Fe in battery grade graphite is <30 ppm and in Ni, Co and Mn salts is likely to be <10 ppm.
43 https://nowchemwatercare.com.au/flocculants/liquid-aluminium-sulphate-alum/
44 USGS, 2019.
45 Australian Aluminium Council. https://aluminium.org.au/australian-industry/industry-description/australian-aluminium/

Essential ingredients – Vanadium



World production of vanadium is only ~80,000 annual tonnes (metal basis). Australia's JORC-compliant reserves are 1.075 million tonnes. The Windimurra Vanadium mine was Australia's last vanadium producer when it was mothballed in 2014. It is estimated that only 5% (4,000 annual tonnes) of vanadium demand is currently for vanadium redox batteries (VRBs) but there has been a large increase in the consumption of vanadium in China recently for large-scale energy storage[46], and the market for battery-grade vanadium is expected to grow 4-fold[47] by 2023. New capacity required is therefore of the order of 16,000 annual tonnes by 2023. Windimurra's new owner, Atlantic, is pursuing a re-start with a capacity of 7,750 annual tonnes of vanadium pentoxide (4,340 t vanadium metal equivalent) or 5.5% of current world demand. TNG's Mount Peake project is under development and aims to produce up to 6,000 annual tonnes of high purity V_2O_5 (3,360 t metal equivalent, 4.2% of world supply). Australian Vanadium has plans to bring 5,600 annual tonnes (metal equivalent) to market (7% of world supply). Table 6 lists the prospective vanadium producers in Australia.

Although the success of the three projects mentioned above would add another 17% to world supply, the forecast need for vanadium in redox batteries significantly exceeds this.

Despite the progression of plans by these three Australian companies, as of December 2019 there are no vanadium producing mines in Australia[48].

Table 6. Prospective vanadium producers in Australia.

COMPANY	LOCATION	STAGE
ATLANTIC[49]	Windimurra, WA	Care and maintenance pending re-start Next stage Engineering and Design
AUSTRALIAN VANADIUM[50]	Meekatharra, WA	Feasibility study
MULTICOM RESOURCES[51]	Julia Creek, Qld	Engineering and Design
AUSTRALIAN VANADIUM[52]	Wundowie, WA (Coates)	Exploration
TNG PTY LTD[53]	Mt Peake, WA and Darwin, NT	Engineering and Design

46 https://investorintel.com/sectors/technology-metals/technology-metals-intel/vanadium-is-still-a-hot-sector-right-now-but-can-it-be-maintained/
47 https://www.asdreports.com/news-28553/flow-battery-market-worth-9463-m-usd-2023
48 It should be noted however that Multicom Resources' Julia Creek project has been awarded major Project ststusby both the Federal and State governments.
49 https://atlanticptyltd.com.au/
50 The major orebody is tianiferous magnetite, but there is also a paleochannel U/V deposit nearby, https://www.australianvanadium.com.au/
51 https://www.mcres.com.au/saint-elmo-project
52 The town of Wundowie has a vanadium mining and refining history. Production commenced in 1980 but was limited to 220 kg/y. Operations ceased in 1982.
53 https://www.tngltd.com.au/

Essential ingredients – Graphite

Graphite is currently the most popular anode material in lithium ion batteries. There are some differences in what is considered battery grade graphite, which is a function of a battery manufacturer's acceptance levels of impurities such as iron, copper, chrome, other metals, sulphur, phosphorus and silica (all at the ppm level). In general, battery grade contains >99.97% C. That is, the sum of the impurities is no more than 300 ppm. Targets for elements such as copper and iron are well below 10 ppm. The common method to achieve this, in China, is to bathe the graphite in a vat of hot hydrofluoric acid for several days. This works well (as may be expected) but in the EU and USA it is increasingly viewed as less desirable[54]. It has been recognised that less environmentally damaging processes can be brought to bear.[55,56]

The value chain for graphite starts at the ore (sometimes at a grade of only a few percent), crushing then floating to create a concentrate usually >95% C. The (usually) flake material is made spherical[57] in a special mill that renders approximately 30% of the mass as near-spherical graphite particles. The remaining 70% is rejected and channelled into other markets (including lubricants, refractories, and pencils). Much of the bulk impurity material reports with the rejected fines, and the retained spherical particles have typically >98% C. Removal of the remaining nearly 20,000 ppm impurity is generally achieved through heat or chemical treatment and this step is considered key IP; each process is optimised to the impurities present in each deposit, and toward the demands of the battery manufacturer. Actual impurity limits vary from customer to customer and are treated as commercial in confidence, but some guidance is given by Hexagon Resources[58], and these data are shown in Table 7.

Table 7. Impurity limits for selected penalty elements in battery grade graphite (Hexagon Resources).

ELEMENT	UPPER LIMIT (PPM)	ELEMENT	UPPER LIMIT (PPM)
As	1	Cr	5
Sn	2	Cu	5
Mo	2	Mn	10
Sb	2	V	10
Zn	2	Al	10
Co	3	Fe	30
Pb	5	Ca	30
Cd	5	S	100
Ni	5	Si	200

54 It is understood that Syrah Resources is using a hydrochloric-hydrofluoric acid route at its Vidalia, Louisiana, battery anode plant.
55 https://www.ecograf.com.au/business/ecograf/
56 https://www.mineralcommodities.com/operations-projects/graphite/munglinup-graphite-project/
57 Variously referred to as "spheronisation" or "spheroidization".
58 https://hexagonresources.com/wp-content/uploads/2018/12/20181218-5-Nines-Graphite-in-Pilot-Scale-McIntosh-Sample-Amended_1883527.pdf

Australia has modest graphite deposits compared with other world sources. S&P Market Intelligence lists Mozambique, Tanzania and Canada as having the largest reserves plus resources (344 million tonnes, 67 million tonnes, and 30 million tonnes respectively), and Australia coming in 4th with 15.5 million[59]. However, USGS data does not rank Australia at all[60], but ranks Turkey (90 million tonnes), China (73 million tonnes), Brazil (72 million tonnes), then Mozambique (25 million tonnes), Tanzania (18 million tonnes). Statista[61] shares the USGS view but the data reference is likely to be circular. The differences between these assessments give concern as to which data to trust. It is likely that the USGS data does not fully consider how economic a given deposit is; e.g. Turkish graphite *may* be of low quality; the USGS *may* have ignored graphite from Mozambique and Australia based on lack of local extraction industries at the time of compiling the data. The S&P data is likely to record realistic estimates, but from companies developing prospects (and in fundraising mode, therefore "best possible case").

Whatever the reason for the lack of agreement, of Australia's 23 potential graphite projects documented by S&P, it appears that **none currently produce any commercial graphite,** battery grade or otherwise. Within the past few years, Quantum Graphite (Uley Graphite Project) produced large flake graphite but according to recent company reports[62] it is not currently receiving income[63] from selling product. SA State Government records[64] indicate that it is under care and maintenance. Twelve potential mines are yet to quantify reserve/resource size, an additional project (EcoGraf) is a graphite refinery for Tanzanian graphite. Nine are projects in feasibility and reserves development, that the present Authors estimate to be 14.5 million tonnes (note: this is close to S&P compiled data which suggests 15.5 million tonnes proven resources in Australia). Table 8 lists the major graphite projects in Australia. There are several smaller deposits around the country, including historically worked mines south of Manjimup, in WA.

Although no graphite is currently produced in Australia, it appears that several companies have acquired or are developing the technology to produce battery-grade graphite. Australian companies such as Syrah and Talga have significant reserves in overseas deposits. These could potentially be processed in Australia in a similar way to that being proposed by Ecograf.

59 The S&P database uses public stock exchange data, company literature and news articles. This data is biased towards public disclosure and not strategic assessments by governments.
60 Contact has been made with the USGS and they have commented that as Australia does not currently export graphite, it was left out of the statistics. This will be corrected in the 2021 country summary.
61 https://www.statista.com/statistics/267367/reserves-of-graphite-by-country/
62 https://www.asx.com.au/asxpdf/20200313/pdf/44g09kgpr259sh.pdf
63 Income seems to be limited to R&D tax incentives.
64 http://www.energymining.sa.gov.au/minerals/mining/mines_and_quarries/uley_graphite_mine

Table 8. Graphite prospects in Australia.

COMPANY	LOCATION	STAGE
ARCHER MATERIALS	Waddikee	Advanced Exploration
	Carrappee Hill	Exploration
	Cleve West	Early Exploration
	Eyre Peninsula	Prefeasibility/Scoping
	Mt Messenger	Exploration
BLACKEARTH MINERALS	Northern Gully	Exploration
	Donnelly River	Exploration
COMET RESOURCES	Springdale	Reserves Development
CRATER GOLD MINING	Golden Gate	Reserves Development
ECOGRAF LTD.[65]	Kwinana Processing Facility	Prefeasibility/Scoping
HAZER PROCESS[66]		Synthetic graphite. Experimental samples.
HEXAGON ENERGY MATERIALS LTD.	McIntosh	Feasibility Started
LINCOLN MINERALS LTD.	Koppio-Kookaburra Gully	Feasibility Complete
LITHEX RESOURCES	Furniss East	Exploration
METALICITY LTD.	Munglinup North	Exploration
METALLICA MINERALS	Esmeralda	Target Outline
MINERAL COMMODITIES LTD.	Munglinup	Feasibility Started
NOVONIX LTD.	Mount Dromedary	Feasibility Started
OAKDALE RESOURCES	Oakdale	Prefeasibility/Scoping
QUANTUM GRAPHITE	Uley	On hold
RENASCOR RESOURCES	Siviour	Feasibility Complete
RENASCOR RESOURCES[67]	Munglinup	Feasibility Complete
SAYONA MINING	East Kimberley	Target Outline
STRIKE RESOURCES, BURKE MINERALS	Burke	Reserves Development

65 EcoGraf have developed an HF-free environmentally friendly technology to produce battery grade graphite from Tanzanian feedstock.
66 The Hazer process uses an iron oxide catalyst to convert methane into hydrogen and graphitic carbon. The efficacy of the Hazer-derived carbon as a battery precursor has not yet been demonstrated.
67 Resnacor are recipients of a CRC-P grant to develop technology to convert their Munglinup graphite to battery grade.

Essential ingredients – Manganese

25
Mn
54.938044
Manganese

Manganese is used in a wide variety of battery chemistries. Of the modern rechargeable battery chemistries, NMC (nickel, manganese, cobalt) is the most obvious.

Manganese occurs in a number of ore types, but usually pyrolusite (MnO_2) and rhodochrosite ($MnCO_3$) at relatively high concentrations. There are hydrometallurgical and pyrometallurgical routes, with the latter preferred for steel-making feedstocks. Hydrometallurgical processes are the only routes to battery-grade manganese salts or oxide.

Existing activity in Australia is headlined by Groote Eylandt Mining Company (GEMCO, South32/Anglo American) which extracts about 25% of the world's annual demand at Groote Eylandt NT and ships high grade ore to a range of international customers, and to the TEMCO ferromanganese plant in Tasmania. Other operating mines in Australia include the Woodie Woodie mine (WA), and another located at Bootu Creek (NT). There are a number of other high-potential projects positioning to produce battery-grade MnO_2 or $MnSO_4$, but none of these are yet at a commercial stage. These companies include Element 25 and Pilbara Metals Group (since renamed Mn Energy Ltd). Table 9 lists companies producing or pursuing manganese in Australia.

No battery-grade manganese is produced in Australia at present, but a number of companies are proceeding down this path.

Table 9. The following companies are either producing, or pursuing manganese production, in Australia.

COMPANY	LOCATION	STAGE
GEMCO[68]	Groote Eylandt	Production
OM HOLDINGS[69]	Bootu Creek, NT	Production
PILBARA MANGANESE[70]	Woodie Woodie, WA	Production
ELEMENT 25[71]	Butcherbird, WA	Pre-Feasibility study
PILBARA METALS GROUP[72]	Meekatharra/Kwinana	Feasibility study

68 https://www.south32.net/our-business/australia/gemco
69 http://www.omholdingsltd.com/our-business/bootu-creek-mine-2/
70 https://www.consmin.com/our-business/australia/manganese/
71 https://www.element25.com.au/site/content/
72 http://pilbarametalsgroup.com/

57	58	59	60	61	62	63	64	65	66	67	68	69	70	71
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
138.90547	140.116	140.90766	144.242	145	150.36	151.964	157.25	158.92535	162.500	164.93033	167.259	168.93422	173.054	174.9668
Lanthanum	Cerium	Praseodymium	Neodymium	Promethium	Samarium	Europium	Gadolinium	Terbium	Dysprosium	Holmium	Erbium	Thulium	Ytterbium	Lutetium

Essential ingredients – Rare Earths

Current lithium ion battery chemistries do not contain rare earths. However, rare earths are included in the current discussion because (a) lanthanum metal (and sometimes mischmetal[73]) is one element of the anode in a nickel metal hydride battery (NiMH); (b) rare earths may be used as stabilisers for the cathode-active materials in vanadium flow batteries; (c) the same may be true for manganese[74] flow batteries; (d) many battery materials may benefit from the incorporation of rare earths[75,76,77].

Lynas Corporation is the only rare earths company in Australia dealing in commercial quantities, exporting concentrate from its Mt Weld (WA) operation to Malaysia where it further processes the ore. Lynas does however plan to conduct first stage "cracking" at a location near Kalgoorlie and has joined[78] with Blue Line in Texas to proceed further down the value chain.

Other rare earth prospects in Australia include Northern Minerals' Browns Range deposit (at pilot plant stage), dominated by heavy rare earths such as Dysprosium, Alkane[79] Resources' Dubbo Zirconium deposit (construction ready), and Arafura[80] Resources' Nolans Bore project (feasibility study complete).

At the present time, there is no in-Australia production of rare earths in any form that could be incorporated into a battery component. However, there are a number of projects in the pipeline that will eventually produce such materials.

73 Mischmetal is literally "mixed metal" from reduction of rare earths produced electrolytically from mixed rare earths extracted from monazite. As such, it is a mixture chiefly of the light rare earths, in order of composition La>Ce>Pr>>Nd. Mischmetal was a commodity created at a time where only the thorium content of monazite was commercially valuable. It is also commonly used in lighter flints.

74 *Characterization and electrochemical performance of CeO_2 and Eu-doped CeO_2 films as a manganese redox flow battery component,* Mônica A.Rodrigues, Ariadne C.Catto, Elson Longo, Edson Nossol, Renata C.Lima, https://doi.org/10.1016/j.jre.2018.05.004

75 *A neodymium oxide nanoparticle-doped carbon felt as promising electrode for vanadium redox flow batteries* Abdulmonem Fetyana Guma, A.El-Nagarab, Igor Derr, Paul Kubella, Holger Dau, Christina Roth https://doi.org/10.1016/j.electacta.2018.02.104

76 *Rare earth incorporated electrode materials for advanced energy storage,* Hongyang Zhaoa, Jiale Xiaa, Dandan Yina, Meng Luoa, Chunhua Yanac, Yaping Du https://doi.org/10.1016/j.ccr.2019.03.011

77 *Research on cathode material of Li-ion battery by yttrium doping,* TIAN Yanwen, KANG Xiaoxue, LIU Liying, XU Chaqing, QU Tao, https://doi.org/10.1016/S1002-0721(08)60081-2

78 https://www.miningglobal.com/operations/lynas-planning-rare-earth-plant-blue-line-texas

79 http://www.alkane.com.au/

80 https://www.arultd.com/

Process Technology Companies – Battery Grade Chemicals

In the past decade several Australian companies have developed a business strategy to move along the battery value chain. Some of these are already mentioned, but a summary of those companies follows in Table 10.

Table 10. Companies pursing battery grade chemicals.

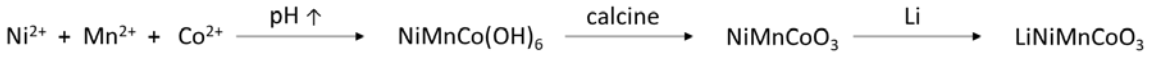
COMPANY	BUSINESS LOCATION	FOCUS	DETAILS OF TECHNOLOGY	READINESS LEVEL
ALPHA FINE CHEMICALS[81]	Osborne Park, WA	$NiSO_4$	MHP dissolution, SX purification, Crystallization	Definitive feasibility for 40,000 tpa plant in Thailand.
BHP (NICKEL WEST)[82]	Kwinana, WA	$NiSO_4$	LME grade Ni powder redissolved in acid, leach solution purified, $NiSO^4$ reprecipitated.	Piloted. Construction commenced.
CLEAN TEQ[83]	Notting Hill, Vic.	$NiSO_4$ $CoSO_4$	Proprietary continuous ion exchange process that can be run as resin-in-pulp.	Technology development
IGO[84]	South Perth, WA	$NiSO_4$ $CoSO_4$	IGO developed a new patented process that can produce a high-quality nickel sulphate from nickel sulphide concentrate (Solvent Extraction)	Technology developed. Not being pursued at this time
PURE MINERALS/ QPM[85]	Sydney, NSW Perth, WA	$NiSO_4$ $CoSO_4$	MHP intermediate. SX/crystallization	Technology development
PURE BATTERY TECHNOLOGIES[86]	Brisbane, Qld	Ni/Co coprecip	"Selective leaching" from MHP to produce battery grade mixed Ni/Co chemicals.	Ready to pilot.
ICS[87]	Waterford, WA Sydney, NSW	Lithium hydroxide	Recyclable reagents. Direct production of LiOH. Market acceptance testing of $LiNO^3$ as battery lithium feed.	Ready to pilot. PFS complete. Seeking investment.
ECOGRAF (KIBARAN)[88]	Kwinana, WA	Battery grade graphite	"EcoGraf downstream business proposes establishing a processing plant in Kwinana, Western Australia, to produce spherical graphite (SpG) using a new eco-friendly process to sell directly to lithium-ion battery manufacturers."	Kwinana refinery planned.
LEPIDICO[89]	Belmont, WA	Lithium chemicals	The L-Max® process involves a sulphuric acid leach of a lithium mica slurry at atmospheric pressure and modest temperature. The product of the process is lithium carbonate.	Ready to pilot.
LITHIUM AUSTRALIA[90]	West Perth, WA	Lithium phosphate	SiLeach recovers Li from a variety of feedstocks including micas by acid leaching in the presence of F-.	Ready to pilot.
LITHIUM AUSTRALIA[91]	West Perth, WA	Lithium Iron Phosphate (LFP)	Production of LFP using a proprietary process developed by Very Small Particle Company (VSPC Ltd) which Lithium Australia NL acquired. LieNA technology avoids roasting.	Piloted and samples available.
TIANQI	Kwinana, WA	Lithium Hydroxide	Tianqi have built a commercial scale LiOH plant at Kwinana. It is understood that the plant has been operated but is not yet fully commissioned.	Commercial scale not yet operating commercially.

81 http://afchemicals.com.au/afc-nickel-sulphate-plant
82 https://www.bhp.com/-/media/documents/media/reports-and-presentations/2018/20180608eduard-haegeldd2018final-ppt.pdf?
83 https://www.cleanteq.com/lithium-ion-batteries/
84 https://www.igo.com.au/site/operations/downstream-processing IGO also own and operate the Nova Ni/Cu/Co mine.
85 https://www.pureminerals.com.au/projects/tech-project/
86 https://purebatterytech.com/our-technology/
87 Personal communication.
88 https://www.ecograf.com.au/
89 https://www.lepidico.com/l-max-technology/l-max/
90 https://lithium-au.com/about-sileach/
91 https://lithium-au.com/about-liena/

Battery Precursor Materials

This is the next manufacturing step in the value chain - assembling pure raw materials into engineered materials and structures that can perform as anodes or cathodes in an electrochemical cell.

Common cathode precursor materials are generally made by co-precipitating the component metals, in the appropriate proportions, by increasing the pH (ammonia or hydroxide addition). A mixed metal hydroxide results and this is turned into the corresponding oxide by baking. The inorganic chemistry is comparatively simple, but the precipitate must form with the correct size distribution, particle shape and porosity. The unbalanced equation below schematically describes the production of an NMC cathode precursor.



Anode precursor materials include spherical, coated, lithiated graphite (discussed previously) and lithium titanate. The companies working in these technologies are listed in Table 11.

Table 11 Australian companies planning to make battery precursor materials.

COMPANY	BATTERY PRECURSOR ACTIVITIES.
KIBARAN/ECOGRAF	Are building a plant to produce spherical natural graphite materials for the lithium-ion battery industry.
RENASCOR	Can make spherical graphite. Developing a purification process with CSIRO. Entered into a non-binding partnership with Sicona for advanced anodes.
ARCHER MATERIALS	Can make spherical graphite. No indication that there is a process to upgrade to battery purity.
TALGA RESOURCES*	Perth-based, Talga has resources in Sweden (possibly the highest total graphite content of any resource in the world), which they are now processing for electrodes and other advanced graphite processes.
SYRAH RESOURCES*	Melbourne-based Syrah Resources owns the Balama Graphite Project in Mozambique. Syrah produced over 100,000 tonnes of graphite in the first full year of operations to become the largest producer globally. Syrah is currently developing its downstream Battery Anode Material (BAM) project in Louisiana, USA.
BHP NICKEL WEST	Nickel West has declared that it will enter the battery grade nickel sulphate market in 2020 (piloted in 2019, plant under construction).
VSPC	VSPC has developed processes for manufacturing lithium iron phosphate cathode powders at its R&D and pilot plant facility in Brisbane, Queensland.

*outside of Australia

Process Technology Companies – Battery Precursors

A variety of Australian companies are pursuing the manufacture of cathode and anode active materials (Table 12).

