BATTERY COMPONENT MANUFACTURING IN AUSTRALIA:

An extended Analysis and Evaluation of the Current Status, Potential Opportunities and Key Challenges

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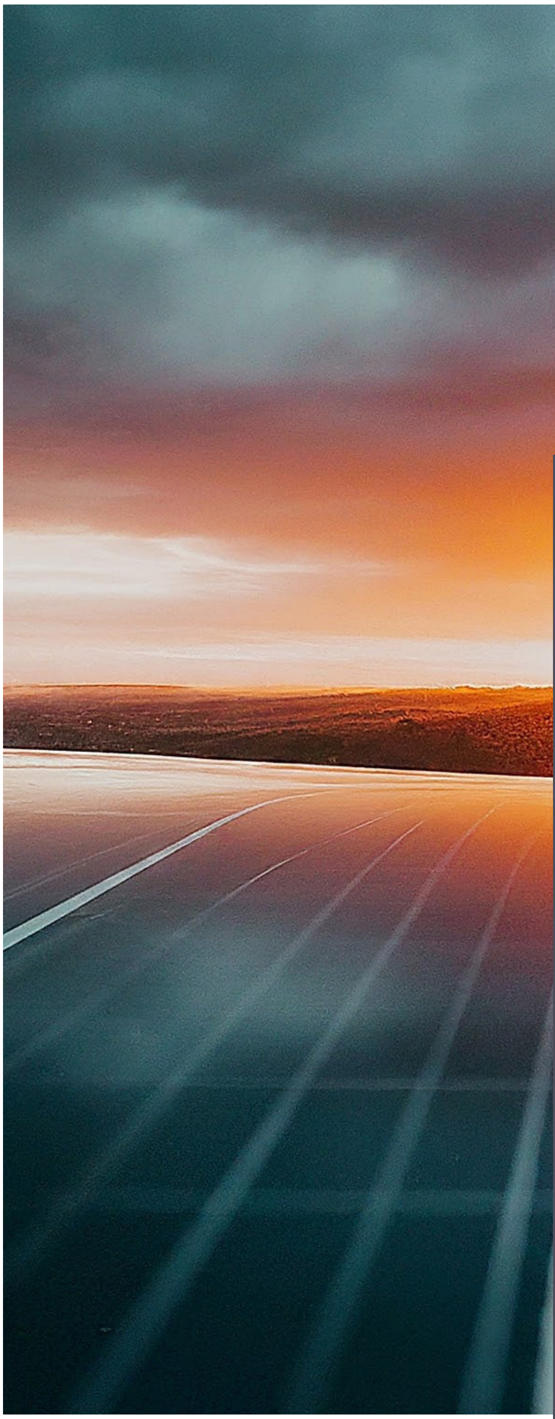
GRIFFITH UNIVERSITY QUEENSLAND AUSTRALIA
ICN Industry Capability Network
ambc Advanced Materials and Battery Council
UNIVERSITY OF WOLLONGONG AUSTRALIA
QUT Queensland University of Technology
UNIVERSITY OF SOUTHERN QUEENSLAND



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Associate Professor Nagesh Shukla, Griffith University
Dr Senevi Kiridena, University of Wollongong
Mrs Nimmi Pushparajan, Industry Capacity Network Queensland
Dr Lynette Molyneaux, Advanced Materials and Battery Council
Dr Nancy Spencer, Griffith University
Mr Abhi Arora, Industry Capacity Network Queensland
Dr Diwakar KC, Griffith University
Dr Towfique Rahman, Griffith University
Professor Ashok Kumar Nanjundan, University of Southern Queensland
Associate Professor Joshua Watts, Queensland University of Technology
Dr Wei Kong Pang, University of Wollongong