Table 12. Australian companies pursuing the manufacture of battery precursor materials:

COMPANY	LOCATION	FOCUS	DESCRIPTION	COMMENT
ANTEO TECHNOLOGIES	Logan, Qld	AnteoCoat for Graphite:Silicon composite electrodes	"At Anteotech we have developed a scalable silicon composite that will allow for the simple integration of larger quantities of silicon into the anode driving up storage capacity. Complementary to the silicon composite as the active material, our cross-linked binder program supports silicon anode development to further drive battery performance."	Materials can be scaled, but further work to validate required.
FBI CRC CONSORTIUM	Perth, WA	Cathode precursors	Intention to establish the capability to produce NCA and NMC materials.	Feasibility of piloting being discussed.
CALIX	Bacchus Marsh, Victoria	Battery-active materials	"The application of the Calix Flash Calciner technology to batteries could be a gamechanger in terms of providing cheaper and more sustainable energy storage across electric transportation, portable electronics, and large kilowatt power systems."	Construction completed on the flash calcination plant.
NANO-NOUVELLE (NOW DEFUNCT)	Sunshine Coast, Qld	Working on a range of battery technology solutions for Lithium-ion	"Nano Nouvelle is developing innovative nanomaterials as a platform technology for use in a wide range of applications. The first product in development, the Tin Nanode, is a high energy tin-based anode for lithium ion batteries that will provide as much as 50% more energy capacity than existing anode technology"	Company no longer in existence.
SICONA BATTERY TECHNOLOGIES	Sydney	Silicon materials for lithium-ion batteries	Sicona's core business is the commercialisation of an innovative silicon-composite battery anode technology, developed and perfected over the last 10 years at the Australian Institute for Innovative Materials in New South Wales. The company's silicon-composite anode technology offers potential to deliver up to 177% higher specific capacity and a resulting higher cell energy density of up to 50% greater than conventional or standard "graphite-only" batteries.	Early stage start-up.
VSPC	Brisbane	Cathode materials	At its electro-chemistry laboratory and pilot production facility in Brisbane, Queensland, VSPC designs, creates and supplies high-purity, high-performance, nano-scale complex metal oxides and cathode materials – from initial research through to pilot-plant (current) and (ultimately) large-scale manufacture.	Technology development.

Process Technology Companies – Engineering Services

Although engineering services can be considered generic, however there are a small number of companies operating in Australia that have battery materials experience (Table 13):

Table 13. Engineering services with battery materials experience.

COMPANY NAME	ACTIVE LOCATIONS	ACTIVITIES	DETAIL
HATCH ENGINEERING	Brisbane, Perth, Toronto	Lithium beneficiation and refining.	"We have a detailed understanding of the various processes available or being developed to produce lithium carbonate and lithium hydroxide. We can help find the best strategies for your operation."
JORDPROXA	Rivervale, WA	Process equipment including crystallizers and dewatering equipment	Engineering crystallisation, dewatering and drying plant for producing high purity battery grade nickel sulphate crystals.
MSP RESOURCE DEVELOPMENT CONSULTANTS	West Perth, WA	Process design and construction	Spodumene beneficiation. EPC for LiOH plant.

Cell Manufacture

Definition: assembly of precursor materials into cells.

The energy density, be it gravimetric or volumetric, is defined as the specific capacity multiplied by the voltage difference divided by the mass or volume of the cell. As such, researchers and companies alike are seeking to either develop cathodes with much higher specific capacity, i.e. the layered-layered NMC types of materials or extract more lithium from lithium cobalt oxide, or increase the potential difference of the cell by seeking cathode materials where the intercalation (de-intercalation) potentials are much higher, such as $LiNi_{0.5}Mn_{1.5O4}$ type materials. Figure 12 below, and Table 14 provide examples of some of the more common materials used as electrodes in lithium-ion batteries.

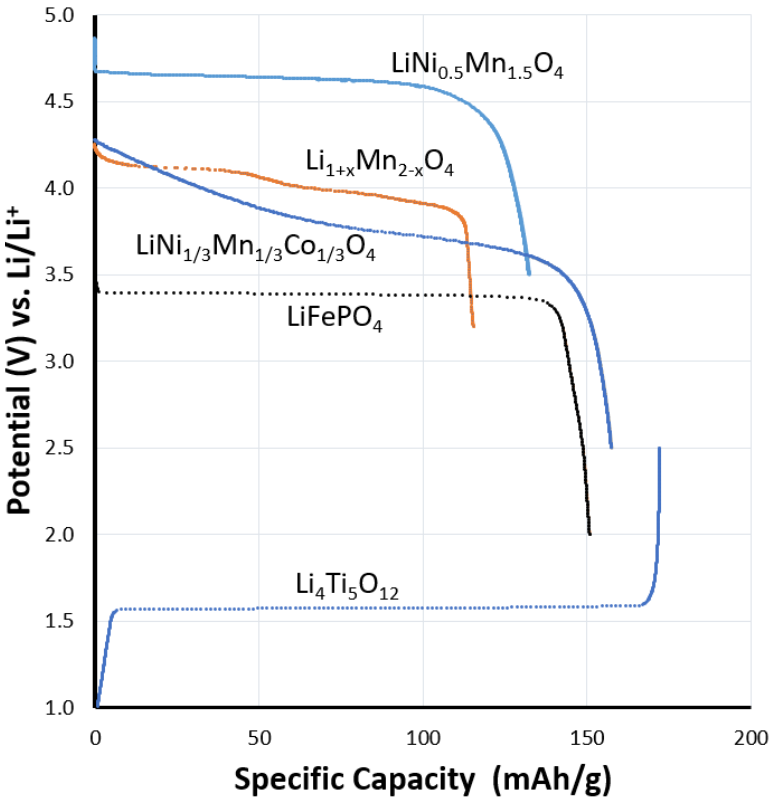


Figure 12 Potential versus capacity for a range of different cathode and anode materials used in lithium-ion batteries. Data courtesy of Marca Doeff, UC Berkley. Also see ref[92] and ref.[93]

There are five common types of lithium-ion cathodes and three common anode chemistries.

Of the active material chemistries described above, the two proposed Australian manufacturers of lithium batteries are discussing the use of traditional cathode materials such as NMC together with a graphite anode. There is no evidence that they are seeking to introduce new or radical battery electrodes at this time.

92 https://www.sigmaaldrich.com/technical-documents/articles/material-matters/electrode-materials-for-lithium-ion-batteries.html

93 Sullivan, J. L.; Gaines, L., Status of life cycle inventories for batteries. *Energy Conversion and Management* 2012, 58, 134-148

Table 14. Common lithium ion cell cathodes and anodes.

CHEMISTRY	ACRONYM	POTENTIAL (V) vs. Li/Li^+	COMMENTS
LITHIUM IRON PHOSPHATE	LFP	3.4	Notable for its lack of nickel, cobalt and manganese, LFP chemistries are common in the vehicle market in China, and for stationary storage worldwide. This chemistry suffers from lower specific energy (90–160Wh/kg) but is remarkably fault tolerant, except for moisture which radically shortens cell life.
LITHIUM NICKEL COBALT ALUMINIUM OXIDE	NCA	4.2	Specific energies of 200-260Wh/kg (and up to 300Wh/kg) are excellent but reliability under high discharge rates and low thermal runaway temperatures make this less desirable than NMC. The chemistry favoured by Panasonic/Tesla.
LITHIUM NICKEL MANGANESE COBALT	NMC	4.2 – 4.5	Currently the dominant lithium rechargeable battery technology due to high specific energy (150–220Wh/kg) and greater safety at temperature compared to LCO.
LITHIUM COBALT OXIDE	LCO	4.2 – 4.5	High specific energy (150–200Wh/kg) makes LCO a popular choice for small devices. The market share is being lost to NMC and NCA chemistries, not least because of the high cost of cobalt.
LITHIUM MANGANESE OXIDE	LMO	4.2	Specific energies in the 100–150Wh/kg range are not spectacular, but this chemistry is capable of delivering high discharge rates relatively safely. Most commonly used in power tools.
GRAPHITE	GRAPHITE	0.05	A common anode chemistry. Typically, spherical artificial graphite is used in the anode due to the ease of manufacture, however, this process is very environmentally unfriendly. Currently, there is a move towards natural graphite sources which are potentially cheaper and environmentally friendlier to produce.
SILICON	SI	0.5	Typically found as a composite with graphite due to the very similar intercalation potentials for Li into these structures. Si has a theoretical specific capacity close to that of Lithium metal, but suffers for poor cyclability due to the 400 % volume change on lithiation / delithiation. Currently, most batteries have between 4% and 7% Si in the anode in order to further boost anode capacity.
LITHIUM TITANATE	LTO	1.55	Lithium titanate is an alternative anode chemistry. It is well known for its high rate performance as it is a "zero strain material" as well as no solid electrolyte interphase (SEI) when in contact with an electrolyte.

There are considerable research activities in Australia around next generation battery electrode chemistries such as Lithium metal and devices that utilise this anode[94] such as Lithium-Sulfur[95] and Lithium-Air, Sodium[96] (ion) and to a limited degree, other chemistries around Potassium and Calcium. This work is being undertaken both at CSIRO and in the university sectors.

Australian companies

Imperium3 aims to be an integrated company from raw materials through to cell technology and batteries. "The Imperium3 Gigafactory will become the central anchor of a new-century innovation and manufacturing precinct in the Townsville region".

Energy Renaissance was established in 2015 and is now actively pursuing a range of activities with relation to cell manufacture as well as a range of different energy storage systems for various applications that utilise technology that has been licensed from Cadenza Innovation (USA).

Table 15. Australian companies pursuing cell manufacture.

COMPANY	LOCATION	CURRENT ACTIVITY	COMMENTS
ENERGY RENAISSANCE[97]	Sydney	Battery manufacture (Proposed)	Energy Renaissance (ER) are wholly owned Australian company that has licensed technology from Cadenza Innovation (USA). ER intends to assemble SuperCells (Cadenza technology) and use this as the building block to assemble physically robust battery systems designed for Australia, such as the SuperCubeTM.
IMPERIUM3[98]	Sydney	Battery manufacture (Proposed)	IM³ is aiming to be an integrated solution of lithium-ion battery manufacture – from raw material supply through to cell technology and batteries.
REDFLOW[99]	Brisbane	Battery manufacture (in Thailand)	Imports zinc-bromide flow batteries (including cells) made in its Thai factory. The batteries are designed to support applications ranging from telecommunications and renewables integration to on-grid and off grid remote power, microgrids and smart grids, and transmission and distribution deferral.
PMB-DEFENCE[100]	Osborne SA	Battery manufacture	Although a manufacturer of specialist lead acid batteries (including cells) for the Collins class submarine, "PMB has recently been awarded a contract to develop a Battery Demonstrator system for the UK Ministry of Defence (MoD) that will involve the design, build, integration and testing of Battery modules incorporating Nickel Zinc (NiZn) cells. PMB Battery Technologies UK is a subsidiary of PMB Defence and has been set-up to manufacture NiZn cells, battery modules and control systems for the UK MoD contract."

94 https://www.batteryinnovationhub.com.au/
95 https://ro.uow.edu.au/cgi/viewcontent.cgi?article=3305&context=aiimpapers
96 https://www.batteryinnovationhub.com.au/sodium-batteries
97 http://www.renaissanceone.com.au/
98 http://www.im3.com.au/
99 https://redflow.com/products/
100 https://www.pmbdefence.com.au/batteries/overview

Battery Manufacture

Definition: assembly of cells, or other batteries into units that are functional and fit for purpose in domestic, automotive, or industrial devices.

Australia has several companies whose business is the manufacture of replacement consumer battery packs from imported cells. Such examples are Battery World and Battery King. Both companies will construct a battery pack made to measure for a given application. This is part of their service offering alongside retailing a large range of new and aftermarket batteries and chargers. There is no significant value-add in these businesses[101] as construction of battery packs is used to facilitate the aftermarket sale of cells. Other companies are skilled in battery management systems, e.g. RedArc[102] and EVPower[103].

Separate to this, there are several companies that are importing larger format lithium-ion cells and then constructing battery packs for use as part of energy storage systems. Examples of these types of companies include Crystal Solar Energy, Toshiba International, Sonnen, Soluna Australia, Hybrid Systems Australia, Zenaji and Relectrify. Relectrify is an ambitious start-up looking to develop second life opportunities for EV lithium-ion batteries using an innovative Battery Management Solution (BMS). Energy Renaissance and Imperium3 are the only two proposed manufacturers of both lithium-ion cells and energy storage systems, however, it is not yet clear when either of these two companies will formally launch products on the market.

In the lead-acid (Pb-acid) domain, there are several manufacturers including PMB Defence (provision of cells exclusively to the Royal Australian Navy), Battery Energy and Century Batteries. Ecoult (now owned by East Pen, USA) is the only ESS manufacturer using Pb-acid batteries, specifically the CSIRO developed UltraBattery™.

There are two proposed vanadium redox-flow battery companies, VSUN Energy, and a joint venture between Multicom and Freedom Energy. In both cases, cell manufacture has not yet commenced. Another alternative redox-flow battery chemistry is Zinc-Bromine. This technology has been championed by RedFlow who are making commercial sales of the technology. Gelion is a start-up in the same chemistry domain, however, rather than using electrolyte tanks as is the case of a traditional redox flow, Gelion uses a gelled electrolyte solution, making the footprint of the battery far smaller.

It is obvious that battery and management system manufacture are growing industries in Australia Table 16). It is however difficult to obtain data on the size of the internal market.

101 Personal communication, Battery World, Bentley WA.
102 https://www.redarc.com.au/battery-chargers/battery-management-systems
103 https://www.ev-power.com.au/

Table 16. Battery manufacturers in Australia (not not all companies are currently producing).

COMPANY	STATE	ACTIVITY	COMMENT
MAGELLAN POWER	WA	Manufacturer of battery pack systems using imported cells.	Manufactures battery packs for use in microgrids.
UON	WA	Manufacturer of battery pack systems using imported cells.	Manufactures battery packs for use in microgrids, particularly mining operations.
OCTILLION POWER SYSTEMS AUSTRALIA	Brisbane	Manufacturer of battery pack systems using imported cells.	A subsidiary of Octillion USA and SinoEV (China). Octillion (Aust) received a $6.3m investment from Southern Cross Renewable Energy Fund in 2015. Its ABN was cancelled December 2020 and it is not registered for GST. It is not clear whether the company is still in business in Australia.
GENZ	Malaga, WA	Importer of LFP battery packs.	Focusing on Lithium Iron Phosphate chemistry, GenZ appears to design battery packs "for Australian conditions" but these are manufactured overseas to order.
ENERGY RENAISSANCE	Sydney	Battery manufacture	Energy Renaissance (ER) are wholly owned Australian company that has licensed technology from Cadenza Innovation (USA). ER intends to assemble SuperCells (Cadenza technology) and use this as the building block to assemble physically robust battery systems designed for Australia, such as the SuperCubeTM.
IMPERIUM^3	Sydney	Battery manufacturer	IM^3 is aiming to be an integrated solution of lithium-ion battery manufacture – from raw material supply through to cell technology and batteries.
ECOULT	Sydney	Selling Renewable Energy solutions based on UltraBatteryTM	Ecoult is a spin-off from CSIRO which integrates our wind energy mapping solution together with the UltraBatteryTM which is a hybrid Pb-acid solution. Ecoult is now owned by East Penn.[104]
SOLUNA AUSTRALIA	Perth	Selling Energy Storage Units	Soluna represent a collaboration between Lithium Australia NL and DLG Battery China. They are part of the wider Lithium Australia NL family that includes VSPC and Envirostream (battery recycling). It is intended that LFP from VSPC will be integrated into batteries that will be eventually sold by Soluna.
CRYSTAL SOLAR ENERGY[105]	Melbourne	Energy Storage Systems	Building battery packs based on lithium-ion cells sourced from third parties.
TOSHIBA INTERNATIONAL CORPORATION LTD. OCEANIA	Sydney	Energy Storage Systems	Joint venture between Toshiba and Mitsubishi Heavy Industries. All components are imported from Japan and assembled in Australia. Market: Energy Storage Systems and other industrial applications
SONNEN	Adelaide	Manufacturing energy storage systems	Sonnen Batteries are assembled at the former Holden site at Elizabeth, SA. These are supplied in the Australia and New Zealand market. Sonnen was acquired by Shell New Energies in February 2019.
RELECTRIFY	Melbourne	Start-up - Developer and manufacturer of a BMS for second life of Li-ion batteries	Relectrify has developed a battery management system that allows end of life electric vehicle batteries to be used in residential energy storage.

104 https://www.eastpennmanufacturing.com/
105 Verbal Communication, Howard Lovatt, CSIRO Manufacturing, 19/03/2020

COMPANY	STATE	ACTIVITY	COMMENT
ZENAJI	Melbourne	Developer of home energy storage system	Claim to manufacture and distribute the Aeon Battery that is based on Lithium Titanium Oxide (LTO) anode; Cells appear to be manufactured in China.
BATTERY ENERGY	Sydney	Manufacturing and selling Pb-Acid Batteries	Development of GEL based Pb-acid batteries that are delivered to a range of different applications both in Australia and overseas
PMB DEFENCE	Adelaide	Manufacturing Pb-Acid Batteries	Manufacturing the Pb-acid batteries and delivering engineering solutions for the Collins Class Submarine of the Australian Navy. Performing research for the UK MoD, in the UK, on NiZn battery technology.
CENTURY BATTERIES	Brisbane	Manufacturing Pb-Acid Batteries	Manufacturing Pb-acid batteries for Starting, Lighting, and Ignition (SLI) applications, specifically for automotive, heavy vehicle and marine industries.
REDFLOW	Brisbane	Manufacturing and installing Flow Batteries for Energy Storage Applications	Manufacturing Zinc-Bromine flow batteries. Redflow batteries are designed for high cycle-rate, long time-base stationary energy storage applications in the residential, commercial and industrial and telecommunications sectors, and are scalable from a single battery installation through to grid-scale deployments
VSUN ENERGY	Perth	Proposed manufacturer of Vanadium flow batteries	VSUN Energy was launched by AVL in 2016 to grow the vanadium redox flow battery market in Australia and currently offers batteries from a range of manufacturers. AVL is planning to construct a commercial vanadium electrolyte plant to supply VSUN Energy's electrolyte demand.
MULTICOM RESOURCES AND FREEDOM ENERGY	Brisbane	Proposed manufacturer of Vanadium flow batteries	Multicom will provide the vanadium to StorEn Technologies, and a joint venture entity will produce VRFBs. Freedom Energy will sell and distribute the proprietary StorEn VRFB's in the Asia Pacific region. Downer Engineering have commenced concept level studies for manufacturing in Townsville.
GELION	Sydney	Start-up manufacturer of Gel-based Zn-Br battery	Gelion, a spin-off company from the University of Sydney, is developing gel-based zinc-bromine batteries – similar to the Redflow battery technology *without the need for liquid tanks.* They are designed for use in residential and commercial applications.
PRINTED ENERGY LTD.	Brisbane	Start-up manufacturer of flexible solid state batteries	The company was "established to develop breakthrough manufacturing techniques for printing batteries and photovoltaics."

EV charging infrastructure in Australia

Examination of commercial offerings indicates that there are at least 600 charging stations accessible to the public across Australia and perhaps as many less formal arrangements involving motorist-supplied cables and discretionary access to various power supplies. See map at https://www.plugshare.com/ Table 17 summarises the major operators.

Table 17. EV charging operators in Australia.

COMPANY NAME	OVERVIEW
CHARGESTAR[106]	Charging stations across Australia.
ELECTRIC VEHICLES AUSTRALIA[107]	Rapid charging systems for BEVs. East coast only.
EVSE	Australia's #1 Supplier and Installer of Universal Electric Vehicle Chargers
CHARGEFOX	"We're Australia's largest and fastest growing EV charging network, we're Australian owned and operated, and we're committed to making charging simple, affordable and fast for all Aussies because simpler charging means more EVs on the road, and that's a very good thing."
EVIE NETWORKS[108]	"Building Australia's Largest Ultra-Fast Charging Network". ARENA has committed $15m to help build the network, and St Baker Energy Innovation Fund has committed $28m. 42 charging stations planned, 16 installed to date.
TRITIUM	Designer and manufacturer of Veefil-RT - the world's smallest DC fast charger for electric vehicles.
EVERTY	Everty allows companies to easily manage, monitor and monetize Electric Vehicle charging stations. But this isn't about infrastructure. Instead, they link up workplaces and accounting systems to the EV charging network, thus making it more like a "Salesforce™ for EV charging." It's available for both commercial and home charging tracking. It's also raised funding through an Angel investor round and is poised to raise further funding.
JETCHARGE	Australian EV Charge Station company that retails charging systems as well as designing some of the backend infrastructure.
BETTER PLACE (AUSTRALIA) PTY LTD	A planned roll-out of 500 charging stations on the east coast of Australia was halted after 16 installations. Worldwide, the company seems to have become bankrupt and was liquidated in 2013.

106 https://www.chargestar.com.au/charging-station-list/
107 https://www.ev-australia.com.au/
108 https://goevie.com.au/

Large Scale Energy Storage Installations

Large Scale Energy Storage Systems or Battery Energy Storage Systems (BESS) are progressively being installed around Australia to manage a range of challenges for business and the grid. Table 18 outlines a range of energy storage solutions that has been open sourced from Australian Renewable Energy Agency (ARENA) website and also from the US Department of Energy (US DoE) via the Energy Storage Systems Program website and database managed by Sandia National Laboratory[109]. The database lists over 1600 energy storage projects worldwide that have been triaged by the authors to highlight the Australian battery-based projects. Where possible, we have cross-referenced these with related communications to ensure that the details provided are correct. A further useful resource is the Australian Energy Storage Alliance[110] whose goal is in part to *"engage with stakeholders and investors for deployment of safe and effective energy storage solutions, enabling increased integration of renewable energy at grid and off-grid level."*

At present, there is 215 MW of large-scale battery storage capacity registered in the National Energy Market (NEM)[111], with this to become 313MW with the expansion of the Hornsdale Power Reserve and a new battery system in NSW[112]. However, this is dwarfed by the scale of pumped hydro energy storage (PHES) of 700 MW that will be expanded to 2,800 MW with the addition of Snowy 2.0 in 2025[113]. The Australian Energy Market Operator (AEMO) undertakes forecasting for the grid and has prepared a forecast plan to 2042 that sets out a scenario for storage technologies to be connected to the NEM. Of note is the very small penetration of large-scale battery technologies, such as the Hornsdale Power Reserve (SA), in the forthcoming years. There will be continuous growth in Behind the Meter batteries that are connected to PV and typically installed in commercial buildings and households[114] – over the period of 2024 through to 2042 under the scenario presented here. However, half of all stored energy by 2042 is forecast to be provided by Pumped Hydro. Under this scenario, there is a significant challenge to continue to build and install BESS to the NEM, however, batteries have a significant advance over PHES, as ably demonstrated by the Hornsdale Power Reserve, for the dispatchability of power to the grid and the low construction time. This will become even more important as coal-fired power stations begin to exit the network around 2030, building the case for the deployment of large scale BESS to grid.[115]

An interesting observation from Figure 13 is the projected growth of Behind the Meter energy storage systems commonly used by households and business; this may present an opportunity for Australian battery manufacturing companies to take advantage of.

109 https://www.sandia.gov/ess-ssl/global-energy-storage-database-home/
110 https/energystoragealliance.com.au/
111 https://aemo.com.au/energy-systems/electricity/national-electricity-market-nem/participate-in-the-market/registration
112 https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/generation_information/kci-datafile-compiled-nem20200430.xlsx?la=en
113 https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp
114 https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_BTM_Batteries_2019.pdf
115 Personal Communication, Dr. Steven Percy, Victoria University, Victoria Energy Policy Centre Victoria University, 2020.

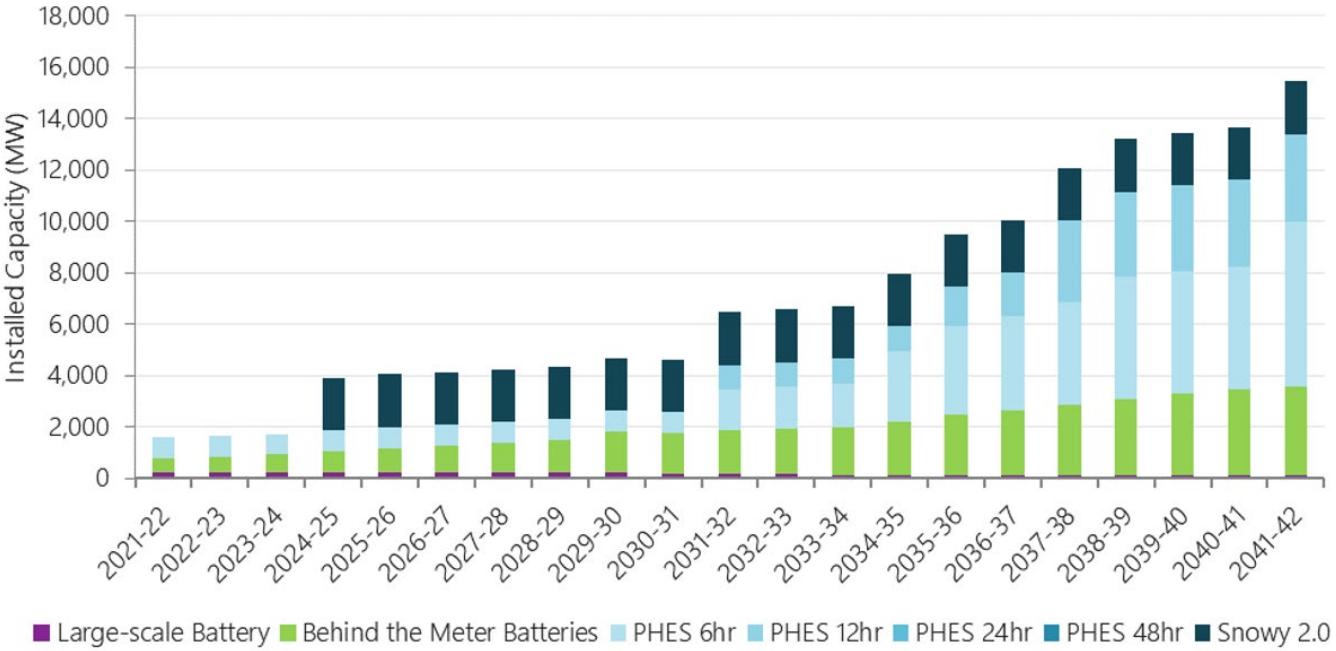


Figure 13. Forecast for Installed Storage Capacity (MW) for a range of technologies to be connected to the NEM through to 2042. (Australian Energy Market Operator, Integrated System Plan[116]).

Of note in Table 18 is the penetration of Australian technologies in many of the projects. Whilst Lithium-ion batteries dominate, especially where stored energy is > 1 MW, we note that in the range from 10 kW to 1 MW, there are significant use of Zinc-Bromine batteries developed by Redflow, and the use of the CSIRO developed UltraBattery™ by Ecoult. The success of energy storage on the grid and specifically the use of Lithium-ion batteries is highlighted by Hornsdale Power Reserve and it's 100 MW Tesla battery which captured the public's attention at the time[117]. The project has been so successful, that Hornsdale is currently being expanded to meet demand. With funding support from ARENA and state and federal governments, Australia is a world leader in the implementation of batteries on the grid.

116 https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp
117 https://www.smh.com.au/business/mike-cannonbrookes-concedes-battery-bet-with-elon-musk-20171124-gzsj25.html

Table 18. Australian battery-based energy storage projects.

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Registered National Energy Market									
Lake Bonney Battery Energy Storage System 25 MW / 52 MWh – Infigen Energy [118]	Li-ion	Operational	25000	2.01	Renewables Capacity, Peak Demand, Frequency Controlled Ancillary Services	South Australia	Mar 2019		Tesla
Gannawarra Energy Storage System – 25MW / 50 MWh	Li-ion	Operational	25000	2	Renewables Capacity, Peak Demand, Frequency Controlled Ancillary Services	Victoria	Mar 2019		Tesla
Ballarat Energy Storage System – 30 MW / 30 MWh[119]	Li-ion	Operational	30000	1	Frequency control ancillary services, Peak Demand	Victoria	Nov 2018		LG Chem
Hornsdale Power Reserve 100MW / 129MWh [120] Expansion 50 MW / 64.5 MWh[121]	Li-ion	Operational Announced	100000 (50000)	1.28 1.28	Frequency Regulation, Renewables Capacity Firming, Renewables Energy Time Shift	South Australia	Dec 2019		Tesla
Dalrymple 30 MW / 8 MWh battery (ESCRI) [122]	Li-ion	Operational	30000	0.27	Frequency Regulation, Resiliency, Voltage Support, Renewables Generation	South Australia	Sep 2018		Samsung
Total (MW)			210 (260)						

118 https://arena.gov.au/projects/lake-bonney-battery-energy-storage-system/
119 https://arena.gov.au/projects/ballarat-energy-storage-system/
120 https://hornsdalepowerreserve.com.au/
121 https://arena.gov.au/projects/hornsdale-power-reserve-upgrade/
122 https://arena.gov.au/projects/energy-storage-for-commercial-renewable-integration-escri-phase-2/

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Behind the Meter Battery Systems									
TransGrid City of Sydney's Alexandra Canal Works Depot	Li-ion	Announced	250	2	Demand Response	NSW			Tesla
Nauly Community Solar + Storage	Li-ion	Operational	2000	0.5	Electric Energy Time Shift, Electric Supply Capacity, Microgrid Capability, On-Site Power, Onsite Renewable Generation Shifting, Renewables Energy Time Shift	NT			
Domino's Pizza 135kW / 135kWh Tesla Powerwall	Li-ion	Operational	135	1	Electric Supply Capacity, On-Site Power	NSW			Tesla
Cape York Solar Storage 20MW / 80MWh - Lyon Group	Li-ion	Operational	20000	4	Renewables Capacity Firming, Renewables Energy Time Shift, Resiliency	Qld			AES
Lakeland Solar and Storage - Lyon Group	Li-ion	Operational	20000	1	Microgrid Capability, Renewables Capacity Firming, Renewables Energy Time Shift, Resiliency	Qld			
Kingfisher Project (Stage 2)	Li-ion	Announced	100000	4	Renewables Capacity Firming, Renewables Energy Time Shift	SA	Jan 2017		AES Energy Storage
Kingfisher Project (Stage 1)	Li-ion	Operational	2000	1	Renewables Capacity Firming, Renewables Energy Time Shift	SA	Jan 2017		AES Energy Storage
Western Power	Electro-chemical	Announced	10	5	Microgrid Capability	WA			
Garden Island Microgrid Project	Electro-chemical	Operational			Electric Bill Management, Electric Bill Management with Renewables, Electric Energy Time Shift, Microgrid Capability, Renewables Capacity Firming, Renewables Energy Time Shift, Resiliency	WA			

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
CSIRO Murchison Radio-astronomy Observatory (MRO) - EMC	Li-ion	Operational	1000	2.5	Electric Energy Time Shift, Microgrid Capability, Onsite Renewable Generation Shifting, Renewables Capacity Firming, Renewables Energy Time Shift, Resiliency	WA			Energy Made Clean (EMC)
Flinders Island - Hydro Tasmania – 750 kW / 266 kWh	Electro-chemical	Operational	750	0.330	Microgrid Capability, On-Site Power, Onsite Renewable Generation Shifting, Renewables Capacity Firming, Resiliency	Tas.	Oct 2018		Toshiba
Cape Barren Island Hybrid System	Electro-chemical	Operational	163	1	Onsite Renewable Generation Shifting, Renewables Capacity Firming	Tas.			
Bundaberg Christian College	Pb-acid	Operational	25	10	Electric Bill Management, Electric Bill Management with Renewables, Onsite Renewable Generation Shifting, Renewables Capacity Firming, Renewables Energy Time Shift	Qld	Dec 2015		HID Australia
Off-Grid Installation in Regional Queensland, Australia	Electro-chemical	Operational	5	10	Electric Bill Management, Electric Bill Management with Renewables, Electric Supply Capacity, Microgrid Capability, Onsite Renewable Generation Shifting, Renewables Energy Time Shift, Voltage Support,	Qld	Nov 2014		Exide/ Sonnenschein
Remote Off-Grid Container - Regional Queensland	Electro-chemical	Operational	2	10	Microgrid Capability, On-Site Power, Resiliency	Qld			Aquion Energy

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Busselton Farm Property - Gildemeister / VSUN Energy	V Flow	Operational	10	10	Demand Response, Electric Energy Time Shift, Grid-Connected Commercial (Reliability and Quality), On-Site Power, Onsite Renewable Generation Shifting, Renewables Energy Time Shift	WA			Gildemeister CellCube (DMG Mori)
Pilbara Meta Maya Regional Aboriginal Corporation - EMC	Electro-chemical	Operational	40	1.6	Microgrid Capability, On-Site Power, Onsite Renewable Generation Shifting, Renewables Energy Time Shift, Resiliency	WA			Energy Made Clean (EMC)
Moora Moora: Residential Storage: 100% Off-grid Community	Hybrid Pb-acid	Operational	20	1	Electric Energy Time Shift, Electric Supply Reserve Capacity - Non-Spinning, Load Following (Tertiary Balancing), Microgrid Capability, On-Site Power, Onsite Renewable Generation Shifting, Renewables Capacity Firming	Vic.			Ecoult
Cedarvale: Small Commercial Storage: Health Retreat, Kangaroo Valley	Hybrid Pb-acid	Operational	20	1	Electric Energy Time Shift, Electric Supply Reserve Capacity - Non-Spinning, Load Following (Tertiary Balancing), Microgrid Capability, On-Site Power, Onsite Renewable Generation Shifting, Renewables Capacity Firming, Voltage Support	NSW			Ecoult
LJW Solar: Small Commercial Storage: Peak Shaving And Solar Self-Consumption	Hybrid Pb-acid	Operational	20	1	Electric Bill Management with Renewables, Electric Energy Time Shift, Grid-Connected Commercial (Reliability and Quality), Onsite Renewable Generation Shifting	NSW			Ecoult

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Small Commercial Storage: Remote Telecomunications Base Station	Hybrid Pb-acid	Operational	20	1	Electric Energy Time Shift, Electric Supply Reserve Capacity - Non-Spinning, Load Following (Tertiary Balancing), Microgrid Capability	NSW			Ecoult
Newcastle Sportsground No 2 - Elmofo / Kokam	Li-ion	Operational	10	1	Electric Bill Management, Electric Bill Management with Renewables, Onsite Renewable Generation Shifting, Renewables Energy Time Shift	NSW			Kokam
RedFlow ³00 kW Adelaide	Zn Br Flow	Operational	300	2.2	Electric Bill Management, Electric Supply Reserve Capacity - Spinning, Microgrid Capability, On-Site Power, Onsite Renewable Generation Shifting, Renewables Capacity Firming	SA	Jun 2015		Redflow
Kind Island Renewable Energy Expansion VRB	V Flow	Offline/ Under Repair	200	4	Onsite Renewable Generation Shifting, Renewables Capacity Firming	Tas.			Sumitomo Electric Industries, Ltd.
UTS (University of Technology) Sydney	Zn Br Flow	Operational	25	2	Renewables Capacity Firming	NSW			ZBB Energy Corporation
Global Change Institute M120	Zn Br Flow	Operational	120	2.5	Onsite Renewable Generation Shifting, Load Following (Tertiary Balancing), Renewables Energy Time Shift	Qld	Jul 2013		
CSIRO, ZBB Experimental Zinc-Bromide Flow Battery	Zn Br Flow	De-Commissioned	100	5	Electric Bill Management, Renewables Energy Time Shift	NSW	Jul 2007	Jan 2012	ZBB Energy Corporation
University of Queensland - Redflow M90	Zn Br Flow	De-Commissioned	90	2	Renewables Capacity Firming, Renewables Energy Time Shift	Qld	Jun 2012	Jul 2014	RedFlow
Ausgrid Smart Grid Smart City (SGSC) Project - RedFlow	Zn Br Flow	De-Commissioned	200	2	Grid-Connected Residential (Reliability), Renewables Energy Time Shift, Stationary Transmission/ Distribution Upgrade Deferral	NSW	Nov 2011	Aug 2013	RedFlow

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Ausgrid Smart Grid Smart City (Scone Project) - RedFlow	Zn Br Flow	De-Commissioned	100	2	Grid-Connected Residential (Reliability), Renewables Energy Time Shift, Stationary Transmission/ Distribution Upgrade Deferral	NSW	Feb 2012	Aug 2013	RedFlow
King Island Renewable Energy Integration Project (UltraBattery)	Hybrid Pb-acid	Operational	3000	0.53	Electric Supply Reserve Capacity - Spinning, Onsite Renewable Generation Shifting, Renewables Capacity Firming	Tas.	Mar 2013		Ecoult
The Cork Trust Medical Centre Dorrigo	Pb-acid	Operational	60	1.33	Demand Response, Electric Energy Time Shift, Grid-Connected Residential (Reliability), Microgrid Capability, On-Site Power, Onsite Renewable Generation Shifting, Renewables Energy Time Shift, Resiliency	NSW			Sacred Sun
Stored Energy Integration Facility (SEIF)	Pb-acid	Operational	150	4.5	Demand Response, Electric Bill Management, Electric Bill Management with Renewables, Electric Energy Time Shift, Grid-Connected Commercial (Reliability and Quality), Load Following (Tertiary Balancing), On-Site Power, Onsite Renewable Generation Shifting, Ramping, Renewables Energy Time Shift, Voltage Support	NSW			
BAI Broadcast Tower, Muswellbrook, Australia	Valve Regulated Pb-acid	Operational	14	15.67	Electric Bill Management with Renewables, Electric Supply Capacity, On-Site Power, Onsite Renewable Generation Shifting, Resiliency	NSW	Oct 2014		BAE Batterien, Photon Energy

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Hampton Wind Park	Hybrid Pb-acid	De-Commissioned	1000	0.5	Ramping, Voltage Support	NSW	Feb 2010	Jun 2014	Ecoult
Tallangatta Integrated Community Centre	Li-ion	Operational	16	1	Resiliency	Vic.			
Ergon	Li-ion	Contracted	1000	2	Electric Bill Management, Electric Bill Management with Renewables, On-Site Power, Resiliency	Qld			
Newtown Housing	Li-ion	Operational	30	2	Electric Bill Management with Renewables	NSW			Tesla
Vector Alice Springs Energy Storage Project[123]	Li-ion	Announced	5000	0.67	Demand Response, Electric Energy Time Shift, Electric Supply Reserve Capacity - Spinning, Frequency Regulation, Grid-Connected Commercial (Reliability andQuality), Grid-Connected Residential (Reliability), Load Following (Tertiary Balancing), Onsite Renewable Generation Shifting, Ramping, Renewables Capacity Firming, Renewables Energy Time Shift, Resiliency	NT			LG Chem
AGL 5MW / 7MWh; Virtual Power Plant [124]	Li-ion	Announced	5000	1.4	Electric Bill Management with Renewables	N/A	2016		Sunverge Energy
Kennedy Energy Park - Windlab / Eurus	Li-ion	Operational	2000	2	Electric Energy Time Shift, Renewables Capacity Firming, Renewables Energy Time Shift	Qld	Jan 2017		

123 https://reneweconomy.com.au/vectorlg-chem-win-5mw-battery-storage-tender-for-alice-springs-12134/
124 https://www.agl.com.au/about-agl/media-centre/asx-and-media-releases/2016/august/agl-launches-world-largest-solar-virtual-power-plant

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Lakeland Solar and Storage Project - Conergy	Li-ion	Operational	1400	3.78	Electric Energy Time Shift, Grid-Connected Commercial (Reliability andQuality), Microgrid Capability, Renewables Capacity Firming, Renewables Energy Time Shift	Qld	Sep 2016		Autarsys GmbH
Nauiyu (Daly River) Solar Project- 2MWh[125]	Li-ion	Operational	800	2.5	Black Start, Microgrid Capability, Onsite Renewable Generation Shifting	NT	May 2016		Qinous GmbH; Samsung
DeGrussa Copper Mine - juwi AG	Li-ion	Operational	6000	0.33	Electric Bill Management with Renewables, Electric Energy Time Shift, Electric Supply Reserve Capacity - Spinning, Frequency Regulation, Microgrid Capability, On-Site Power, Onsite Renewable Generation Shifting, Ramping, Renewables Capacity Firming, Renewables Energy Time Shift, Resiliency	WA	Jul 2015		
Synergy / EMC Alkimos Beach Community Battery Trial	Li-ion	Operational	500	2.2	Distribution upgrade due to solar, Electric Bill Management, Electric Bill Management with Renewables, Electric Energy Time Shift, Grid-Connected Residential (Reliability)	WA			Energy Made Clean (EMC)

125 https://www.solarquotes.com.au/blog/solar-storage-daly-river-mb0164/

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Thomastown Network 1 MW Li-ion Trial - AusNet Services[126]	Li-ion	Operational	1000	1	Electric Energy Time Shift, Grid-Connected Commercial (Reliability and; Quality), Microgrid Capability, Stationary Transmission/ Distribution Upgrade Deferral, Voltage Support	Vic.	Dec 2014		Samsung SDI
ZECO Energy	Li-ion	Operational	33	1.25	Electric Supply Capacity, Microgrid Capability,	Vic.			BYD
Powercor 2 MW Grid Scale Energy Storage - Kokam	Li-ion	Operational	2000	1	Electric Energy Time Shift, Electric Supply Capacity, Electric Supply Reserve Capacity - Non-Spinning, Frequency Regulation, Resiliency, Stationary Transmission/ Distribution Upgrade Deferral, Transmission Congestion Relief, Transmission Support, Voltage Support	Vic.			Kokam
University of Queensland Gatton Campus PV Pilot Plant	Li-ion	Operational	600	1.27	Electric Energy Time Shift, Onsite Renewable Generation Shifting, Renewables Energy Time Shift	Qld	Nov 2015		Kokam
Mackerel Islands (Thevenard Island) Solar Plus Storage	Li-ion	Operational	325	2	On-Site Power, Onsite Renewable Generation Shifting, Renewables Energy Time Shift	WA			Energy Made Clean (EMC)
Ausgrid SGSC - ZEN 60kW BESS	Li-ion	Operational	60	2	Electric Energy Time Shift, Distribution upgrade due to solar, Renewables Capacity Firming, Renewables Energy Time Shift	NSW	Oct 2013		Greensmith
TransGrid iDemand	Li-ion	Operational	100	4	Electric Energy Time Shift, Onsite Renewable Generation Shifting	NSW	Jun 2014		Kokam

126 https://www.energymatters.com.au/renewable-news/ausnet-battery-trial-em4635/

TITLE	TECH.	STATUS	RATED POWER KW	DURATION HRS	SERVICE / USE CASES	STATE	CONSTRUCTED	CLOSED	BATTERY MANUFACTURER
Magellan GPSS - SWR	Li-ion	Operational	25	4	Black Start, Load Following (Tertiary Balancing), Renewables Energy Time Shift, Voltage Support	Qld			Magellan Power
The Smart Sodium Storage Solution (S4) Project	Na-based	Announced	30	1	Renewables Energy Time Shift, Resiliency	NSW	Mar 2019		
Monash University RedT 300kW / 1MWh Hybrid System	V Flow	Announced	300	3.33	Microgrid Capability, Renewables Capacity Firming	Vic.			
30 kW / 130 kWh - University of New South Wales - Gildemeister CellCube	V Flow	Operational	30	4.33	Electric Bill Management, Electric Bill Management with Renewables, Electric Energy Time Shift, Microgrid Capability, Renewables Energy Time Shift, Resiliency	NSW			GILDEMEISTER energy storage GmbH
100 kW / 480 kWh - Ergon Energy - RedFlow	Zn Br Flow	Contracted	100	4.8	Electric Energy Time Shift, Renewables Capacity Firming	Qld	Jan 2016		RedFlow
Alinta Fortescue Solar Gas Hybrid Project – 35 MW / 11 MWh battery[127, 128]		Announced			Emission reduction, renewable energy capacity, hybrid energy solution	WA			

127 https://www.alintaenergy.com.au/vic/about-alinta-energy/power-generation/chichester-project/
128 https://arena.gov.au/projects/alinta-fortescue-solar-gas-hybrid-project/

Battery Recycling

The most up to date analysis of lithium ion battery recycling in Australia is detailed in "Lithium Battery Recycling in Australia"[129] by CSIRO. Paraphrasing, the report's key findings were:

The recycling collection rate for Li-ion batteries is only 2%. There are a variety of reasons for this but the low volume does not inspire confidence in industry investment to recycle.	Lack of an appropriate product stewardship program and lack of consumer education are likely to be responsible for 98% of Li-ion batteries being disposed of in landfill.
Best practice guidelines have not been formulated for the recycling industry. There is no reliable economic or lifecycle modelling to guide the industry.	The cost of collection for recycling imposes a barrier. Appropriate recycling technology is required (perhaps distributed and small scale) to meet Australian challenges. Or does Australia become a regional recycling hub?
Standards surrounding labelling, safety, transport, discharge and processing are required.	An Australian Li-ion battery recycling industry is economically and environmentally achievable.

The report's finding that a recycling industry is economically viable is based on the value, if all batteries are recycled, of the contained materials, and does not necessarily account for the cost of collection and processing. This aspect requires further modelling. The report highlights the low level of collection for recycling, the relative lack of coordination in the industry, and the requirement for legislative and product stewardship initiatives accompanied by consumer education.

In *Hazardous Waste in Australia 2017*[130], waste lithium-ion batteries are projected to increase at an average growth rate of 12% per year in Australia. Recommendation 2 of the *Hazardous waste infrastructure needs and capacity assessment*[131] states: "The potential hazards posed by lithium-ion batteries, and the best means of managing these hazards, needs further assessment. Following the assessment of hazard, assessment of the collection and processing infrastructure needs for lithium-ion batteries in Australia should be completed."

The Australian Battery Recycling Initiative[132] (ABRI) is not-for-profit association established in 2008 to promote the responsible environmental management of batteries at the end of life. ABRI envisages a circular economy for batteries that goes beyond "simple" recycling in that batteries may have a second and subsequent life through refurbishment (Figure 14). However, when we look at battery chemistries there are a wide variety of challenges with respect to recycling, both technological and societal. In the latter case, it is well known and understood that used Pb-Acid batteries are required to be returned for recycling and that disposal to landfill or by other methods is completely inappropriate. For this reason, it is estimated that in Australia, 96% of used Pb-acid batteries are recycled. In the case of lithium-ion batteries, societally, there is a lack of understanding and recognition of the need to recycle lithium-ion batteries. This has also been a policy failing in that governments have not mandated the need, but also a technological challenge in that there is a range of different lithium-ion chemistries in the market making recycling difficult. The lack of appreciation for the inherent value of the materials in a spent lithium ion battery and the environmental damage that these batteries can cause if incorrectly disposed of has meant that recycling rates are as low as 2-3% in Australia.

129 https://www.csiro.au/~/media/EF/Files/Lithium-battery-recycling-in-Australia PDF?la=en&hash=924B789725A3B3319BB40FDA20F416EB2FA4F320
130 https://www.environment.gov.au/system/files/resources/291b8289-29d8-4fc1-90ce-1f44e09913f7/files/hazardous-waste-australia-2017.pdf
131 http://www.environment.gov.au/system/files/resources/8d295260-d9af-46c6-9a3a-824c2fedfb64/files/hazardous-waste-infrastructure-needs-capacity-assessment.pdf
132 https://batteryrecycling.org.au/about-abri/our-vision/

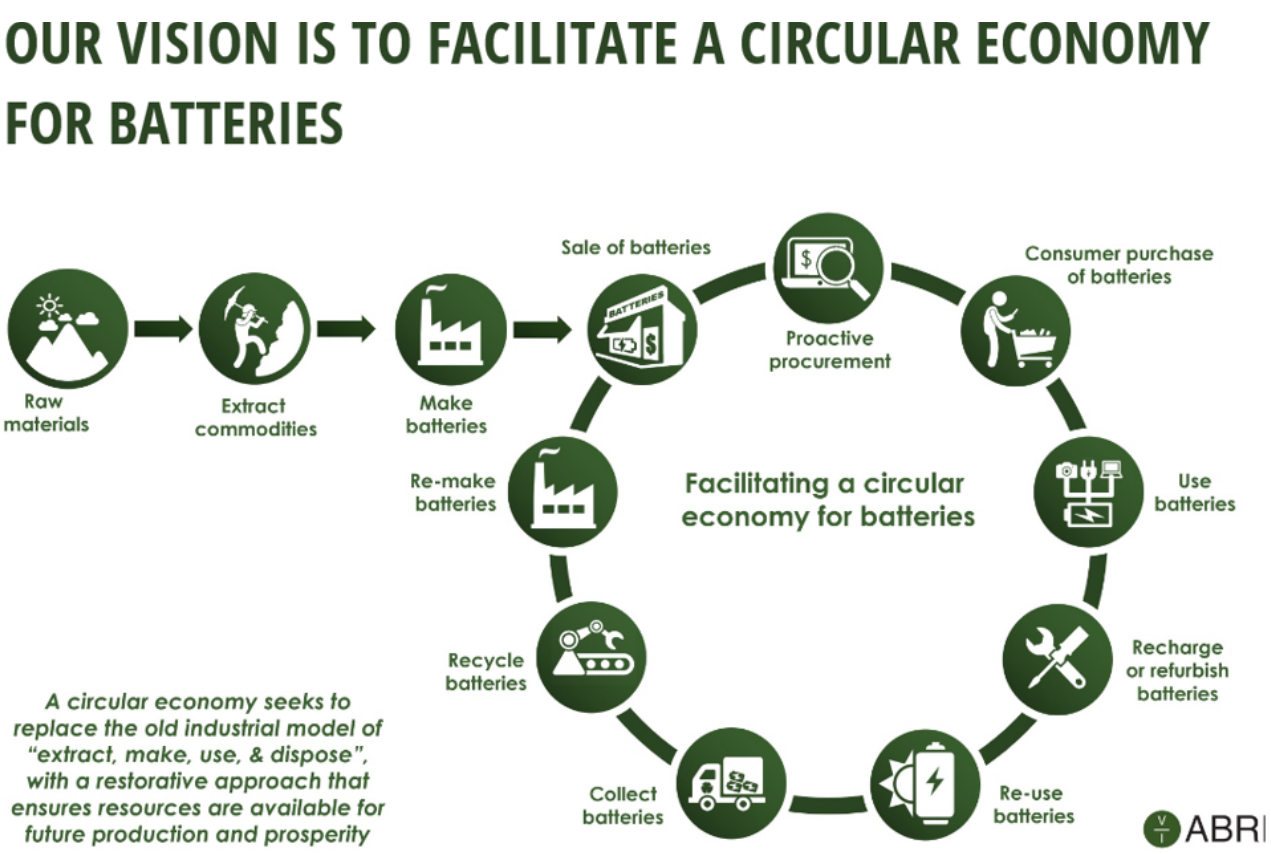


Figure 14. ABRI's circular economy vision for batteries in Australia.

ABRI released a 2019 report on the feasibility of regulatory options for battery stewardship[133], and this appears to be coming to fruition through the Battery Stewardship Council (BSC)[134] who have applied to the ACCC for authority to establish a voluntary, industry-led stewardship scheme. Importers will contribute to the scheme through a modest annual levy based on the weight of imports, equivalent to 4c per AA rechargeable or alkaline battery. The levy will be passed on to consumers in a visible way. Companies will receive a rebate from the scheme as a contribution to the costs of collection, sorting and processing ($2.40/kg for collection, $1.00/kg for sorting, $1.00/kg for processing). In this way, companies do not have to take back their own batteries, but recycling companies will receive additional income from battery recycling. Importantly, the list of battery importers, retailers and recyclers of all kinds participating in the proposed scheme is extensive, setting up a system for collection at retail outlets such as supermarkets, and incentive to perform sorting and processing.

The BSC is also seeking the inclusion of batteries into the Product Stewardship Act[135]. This will be an important step in Commonwealth legislation, making available a penalty for battery importers that do not comply with the BSC scheme, or do not establish their own. **By design therefore, there will be a significant increase in the volumes of consumer batteries available for recycling.**

In understanding the current state of battery recycling in Australia, the 2017 annual report by MRI e-cycle solutions makes for informative reading[136], and MRI has much in common with the other businesses listed in Table 19. Of the 7,320 tonnes of eWaste and battery waste it collected in Australia, 4,090 tonnes were recycled/recovered in Australia, chiefly being steel, aluminium, copper and glass. 3,047 tonnes containing general eWaste and batteries was exported for reprocessing overseas, presumably including anode and cathode materials. The data suggests a recycling rate of 97.5%.

133 https://bsc.org.au/wp-content/uploads/2019/05/04.-Preliminary-Feasibility-Assessment-of-Regulatory-Options-for-Battery-Stewardship-180308.pdf
134 https://bsc.org.au/
135 https://www.environment.gov.au/protection/waste-resource-recovery/product-stewardship/legislation/product-list-2020-21
136 http://mri.com.au/wp-content/uploads/2018/05/MRI-PSO-2016-7-Ann-Report-24Apr181.pdf

A different company, Envirostream, states that it recycles up to 3,000 tonnes of batteries a year at its Melbourne plant, recovering more than 95% of the mass. The main product is "mixed metal dust" that is exported[137] to a Korean recycler to extract nickel and cobalt[138].

Battery recycling in Australia is currently limited to disassembly and rendering into a feedstock for recovery of metals overseas.

Table 19. Australian involved in battery recycling activities.

COMPANY	BATTERIES THAT ARE RECYCLED
ENVIROSTREAM (LITHIUM AUSTRALIA NL)	Alkaline (primary), Pb-Acid; Button Cell; Lithium Batteries (primary); Li-ion Batteries (secondary); Ni-Cd; Flow Batteries; Nickel Metal Hydrides (Ni-MH); Sodium Nickel Chloride ($NaNiCl_2$); Aqueous Hybrid Batteries; Energy Storage Batteries; Mercury Batteries
ENIRGI POWER STORAGE RECYCLING	Alkaline (primary), Pb-Acid; Button Cell; Lithium Batteries (primary); Li-ion Batteries (secondary); Ni-Cd; other Mixed Batteries
ECOBATT	Alkaline (primary), Pb-Acid; Button Cell; Lithium Batteries (primary); Li-ion Batteries (secondary); Ni-Cd; Flow Batteries; Nickel Metal Hydrides (Ni-MH); Sodium Nickel Chloride ($NaNiCl_2$); Aqueous Hybrid Batteries; Energy Storage Batteries; Mercury Batteries
RJ BATTERIES	Used Pb-Acid; Lithium Batteries (primary); Li-ion Batteries (secondary)
NEOMETALS	Lithium batteries (Primary) *Pilot PlantTesting (Canada)*
LEX ENVIRO SERVICES	Used Pb-Acid Batteries
RAMCAR (SUPERCHARGE BATTERIES)	Used Pb-Acid; Lithium Batteries (primary); Li-ion Batteries (secondary)
MRI E-CYCLE SOLUTIONS	Alkaline (primary), Button Cell; Lithium Batteries (primary); Li-ion Batteries (secondary); Ni-Cd; Mixed Batteries
ECOCYCLE	Alkaline (primary), Pb-Acid; Button Cell; Lithium Batteries (primary); Li-ion Batteries (secondary); Ni-Cd; Flow Batteries; Nickel Metal Hydrides (Ni-MH); Sodium Nickel Chloride ($NaNiCl_2$); Aqueous Hybrid Batteries; Energy Storage Batteries; Mercury Batteries
GOLD COAST RESOURCE RECOVERY	Used Pb-Acid Batteries
GNB INDUSTRIAL POWER	Used Pb-Acid; Lithium Batteries (primary); Li-ion Batteries (secondary); Energy Storage Batteries
HYDROMET CORPORATION PTY LTD	Used Pb-Acid Batteries
RESource	Alkaline (Primary)
SUEZ	All battery types
INFOACTIV	Alkaline (primary), Pb-Acid; Button Cell; Lithium Batteries (primary); Li-ion Batteries (secondary); Ni-Cd; other Mixed Batteries
POWERCELL	Lithium Batteries (primary); Li-ion Batteries (secondary); Ni-Cd; Flow Batteries; Nickel Metal Hydrides (Ni-MH)
TOTAL GREEN RECYCLING (WA)	General e-waste, including batteries. Mechanical sorting, shredding and separation only
BATTERY RESCUE (WA)	Used Pb-Acid and LIB Batteries (safe collection)
MRI (VIC)	Collection and mechanical separation

Note: Primary refers to single-use batteries. Secondary refers to rechargeable batteries.

137 https://www.proactiveinvestors.com.au/companies/news/907804/lithium-australia-lifts-stake-in-australian-battery-recycler-envirostream-to-74-907804.html

138 One of the authors visited the recycler, SungEel Hitech, in 2016. At that time the company was only recovering Ni and Co, citing the low value of Li and Mn as a reason not to recover them.

Skills and Education

Nearly every aspect of the battery value chain has several explicit degrees that provide broad skills that will provide the ability to work in this domain (Table 20). However, there are no courses at either the graduate diploma or TAFE level that equip people to work within specific aspects of the battery industry, be it in cell manufacturing or battery-specific electrical skills. In order to support the opportunities that batteries will bring to advanced manufacturing, opportunities to develop courses that produce people with the requisite skills will ensure the faster development for companies to take advantage of opportunities in both the local and global supply chains.

The Authors note the establishment of the ARC funded Industrial Transformation Training Hub, StorEnergy, at Deakin University, but note the current opportunities being provided appear to be focused on PhD positions. This Hub would offer an excellent opportunity to provide graduate diploma courses in various aspects of battery minerals, materials and cells.

The technical skillset in Australia that is lacking is a general understanding of the difference between the mining and minerals commodity market and the battery chemicals market. Whereas Australia is well-skilled in the former, a general understanding and capability of quality/purity requirements does not yet exist.

Table 20. Skills and educational levels required for each activity along the battery value chain.

ACTIVITY	SKILLS REQUIRED	QUALIFICATION REQUIRED	OFFERED BY
Mining	**Geology**	**Degree**	**University**
Mineral Processing	Geological Engineer Chemical Engineer Mining Engineer Metallurgical Engineer Plant Operator	Grad Cert., Degree	University, TAFE
Precursor	Chemical Engineer Metallurgical Engineer Plant Operator	Grad Cert., Degree	University, TAFE
Battery Materials	Chemistry, Physics Materials Science, Chemical Engineering, Materials Engineering	Degree, MSc/MEng	University
Cell Manufacture	Materials Engineering Industrial Engineering Other Trade based certificate to run equipment	Grad Cert., Degree, MSc/MEng	University, TAFE
Battery Manufacture	Electrical Engineering Industrial Engineering Other Trade based certificate to assemble electrical devices	Grad Certificate, Degree	University, TAFE
Battery Installation	Electrician	Grad Certificate, Apprenticeship	University, TAFE
Battery Recycling	Materials Engineering, Chemistry, Chemical Engineering; Metallurgical Engineering, Other Trade based certificate to run equipment	Grad Cert., Degree	

Innovation Capability

Australia has significant capacity through the University system for innovative development of materials for batteries, devices, integration and application of these technologies. Table 21 has been compiled using Google searches and personal knowledge and does not purport to be a complete nor exhaustive list of researchers, research centres or research activity.

Table 21. Innovation capability in Australia.

UNIVERSITY	STATE	RESEARCH LEADER	FOCUS
JAMES COOK UNIVERSITY	Queensland	Rosalind Gummow	Lithium-ion Battery Cathodes
UNIVERSITY OF QUEENSLAND	Queensland	Prof. Lianzhou Wang	Nanomaterials Centre
QUEENSLAND UNIVERSITY OF TECHNOLOGY	Queensland	Prof. Peter Talbot	Lithium-ion batteries
UNIVERSITY OF NEW SOUTH WALES	New South Wales	Assoc. Prof. Neeraj Sharma Prof. Maria Skyllas-Kazacos Dr Chris Menictas	Li, Na, K batteries V redox Flow Batteries
UNIVERSITY OF SYDNEY	New South Wales	Prof. Thomas Maschmeyer	Zn – Br flow batteries Centre for Sustainable Energy Development
UNIVERSITY OF TECHNOLOGY SYDNEY (UTS)	New South Wales	Prof. Gouxiou Wang	Li, Na, K batteries
UNIVERSITY OF WOLLONGONG	New South Wales	Prof. S. X. Dou Prof. Zaiping Guo	Li, Na, K batteries
DEAKIN UNIVERSITY	Victoria	Prof. Maria Forsyth Prof Patrick Howlett Prof Ying (Ian) Chen	BatTRI Hub; Li, Na and other battery chemistries Alfred Deakin Professor in Nanotechnology
MONASH UNIVERSITY	Victoria	Prof. Doug MacFarlane	Mg, Li and Na batteries
SWINBURNE UNIVERSITY	Victoria	Dr. Peter Mahon Prof. Ajay Kapoor	Li batteries Integration of batteries in vehicles
UNIVERSITY OF MELBOURNE	Victoria	Prof. Amanda Ellis Dr Kathryn Mumford Prof Dan Li Dr Wen Li Prof Michael Brear	Li batteries (FBICRC) Battery chemical purification Materials Engineering Manufacturing Engineering Director Melbourne Energy Institute
RMIT	Victoria	Prof. Rachel Caruso	Battery materials
UNIVERSITY OF ADELAIDE	South Australia	Prof. Graham Nathan Prof. Shizhang Qiao Prof Nesimi Ertugrul	Battery recycling Centre for Materials in Energy and Catalysis Australian Energy Storage Facility and Knowledge Bank
UNIVERSITY OF SOUTH AUSTRALIA (UNISA)	South Australia	Dr Mohammed Haque	Power system modelling and simulations
MURDOCH UNIVERSITY	Western Australia	Prof. Aleks Nikoloski	Hydrometallurgy of mineral processing directed to purification.

UNIVERSITY	STATE	RESEARCH LEADER	FOCUS
UNIVERSITY OF WESTERN AUSTRALIA (UWA)	Western Australia	Prof Tyrone Fernando Prof Thomas Braunl Dr Jeffrey Wilson	Centre for Energy Microgrid Development and Design Battery Management Systems for Electric Vehicles Geopolitics of battery value chains
CURTIN UNIVERSITY	Western Australia	Prof. Jacques Eksteen Dr Mark Aylmore Prof Greg Morrison Prof Zongping Shao Prof Arie Van Riesen Dr Evan Jamieson	Battery Minerals beneficiation and battery chemical manufacture Battery mineral characterisation and processing Battery Industry Hubs Li-S, Li-S, Na-S batteries and solid state electrolytes Battery mineral and metal industry waste repurposing and recycling

It should also be noted that Australia has been awarded the right to host the 21st International Meeting on Lithium Batteries (IMLB) 26th June – 1st July 2022, which is the largest gathering of researchers and companies to discuss battery technology developments. This meeting will present a significant opportunity for Australia to showcase it's growing expertise in battery precursor and materials development together with other advances in battery chemistries, deployment and recycling.

ARC Funded Centres of Excellence, Training Centres and Research Hubs.

The Australian Research Council (ARC) offers numerous research funding programs for individual researchers (Discovery Program) as well as a range of Linkage programs including but not limited to Centres of Excellence[139] and Industrial Transformation Research Program[140]. Under the ITRP, there are two funding schemes Industrial Transformation Research Hubs and Industrial Transformation Training Centres. These Centres and Hubs bring together multiple research partners and industry to focus on critical research solutions.

We note there are funds for ARC Linkage Projects (between $50,000 and $300,000 per year for two to five years) and require cash and / or in-kind contributions from at least one Partner Organisation to the Project. Due to the volume of applications each year, these have not been triaged in this report (Table 22).

Table 22. Examples of ARC linkage projects related to batteries research.

CENTRE	LEAD GROUP	PARTNERS	START DATE	CURRENT FUNDING
ARC Centre of Excellence for Enabling Eco-Efficient Beneficiation of Minerals	University of Newcastle	University of Queensland, University of Melbourne, Deakin, University of South Australia, Curtin University, UNSW, CSIRO	2020	$35,000,000
ARC Research Hub for Microrecycling of battery and consumer wastes	UNSW	Nil	2019	$3,357,201
ARC Training Centre for Future Energy Storage Technologies	Deakin University	SupraG, DSTG, Calix, Boron Molecular, Cidetec, Melbourne University, Ionic Industries	2018	$4,482,627
ARC Training Centre in Lightweight Automotive Structures	RMIT	Deakin, ANU, CSIRO, Ford	2016	$3,150,003
ARC Research Hub for Integrated Energy Storage Solutions	UNSW	UTS, Deakin, DSTG	2018	$3,138,503
ARC Centre of Excellence for Electromaterials Science	University of Wollongong	Monash, Deakin, Swinburne, Melbourne, La Trobe, ANU	2014	$27,092,837
The ARC Research Training Centre for Naval Design and Manufacturing	University of Tasmania	University of Wollongong, Flinders University, Babock, DMTC, Thales Australia Ltd., PMB Defence, DSTG	2014	$2,503,299

139 https://www.arc.gov.au/grants/linkage-program/arc-centres-excellence
140 https://www.arc.gov.au/grants/linkage-program/industrial-transformation-research-program

National Infrastructure

A number of institutions in Australia offer distinctive battery research infrastructure for the nation (Table 23).

Table 23. Infrastructure for battery research in Australia.

ORGANISATION	STATE	CAPABILITY	LEAD RESEARCHER / MANAGER
DEAKIN UNIVERSITY	Victoria	Battery Fabrication and small-scale testing facilities BatTRI Hub	Prof. Maria Forsyth Prof. Patrick Howlett
UNIVERSITY OF WOLLONGONG	New South Wales	Institute for Superconducting and Electronic Materials	Prof. S X. Dou Prof Zaiping Guo
UNIVERSITY OF TECHNOLOGY SYDNEY	New South Wales	Centre for Clean Energy Technology	Prof. Guoxiu Wang
QUEENSLAND UNIVERSITY OF TECHNOLOGY	Queensland	Dry Room facility for the production of electrodes, pouch cells and 18650 cells. Ability to up-scale cathode materials in Banyo Facility	Prof. Peter Talbot Prof Jose Alarco Dr Joshua Watts
CSIRO	Victoria	Pre-Pilot electrode coating facility; pouch cells fabrication; battery testing and evaluation from coin cell to 180 kW batteries	Dr. Adam Best and Dr. Anand Bhatt
CSIRO	Western Australia	Minerals to battery metals pilot plant facilities including solvent extraction, ion exchange, and clean room facilities.	Dr. Keith Barnard Dr. Joanne Loh Dr. Chris Vernon
MURDOCH UNIVERSITY	Western Australia	Testing and evaluation of a wide range of renewable energy systems	
CURTIN UNIVERSITY	Western Australia	Cell testing, battery mineral and metal extraction and refining pilot equipment	Prof Jacques Eksteen Dr Mark Aylmore Prof Zongping Shao
DEFENCE SCIENCE AND TECHNOLOGY GROUP (DSTG)	Victoria	Battery testing and abuse facility	Dr. Michael Newman
ANSTO	News South Wales and Victoria	*In Operando* and other methods of battery materials characterisation using neutrons (Opal) and synchrotron sources	See ANSTO website.
ANSTO MINERALS	News South Wales	Mineral processing capability applied to extraction and purification of battery metals.	Dr Robert Gee Dr Chris Griffith

Cooperative Research Centre - Projects (CRC-P)[141]

The Australian Government, as an extension of Cooperative Research Centre (CRC) program, instituted the Cooperative Research Centre – Projects (CRC-P) in 2016. CRC-Ps are intended for specific short-term research collaborations. Project's must be industry led with 2 Australian industry organisations, one of which is a small to medium sized enterprise and at least one research institution. Grants are between $100,000 to $3,000,000 and up to three (3) years in duration.

In Round 7 and 8, funding was set aside specifically for "critical minerals" activity, including those directly related to batteries. In Round 8 of the CRC-Ps, 6 projects were supported to the tune of $11 million dollars[142] (Table 24).

Table 24. CRC-P activities related to battery research.

PROJECT NAME	CRC ROUND	INDUSTRY LEAD	RESEARCH PARTICIPANTS	DATES	TOTAL GRANT AMOUNT	TOTAL PROJECT VALUE
LieNA® – The Process Solution for Fine Spodumene	8	Lithium Australia NL	ANSTO, Murdoch University, Pioneer Resources Limited, VSPC, Ammtec Unit Trust, Curtin University, Carnac - Project Delivery Services Pty Ltd	Jan 2020 – Jan 2022	$1,255,504	$3,587,155
Novel processing of pyrite ore to produce battery grade cobalt and sulfur	8	Cobalt Blue Holdings Limited	University of NSW, ANSTO, Anergy Australia Pty Ltd	Jan 2020 – Jun 2022	$2,400,000	$11,057,683
Advanced Nano-engineered Battery for Fast Charging Catenary-free Trams	8	VSPC	The University of Queensland CSIRO, Soluna Australia Pty Ltd	Jul 2020 – Jun 2023	$1,641,000	$4,896,000
Production of 99.95% pure vanadium pentoxide and vanadium electrolytes	8	Australian Vanadium Limited	Ammtec Unit Trust, Amec Foster Wheeler Australia Pty Ltd, Curtin University, ANSTO	Jan 2020 – Dec 2022	$1,250,000	$4,968,660
Value-added cobalt refining technologies powering advanced batteries	8	Pure Battery Technologies Pty Ltd	The University of Queensland Intdesign Pty Ltd Cronimet Holding GmbH	Jan 2020 – Dec 2021	$2,220,996	$7,023,607
A novel process for producing battery grade nickel and cobalt sulphates	8	Queensland Pacific Metals Pty Ltd	CSIRO Direct Nickel Projects Pty Ltd	Jan 2020 – Sep 2021	$2,550,000	$9,355,275
Volgren Design and Manufacture of the Next Generation E-Bus for the Global Market	7	Volgren Australia Pty Limited	Deakin University, Carrosserie HESS AG, Extrusion Profiles Australia Pty Ltd	Jul 2019 – Jun 2022	$2,900,000	$6,243,684
The CRC-P for Advanced Hybrid Batteries	7	Calix Limited	Deakin University, Boron Molecular Pty Limited	Oct 2019 – Sep 2022	$3,000,000	$9,385,000

141 https://www.business.gov.au/Grants-and-Programs/Cooperative-Research-Centres-Projects-CRCP-Grants/CRC-Projects-selection-round-outcomes

142 https://www.minister.industry.gov.au/ministers/karenandrews/media-releases/research-collaborations-power-critical-minerals (accessed 19/04/2020)

PROJECT NAME	CRC ROUND	INDUSTRY LEAD	RESEARCH PARTICIPANTS	DATES	TOTAL GRANT AMOUNT	TOTAL PROJECT VALUE
Trial of Battery-grade manganese production pilot-plant, capable of utilising low-grade ores	7	Element 25 Limited	Lycopodium Minerals Pty Ltd, Murdoch University, ALS Metallurgy Pty Ltd	Jul 2019 – Dec 2020	$1,342,223	$3,941,933
Using AI and a hybrid ESS solution to fully integrate solar generation into the distribution system	7	Providence Investment Management Pty Ltd,	Queensland Electricity Transmission Corporation Limited, Risen Energy (Australia) Pty Ltd, University of New South Wales, Tongyu Heavy Industy Co. Ltd, Diamond Genest Pty Ltd, CSIRO, Sungrow Australia Group Pty Ltd, H2store Pty Ltd, University of Technology Sydney	Sep 2019 – Aug 2022	$3,000,000	$28,946,500
Innovative Value Adding of Manganese Battery Minerals for a Sustainable Future	7	Pilbara Metals Group Pty Ltd,	Energy Renaissance Pty Ltd, Valdrew Nominees Pty Ltd, Curtin University, FLSmidth Pty Ltd	Jul 2019 – Dec 2021	$1,130,000	$3,352,748
Development of a new commercial-scale process for producing high purity graphite (>99.95%)	7	Mineral Commodities Ltd	Doral Fused Materials Pty Ltd, CSIRO	Sep 2019 – Dec 2021	$812,999	$2,604,700
High performance energy storage alternative to lithium ion batteries	4	First Graphite Limited	Swinburne University of Technology, Flinders University of South Australia Kremford (VIC) Pty Ltd	Jan 2018 – Jun 2020	$1,500,000	$3,447,500
Advanced Printing Technology for New Generation Flexible Batteries	3	Printed Energy Pty Ltd	The University of Queensland The University of New South Wales Sunset Power International Pty Ltd Sonovia Holdings LLC	Oct 2017 – Sep 2020	$2,000,000	$11,977,500

It should be noted that within several other CRCs, there are significant battery research projects being supported. An example of this is the Rail Manufacturing CRC, which has / had a significant number of projects relating to batteries and associated charging systems[143].

143 https://www.manmonthly.com.au/news/hec-group-joins-rail-crc-put-battery-project-track/

Commentary on Australian Investment and Policy Settings

A great deal can be learned by reading "*The governance of battery value chains: Security, Sustainability and Australian Policy"* (Wilson and Martinus, 2020, for the FBI CRC). Their findings regarding Policy are summarised herein, together with a view on Australian government policy distilled from various government publications.

Attractiveness of Australia

In recent years (especially, see reference to reports on page 5), governments and businesses have identified value adding by moving along the value chain as an economic opportunity for Australia, and the fact that the battery industry is set to grow rapidly in a global context, has attracted interest. "Can we make more of our mineral endowment?" Important questions to ask are "why hasn't Australia already stared to do this, organically" and "what do we need to change, to make this happen?" At least part of the answer lies in the attractiveness of making the investment in Australia, and this is also related to policy settings.

Australia receives low to very low political/sovereign risk ratings from all key agencies[144,145,146] behind Norway and Switzerland, but equal to most western European countries, Finland and Sweden, the US, Canada, Japan and South Korea. Australia is in a much lower risk category than some potential competitor nations in the battery minerals race, such as African nations and much of southeast Asia.

Australia is recognised as having some of the best mining environments in the world, and has transparent regulatory and taxation frameworks, making it attractive for mining investment. The most recent (2018) Fraser Institute[147] survey assesses the "Investment Attractiveness Index", which is an index based on perceptions of government policy, plus operational considerations including benchmarking against *"… a world class regulatory environment, highly competitive taxation, no political risk or uncertainty, and a fully stable mining regime".*

The 83 jurisdictions referred to varied from whole-country jurisdictions where policy settings were uniform across those countries, to state by state jurisdictions for e.g. Australia, Canada and USA where states have different policies and attitudes to mining. The 2018 survey ranked Policy perception for Western Australia as 2nd in the world (1st was Nevada). Several other Australian states fall in the top half of rankings, with Queensland 13th, Northern Territory 23rd, South Australia 24th, and NSW 42nd. Countries that might be considered competitors in the supply of raw battery materials ranked 4th and 19th (Quebec and Ontario, graphite), 6th (Chile, lithium), 10th and 12th (Manitoba, NW Territories, nickel), and 43rd (South Africa, nickel). Tanzania (graphite) ranked 66th, and Democratic Republic of the Congo (DRC, cobalt) ranked 67th. Most interestingly though is the ranking of Finland at 17th, a country that has set national policies and redirected investment in favour of developing a battery industry, and is mining-friendly.

There is however a disconnect between these rankings and the reality of mining investment. Whereas a jurisdiction such as the Democratic Republic of the Congo (DRC) is in the bottom half of investment desirability, the Fraser Institute admits that it does not attempt to factor in the quality or size of ore bodies. Investment in the DRC, Tanzania and other lowly-ranked countries can be heavily influenced by factors other than perceived ease of operation, or local policy settings. Often, a large or easily extracted orebody outweighs perceived risk (e.g. DRC remains the majority cobalt supplier despite political and operational risk, and public disapprobation regarding human rights[148]).

144 https://www.bloomberg.com/graphics/global-risk-briefing/
145 https://globaledge.msu.edu/countries/australia/risk/
146 https://www.coface.com/content/download/179407/2960478/file/COFACE_2020_Country_Map-WEB.pdf
147 https://www.fraserinstitute.org/studies/annual-survey-of-mining-companies-2018
148 https://www.dol.gov/agencies/ilab/resources/reports/child-labor/congo-democratic-republic-drc

Battery Industry Growth Initiatives

As observed by Wilson and Martinus, there are a lack of *battery-specific* initiatives in the policy mix. The overwhelming majority of the 59 policies, grants and schemes applicable to the battery industries are also applicable to the entire mining and/or manufacturing sectors. There are, for the most part, no policies designed specifically to facilitate the growth of the battery industry. Battery-related projects compete with a wider pool of applicants from a more established industrial base.

Only four policies/funding pools are directly focused on opportunities in the battery value chain, being: the Western Australian government's commitment of some $6m to the FBI CRC; the Western Australian government's lithium royalty reform; and high-level battery strategies from Austrade and the Western Australian government. While the policy settings in Western Australia are strongly in favour of establishing a battery industry, in other states and federally, this decision seems not to have been made. Despite the relative strength of the policy settings in Western Australia, this may not be enough to become attractive to investment compared with other countries moving along the battery value chain (see for example page 69).

Battery Implementation Initiatives

It is encouraging, for the Australian battery industry, that Australian State governments each have an energy policy that embraces the uptake of battery energy storage, whether supplier-side or consumer-side. In Western Australia for example, there is an Energy Transformation Strategy[149] that seeks to incorporate grid battery storage to account for the changing patterns of energy generation. The Northern Territory government's *Roadmap to Renewables* commits[150] to 50% of the state's energy being generated by renewables by 2030, with the shut-down in gas-fired generation offset by growth in battery storage. In Queensland there is a similar target for renewables[151], but no specific targets for battery storage (there is however a 500 MW target for pumped hydro storage). In Victoria the Ballarat and Gannawarra energy storage systems[152] provide an 80 MWh buffer for the grid.

South Australia already has the world's largest grid storage battery (100 MW, due for upgrade to 150 MW) at the Hornsdale Power Reserve[153]. Most states also have a scheme subsidising consumer-side storage batteries.

The federal government, through ARENA, is also supporting the uptake of large-scale grid storage[154]. See Table 18 for a more comprehensive list.

Electric Vehicle Initiatives

Electric and hybrid (fossil fuel and electric) cars make up 0.2% of the new car sales[155] in 2017 in Australia, a 56% increase from 2016. By comparison, battery and plug-in hybrids account for 49% of new car sales[156] in Norway (March 2019 data). There, mass adoption of non-fossil fuel cars has been enabled due to many tax and financial incentives[157] introduced by the different ruling governments since the 1990's with the common objective to introduce zero emission vehicles[158] into the Norwegian market. Norway is not alone in Europe in incentivising the uptake of electric vehicles. The UK for example pays £3,500 towards each electric vehicle. The Senate Select Committee on Electric Vehicles[159] (Jan 2019) delivered 17 recommendations for the use and manufacture of electric vehicles in Australia which did not include the introduction of financial incentives to promote EV uptake. Another recommendation was the development of a national strategy. A national strategy for electric vehicles forms part of the Climate Solutions Package, and is due to be released by the Australian government in mid-2020.

149 https://www.wa.gov.au/organisation/energy-policy-wa/energy-transformation-strategy
150 https://roadmaptorenewables.nt.gov.au/
151 https://www.dnrme.qld.gov.au/__data/assets/pdf_file/0008/1253825/powering-queensland-plan.pdf
152 https://www.energy.vic.gov.au/batteries-and-energy-storage
153 https://www.abc.net.au/news/2019-11-19/sa-big-battery-set-to-get-even-bigger/11716784
154 https://arena.gov.au/projects/?project-value-start=0&project-value-end=200000000&technology=battery-storage
155 Climateworks data, 2017.
156 https://elbil.no/english/norwegian-ev-market/
157 https://elbil.no/english/norwegian-ev-policy/
158 A comment on "Zero Emission Vehicles": While battery electric vehicles are often marketed as "zero emission", this is of course not the case. Embedded in the vehicle's manufacture are several tonnes of CO_2 emissions, largely via battery manufacturing. Amortized over the lifetime of the vehicle, these emissions per km can be comparatively very low but only if the energy used to charge the vehicle is low or no emission. Norway already has an advantage in this regard with 95% of its grid capacity supplied by hydroelectric power.
159 https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Electric_Vehicles/ElectricVehicles/~/media/Committees/electricvehicles_ctte/report.pdf

Fellow Travellers – Finland, Sweden, United Kingdom and Germany

Australia is at the start of a journey to be part of the battery manufacturing supply chain, specifically lithium-ion batteries. Interestingly, there are other countries who are at a similar point in their journey to cell manufacturing, with some of them having a similar competitive advantage of large mineral resources, whilst others have innovation and manufacturing capacity on their side. For this reason, we have contrasted the status of Finland, Sweden, the United Kingdom, and Germany, on their journey to battery cell manufacture, even though there is a critical difference between Australia and these economies. These are traditionally manufacturing economies with large markets not just for batteries, but for finished articles, produced in those countries, that batteries are an integral part of. Policy settings are therefore quite different in those countries.

Batteries From Finland[160] is an initiative of the Finnish government. In the English version of their website, the headline is "Market potential of 250 billion for battery industry". The Finnish version, "The 250 billion battery market is waiting for its taker" is perhaps more reflective of the competition that is now in play, as battery manufacturing goes into an unprecedented growth phase. In the *Batteries From Finland* literature, the capability profile roughly mirrors that of Australia (Figure 15). Finland sees its strengths in raw materials, and chemical production, with little/no capability in components (precursors), cells, battery and pack production, and a developing capability in device manufacture and recycling. Contrary to that view, Finland is already home to companies such as Festo (automated systems for battery manufacture and handling), BroadBit, Valmet, and the EnergyVassa cluster.

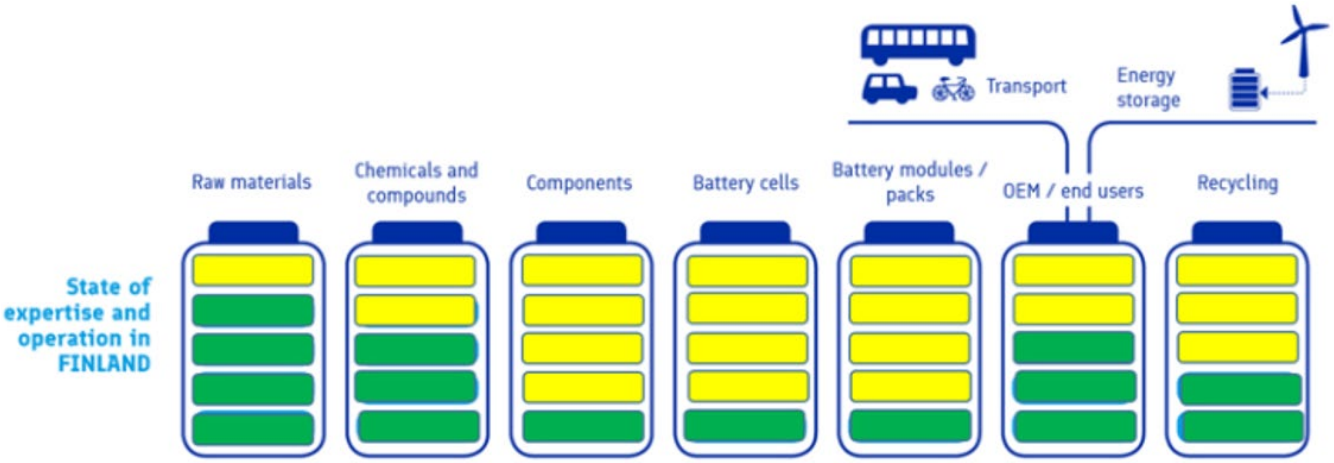


Figure 15. Business maturity of the stages of the battery value chain in Finland (Batteries from Finland report).

BroadBit[161] is based in Espoo, outside of Helsinki, and is hand-manufacturing prototype lithium and sodium based 18650 cells, ahead of commercialising for full-scale production.

As of mid-2019, Valmet-Automotive[162] has started to produce its own batteries for EVs, along with using those produced by the world's largest supplier of EV batteries, CATL[163] in China. Valmet also manufactures 4th generation battery management systems and is a tier 1 supplier of EV systems (and other auto electrics) to various European brands. Valmet builds, among others, complete luxury German vehicles under contract. Valmet has created a professorship in battery technology at the University of Turku, which will commence teaching a Master's degree in battery technology.

160 https://www.businessfinland.fi/en/for-finnish-customers/services/programs/batteries-from-finland/
161 http://www.broadbit.com/#menu-home
162 Formerly Saab-Valmet. https://www.valmet-automotive.com/media/news/valmet-automotive-has-started-battery-production-in-salo/
163 Contemporary Amperes Technology Limited https://www.catlbattery.com/en/

EnergyVassa[164] is an energy hub (cluster[165]) situated in the area of Vassa. Its 140 energy and technology member companies have a Vaasa-based €6 billion annual turnover. It has been joined by Freeport Cobalt, Beowulf (graphite), Nornickel (nickel) and Keliber (lithium), and is offering significant sites for battery precursor manufacture and a "green battery gigafactory". BASF has announced that it will build a battery plant for EVs adjacent to the Nornickel nickel and cobalt refinery, to the north.

While Valmet's batteries are likely of a standard Chinese design provided by CATL and likely not yet made from Finnish materials, and BroadBit is still experimenting and hand-rolling, it cannot be denied that Finland is already producing cells and batteries. BASF will also produce batteries, in Finland, during 2020. The investment offers made by the city of Vaasa and the industrial ecosystem already in place in Finland are very attractive.

Northvolt's first large-scale battery factory (Northvolt Ett) is being established in Skellefteå in northern Sweden. This site will manufacture cathode and anode active materials, assemble cells, build batteries, and perform recycling. The factory will be powered by 100% clean energy (hydro). Large-scale manufacturing is planned to commence in 2021 and annual capacity will ramp up to at least 32 GWh by 2024. Northvolt's philosophy is that cell production should be close to the raw materials.

The United Kingdom is also pursuing battery manufacturing and to this end has developed three programs under the **United Kingdom's Industrial Strategy Challenge Fund: The Faraday Institution**[166], funding research and innovation projects and the UK Battery Industrialisation Centre. **The Faraday Battery Challenge is backed by £246 million (AU$478 million[167]) between 2017 and 2021** and is to support a world class scientific, technology and manufacturing scale-up capability for batteries in the UK. The Faraday Institution[168] receives £78 million and works across a much narrower area of the battery value-chain, not considering battery minerals or precursors like the FBICRC proposes. Underpinned by some of the leading Universities in the UK, including Oxford and Cambridge, their focus is on key areas of manufacturing and use, especially for vehicles; their research focuses on projects "to reduce battery cost, weigh, and volume; to improve performance and reliability; and to develop whole-life strategies including recycling and reuse."

These research and innovation projects are receiving £88 million and are similar to the Australian CRC-Ps, whereby the project must involve at least one small or medium-sized enterprise. The scope of projects being supported range from reducing the cost of battery cells and packs through to new battery management systems.

A key feature of The Faraday Battery Challenge is the establishment of the UK Battery Industrialisation Centre (UKBIC)[169], which was announced in 2017. UKBIC received £80 million from the Challenge and will allow open access to companies and researchers for full scale, high volume battery manufacturing with an initial focus on electric vehicle production. The goal of UKBIC is to build on research that may have been supported by Industry, EPSRC (UK equivalent of the ARC) and the Faraday Institution to accelerate the development of battery technologies to the market. It is anticipated that UKBIC will open in Coventry in 2020. In a report for the Policy Exchange the author, Sir Geoffrey Owen, questioned the wisdom of building UKBIC considering that all the Asian manufacturers, who dominate this space, will have these skills at home[170].

It is arguable that the driver for this effort is around the sustainability of the UK's automotive industry, especially in a post-Brexit world. The Society of Motor Manufacturers and Traders (SMMT)[171] claims that the automotive industry in the UK has a turnover of £82 billion, with some 168,000 people employed directly in manufacturing and supports significant exports. It is worth noting, that the Nissan Leaf is manufactured in Sunderland, UK, only one of three manufacturing plants in the world to build this car[172]. A major fear for the UK is the departure of a significant number of automotive manufacturers from the UK in the event of both falling sales and the inability to compete in the new energy vehicle world[173]. Of note is that low emission vehicles in the UK, irrespective of whether they are built there, are eligible for a discount of £3500[174].

164 http://energyvaasa.vaasanseutu.fi/
165 https://www.clusternavigators.com/
166 https://www.gov.uk/government/collections/faraday-battery-challenge-industrial-strategy-challenge-fund
167 £1 GBP = AU$1.945 as of 03/05/2020
168 https://faraday.ac.uk/#
169 https://www.ukbic.co.uk/
170 https://policyexchange.org.uk/wp-content/uploads/2018/04/Batteries-for-Electric-Cars.pdf
171 https://www.smmt.co.uk/industry-topics/uk-automotive/
172 https://europe.nissannews.com/en-GB/releases/release-6480-nissan-to-build-leaf-electric-vehicle-in-sunderland
173 https://www.ft.com/content/6a2e869a-44c6-11e9-b168-96a37d002cd3
174 https://www.gov.uk/plug-in-car-van-grants/what-youll-get

Germany, like the UK, also has a significant automotive industry and is investing heavily in the development of battery technologies through the BMBF (Federal Ministry of Education and Research). It released a strategy document entitled **"Electric Mobility: Rethinking the Car"**[175] in 2013 looking at all aspects of electrification of vehicles with a strong emphasis on the development of Li-ion battery technologies to disrupt the internal combustion engine. Further, the **German Battery 2020 Programme** supported research into lithium-ion, metal-ion, metal-sulfur and metal-air / oxygen systems with a focus on future electromobility and stationary applications as shown in Figure 16[176].

More recently, the **BMBF announced in mid-2019 the establishment of "Forschungsfabrik Batterie" or Battery Research Factory**[177], worth ~€500 million, which will be built near Münster Electrochemical Energy Technology (MEET) laboratory led by Prof. Dr. Martin Winter and will start operating in mid-2022. The aim of the facility is to validate new production technologies and thus accelerate the transfer of new battery concepts and production into practice. As a result of the fierce competition between 6 research clusters and the anger of some parties missing out, further research investments were disbursed to other parties.[178]

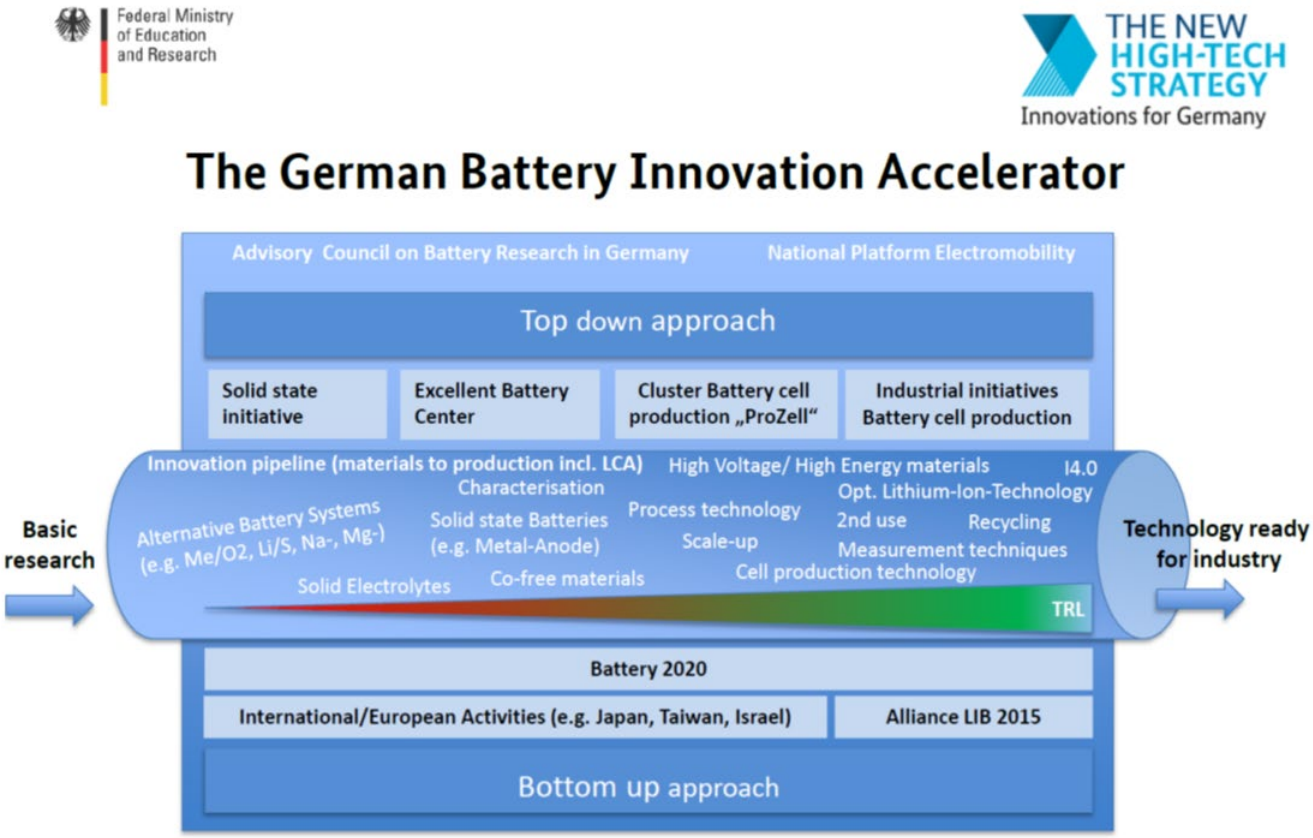


Figure 16. Schematic of the research undertaken within German Battery Innovation Accelerator supported by the BMBF.[179] A German version of this image can be found on the BMBF website.

175 https://www.bmbf.de/upload_filestore/pub/electric_mobility_rethinking_the_car.pdf
176 https://www.bmbf.de/foerderungen/bekanntmachung-1146.html
177 https://www.bmbf.de/de/batterieforschung-in-deutschland---potenziale-fuer-vielfaeltige-anwendungen-nutzen-662.html
178 https://physicsworld.com/a/new-e500m-german-battery-institute-hit-by-scandal-over-site-decision/
179 resentation by RD Dr. Peter Schroth, BMBF, Head of Division 511 "Prospects and Activities in Field of Battery Research in Germany", May, 2018.

With a **strong domestic automotive and chemical industry sector, Germany is well placed to take advantage of the research and production benefits.** Germany has previously had cell and battery pack manufacturing capability through two companies, Li-Tec[180] (cells) and Deutsche ACCUmotive (battery packs), the latter being a joint venture between Evonik Industries AG and Damiler AG. These facilities were established in 2006[181] and batteries from these plants were used to power Smart[182] cars. More recently, Tesla has confirmed that it will build a Gigafactory in the "Berlin area"[183] and has secured subsidies from the German government to achieve this. CATL has announced that it will be building cells at a factory that is under construction in Erfurt, with BMW playing a leading role in assisting in establishing the factory and supply chains as well as securing offtake arrangements[184]. Farasis will establish a 61 GWh battery plant with a start-up expected in 2022, and Northvolt AB and Volkswagen are establishing a 16 GWh (growing to 30 GWh) plant which is due to open in 2023/2024. It is anticipated that the Northvolt-Volkswagen plant will also include a pilot line for battery recycling which will begin operating in 2020. BASF has announced that it will establish cathode manufacturing facilities in Schwarzheide, Germany, with an initial capacity to supply around 400,000 full electric vehicles per year. Of note, this facility will use precursors from BASF's previously announced plant in Harjavalta, Finland. Both plants will be active from 2022[185].

With regards to critical minerals, it should be noted that **in the case of both the United Kingdom and Germany, they are almost entirely reliant on external sources for critical energy metals,** specifically those minerals that are found in batteries. For this reason, a key pillar of the UK Faraday Institution is retention of materials through the recycling of batteries[186] and in the case of Germany, the planned pilot line for battery recycling within the Volkswagen / Northvolt AB plant.

The BMW Group has already started to secure its supply chain for materials such as Lithium and Cobalt. BMW will source its Cobalt from Australia's Murrin Murrin refinery[187]. It also has an agreement secured in December 2019 with Ganfeng[188] for lithium sourced in Australia. This agreement allowed BMW to secure 100% of its lithium hydroxide needs for the fifth-generation battery cells in its high voltage batteries. Both the lithium and cobalt supplies will be made available to both CATL (China) and Samsung SDI (South Kora) for the manufacture of cells. BMW has also examined the supply of nickel from Australia, but no decisions have been made. However, it should be noted that **BMW is impressed by the high environmental and safety standards in Australia.**[189] BMW's deals were thought to be prompted by an LME initiative[190] to delist brands that do not comply with responsible sourcing guidelines, which could involve de-listing of Cobalt from the DRC.

It becomes clear, when reading promotional material for European battery manufacturing, that local and federal government support is strong. Advantageous local property, taxation allowances and infrastructure support are generous (e.g. in Vaasa). Investment is available through government-supported bodies such as the European Investment Bank and EU research funding is available. The German Battery Innovation Accelerator is also very well-funded.

180 https://www.li-tec.de/en/company
181 https://corporate.evonik.com/en/daimler-and-evonik-restructure-lithium-ion-activities-106466.html
182 Mercedes's small battery powered offering.
183 https://electrek.co/2020/01/28/tesla-subsidies-production-battery-cells-germany/
184 https://techcrunch.com/2019/11/21/bmw-locks-up-10-2-billion-euro-battery-order-ahead-of-ev-onslaught/
185 https://www.basf.com/global/en/media/news-releases/2020/02/p-20-127.html
186 https://www.mining-technology.com/features/critical-minerals-and-the-uk-5-things-to-know/
187 https://www.reuters.com/article/us-bmw-electric-cobalt/bmw-to-buy-cobalt-direct-from-australia-morocco-for-ev-batteries-idUSKCN1RZ1RK
188 http://www.ganfenglithium.com/about_en.html
189 Personal Communication, Andreas Siedel, Austrade, Frankfurt, 2020.
190 https://www.lme.com/News/Press-room/Press-releases/Press-releases/2019/10/LME-sets-out-responsible-sourcing-requirements

Competitive position compared to established battery manufacturing countries

Could we compete?

The established major players in the lithium ion battery industry are China (62% of global capacity), the USA (13%), Japan (12%) and South Korea (10%)[191]. It has been suggested[192] that China leads the USA due to lower labour costs, and greater lithium reserves and processing capacity. This is not believable, especially when Albemarle (USA) controls nearly double China's total production through its part ownership of Talison (Greenbushes). Australia, Chile, and Argentina outperform China in lithium ore production and yet do not outperform China in processed lithium or battery chemical or battery manufacture. Labour cost differences are real, but lithium ion battery manufacturing can be highly automated. Rather, as one observer put it[193] *"The key driver of China's battery manufacturing ramp-up has been the generous subsidies offered by the Chinese government solely to domestic vendors."* China is not alone in this regard, with the USA announcing ~$27 billion in subsidies for advanced technologies.

If not, then what?

In the context of Chinese dominance of the market, in deciding to proceed further along the value chain, Australia needs to consider reasons for doing this. The answer cannot reasonably include competing with China for world market share. Rather, Australian-built cells and batteries could compete as niche products designed and built for our unique climate, in mining and defence applications, and to fill the need for reliable mass energy storage. Figure 17 summarises Australia's capability and potential for economic development at the present time.

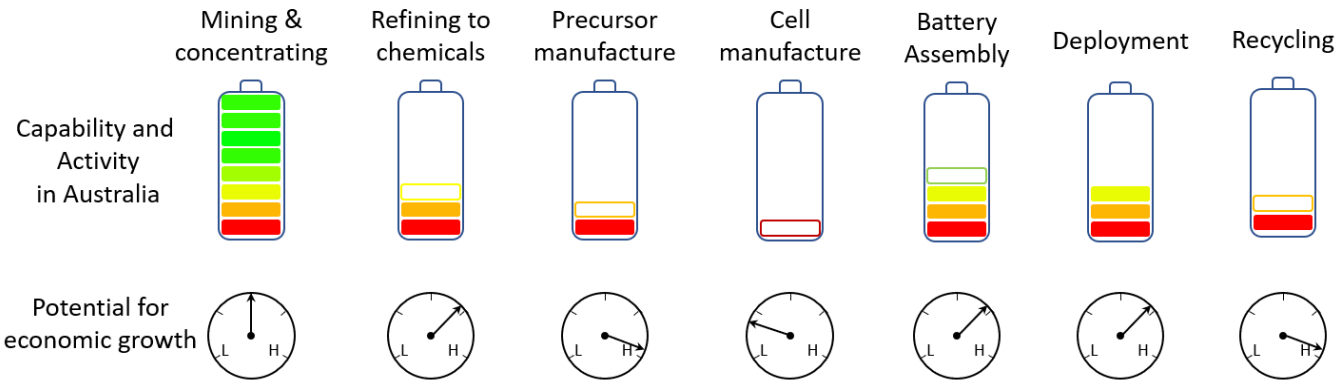


Figure 17. Australia's current capability and potential for economic development

191 The case for recycling: Overview and challenges in the material supply chain for automotive li-ion batteries https://doi.org/10.1016/j.susmat.2018.e00087

192 https://www.forbes.com/sites/rrapier/2019/08/04/why-china-is-dominating-lithium-ion-battery-production/#4d0b722f3786

193 Mitalee Gupta, energy storage analyst at Wood Mackenzie Power & Renewables, reported on: https://www.greentechmedia.com/squared/electric-avenue/china-poised-to-dominate-ev-battery-manufacturing

Gaps and Opportunities

During the writing of this report, the following SWOT table was been constructed:

STRENGTHS	WEAKNESSES
• Australia is an accomplished mining nation and has an abundance of most of the raw materials required for batteries. • Australia has world-class technical expertise to assist in establishing battery industries. Universities, research institutions and the private sector have the skills. • There are of the order of 50 companies in Australia with technology and developing value propositions for their own investment in the battery value chain. • Although variable across the states, Australian governments are now investing in the growth of the battery industry.	• Lack of co-ordination between State and Federal Governments in policies to support the battery minerals industry and downstream production. • Lack of co-ordination in funding of activities within the battery value chain[194]. • Lack of current activity or experience in producing battery-grade chemicals, precursor materials, and manufacturing capability for cells. • Uncertainty as to whether investors will support a high-tech manufacturing industry in Australia.
OPPORTUNITIES	**THREATS**
• There is a significant increase in the value of battery materials along the value chain. The step to anode or cathode precursor results in a very attractive value multiplier and is perhaps in easy reach of Australian companies. • At the present time, Australia only performs the first parts of recycling of lithium ion batteries. There is an opportunity to close this part of the battery lifecycle loop in Australia by recovering battery metals for use in the Australian battery materials industry. • Policy could be used to drive greater adoption of Behind the Meter and Grid battery storage systems to support the huge penetration of PV and other renewables in the country. This would open more opportunities for cell and battery manufacture in Australia. • The international battery industry is growing rapidly and demand is increasing.	• Investment in Australia, to date, is insufficient to incubate cell manufacturing businesses. The scale of the capital expenditure required is large even for pilot scale activity[195]. • Australia is yet to produce, at commercial scale, chemicals that satisfy the criteria for being incorporated into a battery, without further purification. We have no history in this type of fine chemicals manufacturing, and companies and their workforces are learning as they go. • Price competitiveness will always be a threat. Australia needs to consider "where to play" in the domestic and global markets[196].

194 Multiple funding bodies and organisations exist but are not co-ordinated to maximise the return on investments being made. In many cases there is duplication and where direct grants to industry are concerned, competition. Some consideration could be given to a funding model like the German BMBF, Sweden and Swedish Energy Agency, United Kingdom and the Faraday Challenge, where funding is targeted at specific research challenges.

195 Prototyping and experimental production require infrastructure, preferably available to all emerging companies. Collaboration with Germany in the "Forschungsfabrik Batterie" or with the UKBIC in order to connect Australian researchers and industry to cell manufacturing capability.

196 For example, should Australia only develop its value-add to the point of producing precursors? Does it need to compete in the market for bulk cells? Are there economic or strategic niches for batteries made in Australia?

Short Biographies

Dr Adam Best received his PhD from Monash University, Australia in 2002 before completing a post-doctoral Fellowship at Delft University of Technology, The Netherlands. Dr Best joined CSIRO in 2004 and is currently a Principal Research Scientist with the Metal Industries Program of CSIRO Manufacturing. Adam was Co-Chair of the International Battery Association (IBA) meeting held in Brisbane, Australia, in 2014. He has 81 publications and 14 patents, with an h-index of 40 and over 4500-lifetime citations. In 2017, Dr Best was awarded a Winston Churchill Memorial Fellowship to study battery electrolytes and how to develop a battery industry in Australia. Adam leads several battery research programs developing novel electrolytes and battery concepts including for next-generation Lithium batteries with a range of Australian and International Companies. Due to Australia's mineral wealth, Adam is passionate about the opportunities for Australian industry to be part of the global battery value chain and works to connect them locally and globally.

Dr Chris Vernon received a PhD from The University of Western Australia in 1988 and since that time has been working in CSIRO and in the minerals industry. He currently leads CSIRO's mineral processing program and its Green Minerals initiative. Much of Chris' program concentrates on critical energy metals, which includes battery metals and graphite, and including the refining of these to *battery grade* materials.

APPENDICES

Appendix 1. Nickel refining capability

OWNER	LOCATION	PRODUCTS	NI CAPACITY	CO CAPACITY	STATUS
BHP Nickel West	Kwinana WA	Ni briquettes Ni Powder Co precipitate	75,000	1,000*	Operating
Glencore	Murrin Murrin WA	Ni briquettes Co precipitate	40,000	4,000	Operating
Queensland Nickel	Townsville, Qld	Ni briquettes Co precipitate	76,000	3,500	Care and maintenance
First Quantum	Ravensthorpe, WA	Mixed Hydroxide Product	28,000	2,800*	Care and maintenance

*Estimates

Appendix 2. Operational/operable nickel/cobolt mines

PROPERTY	OWNER	PRODUCTS	NI OUTPUT TONNES/Y	OTHER REPORTED	LAT	LONG
Murrin Murrin Mine	Glencore Plc	Ni, Co	39,700[a]	3,200 Co	-28.7601	121.8768
Mt Keith	BHP Group	Ni/Co Concentrate	40,000	-	-27.2306	120.545
Leinster	BHP Group	Ni/Co Concentrate	27,000[b]	-		
Nova-Bollinger	Independence Group NL (IGO)	Concentrate	30,708	13,700 Cu 1,100 Co	-31.8139	123.1778
Savannah	Panoramic Resources Ltd., Ora Gold Ltd.	Ni/Cu/Co Concentrate[c]	8,000	4,500 Cu 600 Co	-17.3509	128.0261
South Kambalda	Mincor Resources NL	Care and maintenance			-31.6831	121.6489
Ravensthorpe	First Quantum Minerals Ltd.	Care and maintenance			-33.645	120.3961
Mariners	Mincor Resources NL	Care and maintenance			-31.6301	121.6563
Palmer Nickel and Cobalt Refinery	Queensland Nickel	Care and maintenance			-19.2156	146.6011
Forrestania/ Cosmic Boy/Flying Fox/Spotted Quoll/Cosmos/ Odysseus	Western Areas	Concentrate[d]	15,800			

a Includes third-party ore feeds
b The Leinster concentrator has a capacity for more than 40,000 tonnes.
c Savannah concentrate is exported to the Jinchuan group in China.
d Offtake agreements with BHP and Jinchuan.

Appendix 3. All nickel related activity in Australia

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
PJSC MMC Norilsk Nickel, LionOre Mining International	Honeymoon Well	Nickel, Cobalt	-26.9231	120.3789	Preproduction	4007000	Active
BHP Group	Nickel West	Nickel, Cobalt	-27.2306	120.545	Operating	3622000	Active
BHP Group	Yakabindie	Nickel, Cobalt	-27.4555	120.5775	Reserves Development Now operating	3570000	Active
Wingstar Investments Pty. Ltd., Dragon Mountain Gold Ltd.	Avalon	Nickel, Cobalt	-30.6904	121.822	Reserves Development	1403000	Active
Wingstar Investments Pty. Ltd., Dragon Mountain Gold Ltd.	Cawse	Nickel, Cobalt	-30.3706	121.1461	Feasibility	1219300	Temporarily On Hold
Western Areas Ltd., Alkane Resources Ltd.	Cosmos	Nickel, Cobalt	-27.6	120.5747	Feasibility Complete	592408	Active
Western Areas Ltd., Wesfarmers Ltd.	Forrestania	Nickel, Cobalt, Lithium	-32.581	119.7432	Expansion	355474	Active
Ardea Resources Ltd., Ora Banda Mining Ltd.	Kalgoorlie	Nickel, Cobalt, Copper, Platinum, Palladium, Gold, Scandium, Chromium, Manganese, Vanadium, Aluminum, Silver	-30.0106	121.1481	Feasibility Started	330300	Active
BHP Group	Venus	Nickel, Cobalt, Platinum, Palladium	-27.7889	120.6972	Reserves Development Now operating	268000	Active
Dundas Mining Pty Ltd.	Avebury	Nickel, Cobalt	-41.9196	145.2567	Operating	259400	Care And Maintenance
Gladstone Pacific Nickel	Marlborough	Nickel, Cobalt	-22.9481	149.8311	Target Outline	220000	Inactive
	Black Hill	Nickel	-30.9216	121.853	Reserves Development	192000	Inactive
PJSC MMC Norilsk Nickel, BHP Group	Jericho	Nickel	-27.0575	120.4478	Reserves Development	180000	Active
Glencore Plc	Murrin Murrin	Nickel, Cobalt	-28.7691	121.8935	Expansion	179400	Active

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
Clean TeQ Holdings Ltd.	Clean TeQ Sunrise	Nickel, Cobalt, Scandium, Platinum, Palladium	-32.7622	147.4271	Construction Planned	162000	Active
Metals X Ltd.	Central Musgrave	Nickel, Cobalt, Iron Ore, Platinum, Palladium, Scandium	-26.0576	128.9533	Feasibility Complete	154423	Active
BHP Group	Leinster Tailings	Nickel	-27.77	120.7589	Prefeas/ Scoping	132200	Active
	Mount Margaret	Nickel, Cobalt	-28.3139	120.9861	Prefeas/ Scoping	122310	Inactive
	Duck Hill	Nickel, Cobalt	-29.5189	122.2719	Reserves Development	118000	Inactive
Black Mountain Metals LLC	Lanfranchi	Nickel, Copper, Cobalt	-31.505	121.834	Operating	95500	Care And Maintenance
Mincor Resources NL	South Kambalda	Nickel, Cobalt, Copper, Gold, Platinum, Palladium, Silver	-31.7009	121.6242	Operating	93400	Active
Rox Resources Ltd.	Fisher East	Nickel, Copper, Palladium, Platinum, Gold, Cobalt	-26.8057	121.5517	Prefeas/ Scoping	78000	Active
Ardea Resources Ltd.	Yerilla	Nickel, Cobalt	-29.7151	122.0605	Feasibility	74200	Active
Caeneus Minerals Ltd., Arrow Minerals Ltd.	Pardoo-Highway	Nickel, Copper, Cobalt	-20.1877	119.6572	Reserves Development	58110	Active
	Eucalyptus	Nickel, Cobalt	-29.0836	122.1801	Reserves Development	57000	Inactive
GME Resources Ltd., Private Company	Niwest	Nickel, Cobalt	-28.6772	121.7161	Prefeas/ Scoping	55400	Active
Poseidon Nickel Ltd., Lithium Australia NL, Pioneer Resources Ltd.	Lake Johnston	Nickel, Cobalt, Copper, Lithium, Tantalum	-32.1981	120.4831	Commissioning	52000	Care And Maintenance
Jervois Mining Ltd.	Young	Nickel, Cobalt, Scandium, Magnesium, Iron Ore, Aluminum	-34.1779	148.0523	Prefeas/ Scoping	46000	Active
Gladstone Pacific Nickel	Gladstone	Nickel, Cobalt	-23.0651	149.8969	Feasibility	44000	Active

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
Mincor Resources NL	North Kambalda	Nickel, Cobalt, Copper, Gold, Platinum, Palladium, Silver	-31.167	121.65	Feasibility Complete	40500	Active
OZ Minerals Ltd., Cassini Resources Ltd.	West Musgrave	Nickel, Copper, Platinum, Palladium, Cobalt, Gold, Platinum Group Metals	-26.0817	127.7831	Prefeas/ Scoping	31240	Active
Pioneer Resources Ltd.	Golden Ridge	Nickel, Gold, Cobalt	-30.9106	121.7169	Reserves Development	31010	Active
Mincor Resources NL	Long Complex	Nickel, Cobalt, Copper	-31.1891	121.6897	Operating	31000	Care And Maintenance
Glencore Plc	Irwin-Coglia	Nickel, Cobalt, Copper	-29.1428	123.0575	Reserves Development	23000	Active
Mincor Resources NL	Bluebush Line	Nickel	-31.607	121.792	Reserves Development	19900	Active
Stonehorse Energy Ltd.	Canegrass	Nickel, Cobalt	-30.2859	120.9766	Prefeas/ Scoping	17600	Active
Saracen Mineral Holdings Ltd.	Sinclair	Nickel, Copper, Cobalt, Gold	-28.3741	120.8645	Reserves Development	16200	Active
Quest Capital Corp.	New Morning	Nickel	-32.4531	119.68	Reserves Development	15000	Inactive
	Goodyear	Nickel	-31.0091	121.6862	Reserves Development	15000	Inactive
Panoramic Resources Ltd., Ora Gold Ltd.	Savannah	Nickel, Copper, Cobalt, Vanadium, Titanium, Iron Ore, Graphite	-17.3509	128.0261	Operating	14800	Active
Saracen Mineral Holdings Ltd.	Waterloo	Nickel, Copper, Platinum	-28.1438	120.978	Operating	14400	Care And Maintenance
Focus Minerals Ltd.	Nepean	Nickel	-31.165	121.085	Feasibility	13008	Inactive
First Quantum Minerals Ltd.	Ravensthorpe	Nickel, Cobalt, Copper, Zinc, Iron Ore	-33.645	120.3961	Operating	11400	On Hold Awaiting Higher Prices
Golden Mile Resources Ltd.	Quicksilver	Nickel, Cobalt, Copper, Scandium	-32.7435	118.6678	Reserves Development	11300	Active
Duketon Mining Ltd.	Duketon	Nickel, Copper, Platinum, Palladium	-27.622	122.0104	Reserves Development	10000	Active

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
Alpha HPA Ltd.	Homeville	Nickel, Cobalt, Magnesium, Aluminum, Scandium	-32.0148	147.0463	Prefeas/ Scoping	9900	Active
	Summervale	Nickel, Cobalt, Iron Ore	-31.4311	147.0341	Reserves Development	9600	Inactive
Independence Group NL	Nova-Bollinger	Nickel, Copper, Cobalt, Platinum, Silver	-31.8139	123.1778	Operating	9000	Active
Cougar Metals NL	Pyke Hill	Nickel, Cobalt	-29.0467	122.15	Reserves Development	8900	On Hold Awaiting Higher Prices
Norwest Minerals Ltd.	Marriott's	Nickel	-28.4512	120.9914	Reserves Development	8700	Active
Minotaur Exploration Ltd.	Kambalda West	Nickel, Gold	-31.3581	121.5031	Reserves Development	8300	Active
Carnavale Resources Ltd.	Grey Dam	Nickel, Cobalt, Copper	-30.4743	122.1514	Reserves Development	7200	Active
Tasmania Energy Metals Pty Ltd	Barnes Hill	Nickel, Cobalt, Iron Ore	-41.2186	146.774	Prefeas/ Scoping	7158	Active
Sabre Resources Ltd., Sherlock Investors Pty Ltd, Metals Australia Ltd.	Sherlock Bay	Nickel, Copper, Cobalt, Lead	-20.8139	117.5411	Feasibility Started	5400	Active
	Larkin's Find	Nickel, Cobalt	-29.4689	122.2581	Reserves Development	4200	Inactive
	Miriam	Nickel	-31.0739	121.0881	Target Outline	3900	Inactive
	Toomey Hill	Nickel, Cobalt	-28.805	121.8881	Reserves Development	3300	Inactive
	Snake Hill	Nickel	-29.2215	120.5345	Exploration	3200	Inactive
Estrella Resources Ltd.	Carr Boyd	Nickel, Copper, Platinum, Palladium, Cobalt	-30.0566	121.6306	Reserves Development	3020	Active
Mincor Resources NL, Celsius Resources Ltd.	Carnilya Hill	Nickel, Gold	-31.0556	121.8639	Reserves Development	3000	Inactive
Auroch Minerals Ltd., PVW Resources NL	Leinster	Nickel, Copper, Platinum, Palladium, Gold	-28.1646	120.9172	Reserves Development	1800	Active
	Mt Jewell	Nickel	-30.1803	121.4561	Reserves Development	1700	Inactive

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
	Waite Kauri	Nickel, Cobalt	-28.6601	121.7157	Reserves Development	1600	Inactive
	Corkwood	Nickel	-17.295	128.1878	Exploration	1500	Inactive
Riverina Resources Pty Ltd, Barra Resources Ltd.	Riverina	Nickel, Cobalt, Gold	-29.745	120.5639	Reserves Development	1300	Inactive
Mali Lithium Ltd.	Waite Kauri	Nickel, Cobalt	-28.6989	121.7203	Reserves Development	1300	Inactive
Poseidon Nickel Ltd.	Windarra	Nickel, Gold, Cobalt, Copper	-28.6103	122.2427	Construction Planned	1200	Care And Maintenance
White Cliff Minerals Ltd.	Ghan Well	Nickel, Cobalt	-28.8708	122.1311	Reserves Development	900	Active
Tyranna Resources Ltd.	Pacific Express	Nickel, Cobalt, Scandium	-31.571	152.7901	Reserves Development	806	Active
Auroch Minerals Ltd., Shine Resources Pty Ltd.	Scotia	Nickel, Gold, Copper, Cobalt	-30.059	121.2321	Reserves Development	600	Active
Aus Tin Mining Ltd.	Mt Cobalt	Nickel, Cobalt, Gold, Copper, Platinum	-26.1952	152.2744	Reserves Development	572	Active
Metallica Minerals Ltd.	Lucky Break	Nickel, Cobalt	-19.4724	145.691	Feasibility	546	Active
Rox Resources Ltd.	Collurabbie Hills	Nickel, Copper, Platinum, Palladium, Gold, Cobalt	-26.8204	122.1873	Reserves Development	470	Active
Artemis Resources Ltd.	Radio Hill	Nickel, Copper, Cobalt, Palladium, Platinum, Zinc, Gold	-20.9824	116.8682	Feasibility	318	Active
Unnamed Owner, Estrella Resources Ltd., Neometals Ltd.	Armstrong	Nickel, Gold, Lithium, Copper	-31.5036	121.5309	Reserves Development	190	Active
Neometals Ltd.	Mt Edwards	Nickel, Copper, Iron Ore, Cobalt	-31.6867	121.6134	Reserves Development	160	Active
Unnamed Owner	Mt Eaton	Nickel	-31.692	121.574	Exploration	unknown	
Unnamed Owner	East Ruth Well	Nickel	-20.8595	116.881	Exploration	unknown	
QNI Pty Ltd	Yabulu Refinery	Nickel, Cobalt	-19.201	146.614	Operating	unknown	

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
Temple Resources Pty Ltd.	Devil's Creek	Nickel, Copper, Platinum, Palladium	-34.2589	119.065	Exploration	unknown	Active
Ardea Resources Ltd.	Bedonia	Nickel, Copper, U_3O_8, Gold, Platinum, Palladium	-31.9492	122.5452	Exploration	unknown	Active
Independence Group NL, Buxton Resources Ltd.	Zanthus	Nickel, Copper	-31.3847	123.8496	Exploration	unknown	Active
TasEx Geological Services Pty	Fraser Range North	Nickel, Copper, Palladium	-30.3	124.37	Exploration	unknown	Active
Celsius Resources Ltd., Unnamed Owner	Murrin Murrin South	Nickel, Gold, Cobalt	-28.842	121.917	Exploration	unknown	Active
St George Mining Ltd.	Hawaii	Nickel, Gold	-28.3651	120.2986	Exploration	unknown	Active
Strategic Elements Ltd.	Behemoth	Nickel, Copper, Gold	-28.3498	127.5021	Exploration	unknown	Active
Cullen Resources Ltd.	Irwin Bore	Nickel	-26.725	121.5208	Exploration	unknown	Active
PepinNini Lithium Ltd., Rio Tinto Exploration Pty. Ltd	Musgrave Joint Venture	Nickel, Copper, Silver, Platinum, Lead, Zinc, Palladium, Rhodium, Cobalt	-26.26	129.655	Exploration	unknown	Active
Sandfire Resources NL, Great Western Exploration Ltd.	Yerrida North	Nickel, Gold, Copper, Cobalt, Lead, Silver, Zinc	-25.788	119.4594	Exploration	unknown	Active
Western Desert Resources Ltd., Todd River Resources Ltd.	Peterman Ranges	Nickel, Gold, Copper, Diamonds, Zinc, Lead	-25.375	130	Exploration	unknown	Active
	Marlborough	Nickel, Platinum, Palladium, Chromite, Copper, Zinc, Gold, Cobalt, Rhodium	-22.929	149.923	Exploration	unknown	Active
Independence Group NL, Apollo Consolidated Ltd.	Louisa	Nickel, Copper, Platinum, Palladium, Rhodium	-18.42	126.149	Exploration	unknown	Active
Gladstone Pacific Nickel	Yarwun HPAL Refinery	Nickel, Cobalt	-23.849	151.176	Feasibility	unknown	Active

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
Caeneus Minerals Ltd., Private Interest	Super Nova	Nickel, Copper, Cobalt	-32.049	123.107	Grassroots	unknown	Active
	Musgrave Province	Nickel, Gold, Copper, Platinum, Palladium, Rhodium	-26.7389	132.7715	Grassroots	unknown	Active
Nickel West Mines	Kwinana Refinery	Nickel, Gold	-32.23	115.77	Operating	unknown	Active
Nickel West Mines	Kambalda Concentrator	Nickel, Platinum, Cobalt, Copper, Gold, Palladium, Rhodium, Platinum Group Metals	-31.189	121.668	Operating (has capability to process both 3rd party ores and concentrates in preparation for smelting	unknown	Active
Nickel West Mines	Kalgoorlie Smelter	Nickel	-30.875	121.484	Operating	unknown	Active
Glencore Plc	Murrin Murrin Refinery	Nickel, Cobalt	-28.768	121.893	Operating	unknown	Active
Mount Ridley Mines Ltd.	Mt Ridley	Nickel, Copper, Zinc, Platinum, Gold, Silver, Palladium, Rhodium, Cobalt, Lead	-33.2012	122.0954	Target Outline	unknown	Active
AusQuest Ltd., South32 Ltd.	Balladonia	Nickel, Copper, Silver, Lead, Zinc	-32.673	123.3519	Target Outline	unknown	Active
Pioneer Resources Ltd., National Minerals Pty Ltd	Fairwater	Nickel, Gold, Copper, Silver, Lead, Zinc, Platinum, Palladium	-32.667	122.1989	Target Outline	unknown	Active
Geotech International Pty Ltd	Fraser Range South	Nickel, Copper	-32.45	122.92	Target Outline	unknown	Active
Element 25 Ltd., Hannans Ltd	Lake Johnston	Nickel, Copper, Molybdenum, Gold, Lithium	-32.4129	120.6591	Target Outline	unknown	Active
AusQuest Ltd.	Jimberlana	Nickel, Copper	-32.2839	120.3454	Target Outline	unknown	Active
Hannans Ltd, Cullen Resources Ltd.	Forrestania	Nickel, Lithium	-32.2538	119.667	Target Outline	unknown	Active
Alkane Resources Ltd.	Trangie	Nickel, Copper	-32.0035	148.0227	Target Outline	unknown	Active

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
Constellation Resources Ltd., Enterprise Metals Ltd.	Orpheus	Nickel, Copper, Gold	-31.988	122.8443	Target Outline	unknown	Active
Liontown Resources Ltd., Cullen Resources Ltd., Yilun Pty Ltd	Killaloe	Nickel, Gold	-31.9583	121.9254	Target Outline	unknown	Active
Galileo Mining Ltd., Private Interest	Fraser Range	Nickel, Copper, Cobalt	-31.946	122.8192	Target Outline	unknown	Active
White Cliff Minerals Ltd.	Bremer Range	Nickel, Copper, Cobalt, Lithium	-31.9218	120.3743	Target Outline	unknown	Active
Matsa Resources Ltd.	Symons Hill	Nickel, Copper	-31.9149	123.1703	Target Outline	unknown	Active
Independence Group NL, Private Interest	Fraser Range	Nickel, Copper, Cobalt, Platinum, Palladium, Rhodium, Chromite	-31.8184	123.1965	Target Outline	unknown	Active
Boadicea Resources Ltd.	Symons Hill	Nickel, Copper, Gold, Platinum, Chromite, Palladium, Rhodium, Cobalt	-31.7283	123.2784	Target Outline	unknown	Active
Independence Group NL, Buxton Resources Ltd.	Widowmaker	Nickel, Copper, Platinum, Cobalt, Palladium, Rhodium	-31.669	123.4696	Target Outline	unknown	Active
Western Areas Ltd., Strandline Resources Ltd.	Fowlers Bay	Nickel, Copper, Gold	-31.6485	132.3013	Target Outline	unknown	Active
Independence Group NL, Classic Minerals Ltd.	Fraser Range	Nickel, Copper, Cobalt, Zinc, Silver, Gold	-31.459	123.4572	Target Outline	unknown	Active
Independence Group NL, Creasy Group Pty. Ltd., Ponton Minerals Pty Ltd	Fraser Range North	Nickel, Copper, Cobalt, Platinum, Gold, Zinc, Silver	-31.363	123.6309	Target Outline	unknown	Active
Hannans Ltd	Queen Victoria Rocks	Nickel	-31.3021	120.8553	Target Outline	unknown	Active

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Kairos Minerals Limited	Roe Hills	Nickel, Gold, Cobalt, Copper, Platinum, Palladium, Molybdenum	-31.2278	122.5811	Target Outline	unknown	Active
Fraser Range Metals Group Ltd.	Fraser Range	Nickel, Copper	-31.0944	123.9664	Target Outline	unknown	Active
Legend Mining Ltd.	Mamba	Nickel, Copper, Gold, Palladium	-30.963	123.951	Target Outline	unknown	Active
Legend Mining Ltd., Creasy Group Pty. Ltd., Independence Group NL	Fraser Range	Nickel, Copper, Gold, Cobalt, Silver, Zinc	-30.7393	124.4457	Target Outline	unknown	Active
St Barbara Ltd.	Green Dam	Nickel, Copper, Platinum, Palladium, Gold	-30.7374	122.765	Target Outline	unknown	Active
Carnavale Resources Ltd., Mithril Resources Ltd.	Kurnalpi	Nickel, Gold, Cobalt, Copper, Zinc	-30.4882	122.1451	Target Outline	unknown	Active
Blackstone Minerals Ltd.	Silver Swan South	Nickel, Gold	-30.4672	121.6602	Target Outline	unknown	Active
Independence Group NL, Unnamed Owner	Big Red	Nickel, Copper, Cobalt	-30.2757	124.9722	Target Outline	unknown	Active
Great Boulder Resources Ltd., Mithril Resources Ltd.	Lignum Dam	Nickel, Gold, Platinum, Palladium, Copper	-30.2682	121.6534	Target Outline	unknown	Active
Capital Mining Ltd.	Scotia	Nickel, Cobalt	-30.1388	121.4087	Target Outline	unknown	Active
Independence Group NL, Arrow Minerals Ltd.	Plumridge	Nickel, Copper, Gold, Zinc	-30.0145	124.6098	Target Outline	unknown	Active
Independence Group NL, Carawine Resources Ltd.	Fraser Range	Nickel, Copper, Gold, Cobalt	-29.9861	124.855	Target Outline	unknown	Active
Impact Minerals Ltd.	Mulga Tank	Nickel, U_3O_8, Copper, Gold, Platinum, Palladium, Cobalt	-29.9151	123.2209	Target Outline	unknown	Active

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St George Mining Ltd.	East Laverton	Nickel, Gold, Copper, Platinum, Palladium, Magnesium, Zinc	-29.5174	123.324	Target Outline	unknown	Active
Superior Lake Resources Ltd.	Laverton	Nickel, Gold	-29.0442	121.8901	Target Outline	unknown	Active
Rossiter Minerals Ltd.	Calypso	Nickel, Copper	-29.0196	121.5629	Target Outline	unknown	Active
White Cliff Minerals Ltd.	Merolia	Nickel, Copper, Gold, Platinum, Palladium, Cobalt, Zinc, Iron Ore, Manganese, Magnesium	-28.8417	122.8428	Target Outline	unknown	Active
St George Mining Ltd., Western Areas Ltd.	Mt Alexander	Nickel, Copper, Cobalt, Platinum, Palladium, Gold, Silver	-28.8415	120.2452	Target Outline	unknown	Active
Acacia Coal Ltd.	Mt Windarra	Nickel, Cobalt, Copper	-28.514	122.2255	Target Outline	unknown	Active
Aldoro Resources Ltd.	Leinster	Nickel, Copper, Zinc	-28.2105	120.6996	Target Outline	unknown	Active
Private Interest	Falcon Bridge	Nickel, Copper	-27.8922	122.4208	Target Outline	unknown	Active
Venture Minerals Ltd., Muggon Copper Pty Ltd.	Caesar	Nickel, Copper, Cobalt, Gold, Silver, Zinc, Lead	-27.0235	115.4375	Target Outline	unknown	Active
Regis Resources Ltd., Robo 3D Ltd., Private Interest	Collurabbie	Nickel, Copper, Gold, Platinum, Palladium	-26.8852	122.2648	Target Outline	unknown	Active
Woomera Mining Ltd.	Alcurra-Tieyon	Nickel, Copper, Cobalt	-26.1808	133.7271	Target Outline	unknown	Active
VRX Silica Ltd.	Warrawanda	Nickel, Silica	-23.726	119.813	Target Outline	unknown	Active
Fin Resources Ltd., Cazaly Resources Ltd.	McKenzie Springs	Nickel, Graphite, Copper, Platinum, Cobalt, Palladium, Rhodium	-17.499	127.905	Target Outline	unknown	Active
Chalice Gold Mines Ltd.	King Leopold	Nickel	-16.9714	124.5649	Target Outline	unknown	Active

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
Independence Group NL, Buxton Resources Ltd.	Double Magic	Nickel, Copper, Cobalt	-16.9378	124.4611	Target Outline	unknown	Active
Dreadnought Resources Ltd., Whitewater Resources Pty. Ltd.	Yampi	Nickel, Copper, Gold, Zinc, Lead, Silver, Platinum, Tin, Bismuth, Cobalt, Arsenic, Molybdenum, Antimony	-16.5627	124.2079	Target Outline	unknown	Active
	Rocky Gully North	Nickel, Copper, Zinc	-34.476	117.354	Exploration	unknown	Inactive
	Gibson Soak	Nickel, Copper	-33.51	122.01	Exploration	unknown	Inactive
Ucabs Pty Ltd	Oldfield	Nickel, Copper	-33.494	120.552	Exploration	unknown	Inactive
	Deralinya	Nickel, Copper, Platinum, Palladium	-33.1431	122.5482	Exploration	unknown	Inactive
	Lake King	Nickel	-32.999	119.524	Exploration	unknown	Inactive
	Dundas	Nickel, Copper, Gold	-32.7083	122.8167	Exploration	unknown	Inactive
	Maggie Hays Hill	Nickel, Gold	-32.3071	120.6292	Exploration	unknown	Inactive
	Mt Thirsty South	Nickel, Manganese, Cobalt	-32.168	121.617	Exploration	unknown	Inactive
	Cowan	Nickel	-31.857	121.7791	Exploration	unknown	Inactive
Gondwana Resources Ltd.	Lindsays	Nickel	-31.848	119.878	Exploration	unknown	Inactive
	Cat Camp	Nickel, Copper, Platinum, Palladium, Cobalt	-31.8331	120.3479	Exploration	unknown	Inactive
	Boorara	Nickel	-31.461	121.914	Exploration	unknown	Inactive
	Hilditch	Nickel, Gold, Tantalum	-31.3024	121.4776	Exploration	unknown	Inactive
	Nepean South	Nickel, Copper, Gold	-31.1997	121.0567	Exploration	unknown	Inactive
	Londonderry	Nickel, Gold, Tantalum	-31.0972	121.0753	Exploration	unknown	Inactive
Metals X Ltd.	East Location 45	Nickel	-31.0194	121.7391	Exploration	unknown	Inactive
	Koolyanobbing East	Nickel, Gold	-30.853	119.608	Exploration	unknown	Inactive
	Koolyanobbing Central	Nickel, Gold	-30.8347	119.5613	Exploration	unknown	Inactive

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
	Koolyanobbing North	Nickel	-30.7836	119.4917	Exploration	unknown	Inactive
Barranco Resources NL	Mt Finnerty	Nickel	-30.6493	120.0666	Exploration	unknown	Inactive
	Kalgoorlie Regional Nickel	Nickel	-30.564	121.402	Exploration	unknown	Inactive
	Kawana	Nickel	-30.48	118.84	Exploration	unknown	Inactive
	Bardoc	Nickel, Cobalt	-30.3301	121.2812	Exploration	unknown	Inactive
	Silver Swan Northwest	Nickel, Gold	-30.3227	121.5484	Exploration	unknown	Inactive
	Earoo	Nickel	-30.2211	118.621	Exploration	unknown	Inactive
	Comet Vale	Nickel, Cobalt	-29.959	121.1442	Exploration	unknown	Inactive
	Shell Lakes	Nickel	-29.6667	127.1667	Exploration	unknown	Inactive
	Mt Marmion	Nickel, Copper	-29.3668	119.8254	Exploration	unknown	Inactive
	Minigwal	Nickel, Gold	-29.1894	122.5686	Exploration	unknown	Inactive
Unnamed Owner	Currans Well	Nickel, Platinum, Copper, Palladium, Rhodium	-28.807	118.757	Exploration	unknown	Inactive
	Youanmi	Nickel, Copper	-28.7372	118.6589	Exploration	unknown	Inactive
	Muleryon Hill	Nickel, Platinum, Palladium, Rhodium	-28.55	118.37	Exploration	unknown	Inactive
	Sidewinder	Nickel, Copper, Cobalt	-28.5332	118.5028	Exploration	unknown	Inactive
Red 5 Ltd.	Randles Find	Nickel, Copper, Platinum, Palladium	-28.4697	120.9961	Exploration	unknown	Inactive
	Leinster	Nickel	-28.1	120.8333	Exploration	unknown	Inactive
	Miranda	Nickel, Gold	-27.889	120.553	Exploration	unknown	Inactive
	Toby	Nickel, Platinum, Palladium	-27.55	136.1333	Exploration	unknown	Inactive
	West Bungarra	Nickel, Copper, Palladium, Platinum	-27.2995	119.5397	Exploration	unknown	Inactive
	Yarrabubba	Nickel, U_3O_8, Gold, Tin, Copper	-27.2367	118.8583	Exploration	unknown	Inactive
Rossiter Minerals Ltd.	Dingo Range	Nickel, Copper	-27.1893	121.3643	Exploration	unknown	Inactive

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PepinNini Lithium Ltd.	Musgrave	Nickel, Copper, Silver, Platinum, Lead, Zinc, Palladium, Rhodium	-27.0069	131.151	Exploration	unknown	Inactive
	Collurabie North	Nickel	-26.69	122.15	Exploration	unknown	Inactive
	Millrose	Nickel, Gold	-26.3574	120.9477	Exploration	unknown	Inactive
	Skirmish Hill	Nickel, Platinum, Palladium, Copper, Gold	-26.3283	128.4144	Exploration	unknown	Inactive
	Warburton	Nickel, U_3O_8, Copper	-26.03	127.4008	Exploration	unknown	Inactive
	Bell Rock Range	Nickel, Copper, Gold, Platinum, Palladium	-26	128.6	Exploration	unknown	Inactive
	Spinifex Range	Nickel, Copper, Vanadium, Titanium, Platinum	-25.9106	127.691	Exploration	unknown	Inactive
Anson Resources Ltd.	Hooley Well	Nickel, Cobalt, Chromium	-25.617	116.718	Exploration	unknown	Inactive
IronRidge Resources Ltd.	Quaggy	Nickel, Copper, Platinum, Palladium, Cobalt	-25.4701	150.6388	Exploration	unknown	Inactive
	Harts Range	Nickel, Copper, Gold, U_3O_8, Lanthanides	-23.2834	135.2273	Exploration	unknown	Inactive
	Treasure	Nickel, Copper, U_3O_8, Platinum, Silver, Palladium, Tungsten, Gold, Rhodium	-23.282	135.457	Exploration	unknown	Inactive
	Lilleyvale	Nickel, Platinum, Palladium	-22.6119	141.2208	Exploration	unknown	Inactive
	Arunta	Nickel, Copper, Lead, Zinc, Silver, Gold	-21.5814	133.2614	Exploration	unknown	Inactive
	West Pilbara	Nickel, Copper, Zinc	-21.0256	117.2406	Exploration	unknown	Inactive

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	East Pilbara	Nickel, Copper, Platinum, Palladium, Gold, Silver, Rhodium	-20.9429	119.9757	Exploration	unknown	Inactive
Sabre Resources Ltd., Sherlock Investors Pty Ltd, Metals Australia Ltd.	Sherlock Bay Extended	Nickel, Iron Ore, Copper, Silver, Gold	-20.816	117.5473	Exploration	unknown	Inactive
	Ruby Lakes	Nickel	-19	128	Exploration	unknown	Inactive
	Lindeman's Bore	Nickel, Gold, Palladium, Cobalt, Copper	-17.4892	130.1398	Exploration	unknown	Inactive
	Wave Hill	Nickel, Copper, Platinum, Palladium, Rhodium	-17.39	131.2	Exploration	unknown	Inactive
	East Kimberley	Nickel, Copper, Platinum, Palladium, Gold	-17.1481	127.9731	Exploration	unknown	Inactive
	Rayne	Nickel	-41.846	145.354	Grassroots	unknown	Inactive
	Renison East	Nickel	-41.803	145.473	Grassroots	unknown	Inactive
Encounter Minerals Pty Ltd	Casterton	Nickel	-37.485	141.357	Grassroots	unknown	Inactive
	Light	Nickel	-35.02	148.26	Grassroots	unknown	Inactive
ACH Global Pty Ltd., Traka Resources Ltd.	Bandalup	Nickel, Copper, U_3O_8, Lead, Gold	-33.648	120.273	Grassroots	unknown	Inactive
Australasian Mining Ltd.	Ravensthorpe	Nickel	-33.597	120.278	Grassroots	unknown	Inactive
	Bills Paddock	Nickel, Copper, Platinum, Palladium, Rhodium	-33.02	123.46	Grassroots	unknown	Inactive
	Wylie	Nickel, Copper, Platinum, Palladium, Rhodium	-32.91	124.245	Grassroots	unknown	Inactive
	Gambanca	Nickel, Copper, Platinum, Palladium, Rhodium	-32.56	124.46	Grassroots	unknown	Inactive

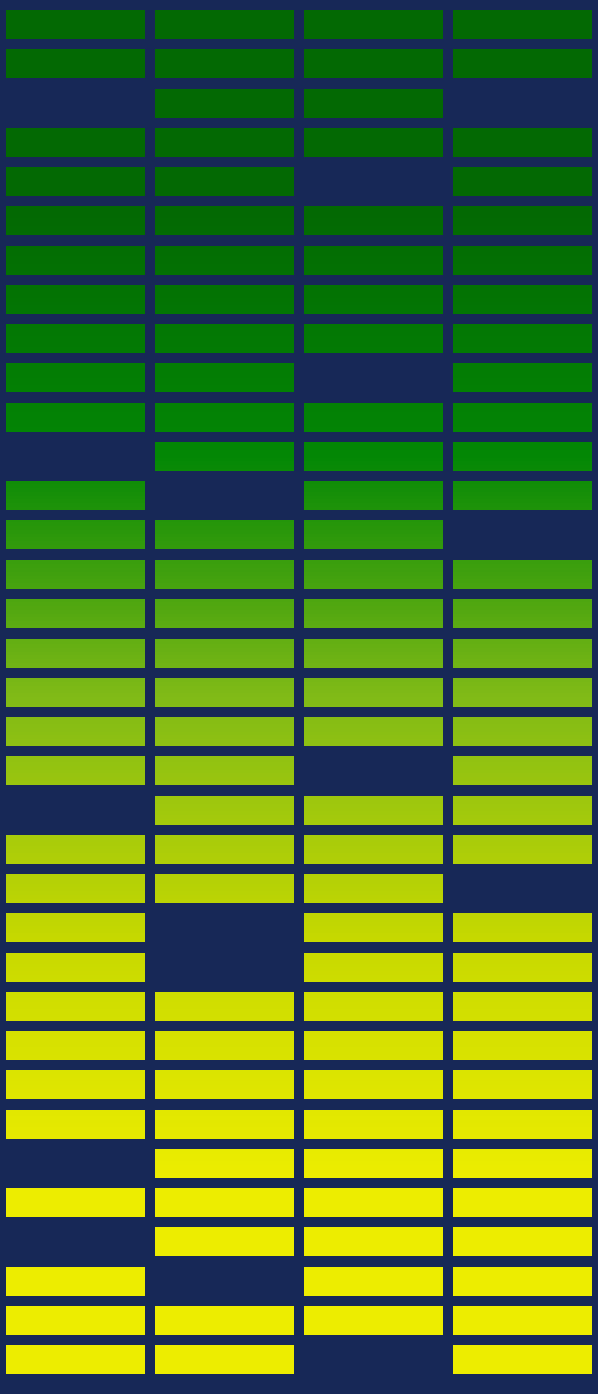
OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
	Jackaboy	Nickel, Copper, Platinum, Palladium, Rhodium	-32.34	123.86	Grassroots	unknown	Inactive
Kairos Minerals Limited	Fraser Range East	Nickel, Copper, Gold	-32.26	123.844	Grassroots	unknown	Inactive
Gondwana Resources Ltd.	Tamarin	Nickel	-31.635	119.57	Grassroots	unknown	Inactive
	Widgie South	Nickel	-31.513	121.592	Grassroots	unknown	Inactive
	Fraser Range	Nickel, Copper, Cobalt	-31.422	123.348	Grassroots	unknown	Inactive
Maincoast Pty Ltd.	Spa Go West	Nickel, Copper, Gold	-31.4	121.45	Grassroots	unknown	Inactive
Barrambie Minerals	Long Horse	Nickel, Gold	-31.38	120.91	Grassroots	unknown	Inactive
	Far East	Nickel, Copper	-31.2248	124.1914	Grassroots	unknown	Inactive
Private Interest	Bullfinch North	Nickel, Gold	-30.9392	119.0361	Grassroots	unknown	Inactive
	Koonenberry	Nickel, Copper, Platinum, Palladium, Rhodium, Gold	-30.7287	142.0445	Grassroots	unknown	Inactive
	Kitchener	Nickel, Copper	-30.65	124.3	Grassroots	unknown	Inactive
	Gidji	Nickel	-30.5786	121.4599	Grassroots	unknown	Inactive
	Koonenberry	Nickel, Copper, Platinum, Palladium, Rhodium	-30.16	141.63	Grassroots	unknown	Inactive
	East Salt Creek	Nickel, Copper	-29.61	125.06	Grassroots	unknown	Inactive
Bellmount Holdings Pty Ltd	Yerilla	Nickel	-29.5375	121.9281	Grassroots	unknown	Inactive
Sulphide Resources Ltd	Stella Range South	Nickel, Gold	-29.423	123.212	Grassroots	unknown	Inactive
	Stella Range	Nickel, Gold	-29.187	122.9724	Grassroots	unknown	Inactive
	Diorite Hill	Nickel, Gold	-28.5	122.52	Grassroots	unknown	Inactive
Gold Fields Ltd.	Vivien	Nickel, Gold	-27.698	120.565	Grassroots	unknown	Inactive
	Bellevue	Nickel	-27.64	120.555	Grassroots	unknown	Inactive
Australian Asiatic Gems	Maranoa	Nickel, Copper, Cobalt	-25.362	147.706	Grassroots	unknown	Inactive
	Nickel Hills	Nickel, Iron Ore	-23.5968	119.7813	Grassroots	unknown	Inactive

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
Gondwana Resources Ltd.	Bobs Bore	Nickel	-22.44	115.4	Grassroots	unknown	Inactive
	Pannawonica	Nickel, Copper	-21.14	116.59	Grassroots	unknown	Inactive
	Twin Table Hills	Nickel, Copper	-20.9	116.815	Grassroots	unknown	Inactive
	Minnamolka	Nickel	-18.175	145.118	Grassroots	unknown	Inactive
Kimberley Mining Pty Ltd	Argyle Corridor	Nickel, Copper	-17.522	129.253	Grassroots	unknown	Inactive
Uramin Pty Ltd, Kimberley Mining Pty Ltd	Ord East Basin	Nickel, Copper	-17.153	128.876	Grassroots	unknown	Inactive
	Waterloo	Nickel, Copper, Platinum, Palladium, Rhodium, Silver	-16.35	129.33	Grassroots	unknown	Inactive
Riding Resources Pty Ltd	Rosewood	Nickel, Copper, Platinum, Palladium, Rhodium	-16.29	129.3	Grassroots	unknown	Inactive
	Rocky Gully	Nickel, Copper, Graphite, Gold, Cobalt, Zinc	-34.4749	117.0027	Target Outline	unknown	Inactive
ACH Global Pty Ltd.	RAV 8	Nickel, Copper, Cobalt	-33.6039	120.3011	Target Outline	unknown	Inactive
	Nindilbillup	Nickel	-33.5931	120.2811	Target Outline	unknown	Inactive
	Ravensthorpe	Nickel, Copper	-33.5017	120.5492	Target Outline	unknown	Inactive
	Cockabidnie	Nickel, Cobalt, Copper, Lead, Zinc, Gold	-33.4908	136.418	Target Outline	unknown	Inactive
	Tottenham	Nickel, Cobalt	-32.0852	147.1681	Target Outline	unknown	Inactive
	Mt Day	Nickel, Copper, Cobalt	-32.0564	120.2728	Target Outline	unknown	Inactive
Blackham Resources Ltd.	Zanthus	Nickel	-31.893	123.486	Target Outline	unknown	Inactive
	Fraser Range	Nickel, Copper, Cobalt, Gold	-31.8676	122.8779	Target Outline	unknown	Inactive
OZ Minerals Ltd., Mithril Resources Ltd.	Coompana	Nickel, Copper, Platinum, Palladium	-31.1391	129.585	Target Outline	unknown	Inactive
	East Kambalda	Nickel	-31.1339	121.8808	Target Outline	unknown	Inactive

OWNERSHIP	PROPERTY NAME	PRODUCTS	LAT	LONG	STAGE	RESERVES AND RESOURCES TONNES	STATUS
	Mt Vetters	Nickel, Gold, U_3O_8	-30.4912	121.6455	Target Outline	unknown	Inactive
	Emu Lake	Nickel, Copper	-30.26	121.9335	Target Outline	unknown	Inactive
	Richie	Nickel, Cobalt	-30.2303	120.8604	Target Outline	unknown	Inactive
	Mulgarrie	Nickel	-30.1792	121.5189	Target Outline	unknown	Inactive
	Peel	Nickel, Copper	-29.9894	150.6159	Target Outline	unknown	Inactive
	Mt Remarkable	Nickel, Gold	-29.3531	121.7458	Target Outline	unknown	Inactive
WPG Resources Ltd.	Northern Gawler	Nickel, Copper, Gold, Iron Ore, U_3O_8	-29.321	134.013	Target Outline	unknown	Inactive
	White Cliff	Nickel	-28.9506	123.1025	Target Outline	unknown	Inactive
	Laverton Extended	Nickel, Copper, Platinum, Palladium, Gold	-28.575	122.3261	Target Outline	unknown	Inactive
Barrick Gold Corp.	Lawlers	Nickel, Gold	-28.0643	120.5963	Target Outline	unknown	Inactive
	McFarlanes Find	Nickel	-27.3358	120.5412	Target Outline	unknown	Inactive
	East Musgrave	Nickel	-26.6468	132.7867	Target Outline	unknown	Inactive
	Gunbarrel	Nickel	-26.4014	121.5161	Target Outline	unknown	Inactive
	Deering Hills	Nickel, Copper, Platinum, Palladium	-26.2259	129.906	Target Outline	unknown	Inactive
	Black Snake	Nickel, Copper, Gold, Silver	-26.1911	152.275	Target Outline	unknown	Inactive
	Camel Hills	Nickel, Copper, Gold, Iron Ore	-25.6817	116.605	Target Outline	unknown	Inactive
	Plenty River	Nickel, Copper, Gold, Diamonds	-23.4146	136.0952	Target Outline	unknown	Inactive
	Beasley	Nickel	-22.6989	117.2561	Target Outline	unknown	Inactive
	Lynd	Nickel, Gold	-19.0331	144.6925	Target Outline	unknown	Inactive
	Mabel Hill	Nickel, Copper, Cobalt	-17.6818	127.8528	Target Outline	unknown	Inactive

State of Play

AUSTRALIA'S BATTERY INDUSTRIES



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