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Abbreviations

ABIC	Australilan Battery Industrialisation Centre
Al	Aluminium
AMBC	Advanced Material and Battery Council
AEMO	Australian Energy Market Operator
AEM	Anion Exchange Membrane
ARC	Australian Research Council
AMPAM	Centre for Advanced Materials Processing and Manufacturing
ANL	Argonne National Lab
ARMHub	Advanced Robotics Manufacturing Hub
AVL	Australian Vanadium Limited
BMS	Battery Management System
BTM	Behind-the-Meter
BYD	Build Your Dreams
Br	Bromine
C	Carbon
CAM	Cathode Active Material
CATL	Contemporary Amperex Technology Co. Limited
CMBTF	Critical Minerals and Battery Technology Fund
CMM	Centre for Microscopy and Microanalysis
Co	Cobalt
CRC	Cooperative Research Centres
Cu	Copper
DA	Development Application
DST	Defence Science and Technology Group
ESS	Energy Storage System
EV	Electric Vehicle
F	Fluorine
Fe	Iron
FTM	Front-of-the-Meter
FBICRC	Future Battery Industries CRC
FFI	Fortescue Future Industries
GMG	Graphene Manufacturing Group
HPA	High Purity Alumina
HV	High Voltage
ICN	Industry Capability Network
IEC	International Electrotechnical Commission
LDES	Long Duration Energy Storage
Li	Lithium
LiPF6	Lithium Hexafluorophosphate
Li-S	Lithium-Sulfur
LFP	Lithium Iron Phosphate
LMO	Lithium Manganese Oxide
LMFP	Lithium Manganese Ferro Phosphate
LV	Low Voltage
Mn	Manganese
NCA	Nickel Cobalt Aluminium Oxide
NMC	Nickel Manganese Cobalt
Ni	Nickel
NRF	National Reconstruction Fund
NTBC	National Battery Testing Centre
P	Phosphorus
PFSA	Perfluorinated Sulfonic Acid
QDEC	Queensland Depart. of Energy and Climate
QDESI	Queensland Depart. of Environment, Science & Innovation
QDRDMW	Queensland Depart. of Regional Development, Manufacturing and Water
QEJP	Queensland Energy and Jobs Plan
QUT	Queensland University of Technology
RFB	Redox Flow Battery
SC	Supply Chain
SCADA	Supervisory Control and Data Acquisition
TIQ	Trade and Investment Queensland
TAM	Total Addressable Market
UQ	University of Queensland
UQMP	UQ Material Performance
Uni-SQ	University of Southern Queensland
V	Vanadium
VRFB	Vanadium Redox Flow Battery
Zn	Zinc

Contents

Executive Summary

- Battery storage market in Australia is projected to undergo rapid growth within the current decade.
- Opportunities for Australian businesses to integrate into global battery supply chain spans across the entire value chain; e.g. critical minerals refining and processing, active materials manufacturing, and battery pack assembly.
- Australia can capture more value and secure a stronger position in the global battery supply chain (SC) through investments and innovations in the space of producing active materials used in battery components.
- Investing in next-generation and emerging technologies and focusing on specialised applications hold promise for developing a competitive advantage in the longer run, and establish as a key player in the global battery SC.
- Australia has a relative advantage in producing flow batteries for stationery storage and assembling lithium-ion batteries for niche applications, compared to the highly competitive electric vehicles market.
- Priority areas for strengthening component manufacturing in Queensland include strategic investments in research and development for developing membrane materials, producing battery-grade foils and selected active materials.
- Understanding market dynamics, accessing capital, and meeting regulatory requirements are all key factors affecting the capacity of Australian businesses looking to scale up their operations.
- Lack of local testing facilities, skilled workforce, and access to reliable suppliers, as well as inconsistent regulatory regimes, developing government support compared to some international markets, and the abscence of comprehensive collaborations are major barriers to strengthening domestic manufacturing in Australia.
- Australia's technology infrastructure, regulatory setting and investment climate all need to be substantially strengthened for it to become a key player within the global battery supply chain.

This study was commissioned by the Queensland Government. This study undertook a comprehensive analysis of the current state of battery component manufacturing in Australia, identifying challenges faced against the potential for domestic value-add and value capture. This analysis was followed by a rigorous evaluation of the key opportunities for growth, considering market dynamics, technology trends, and Australia's unique advantages. The analysis and evaluation served as the basis for making a set of key findings aimed at developing a robust battery component manufacturing industry in Queensland and more broadly in Australia.

The study consisted of: (i) a comprehensive desk research component aimed at analysing the existing literature and a value chain analysis to understand the broader context of battery manufacturing; and (ii) a mixed-method primary data collection component consisting of interviews and surveys with mainly Queensland business stakeholders aimed at assessing the current state of battery component manufacturing in Australia. Insights drawn from both the desk research and empirical data analysis were used to identify the challenges faced by the industry and potential for local value-add and value-capture, as well as opportunities for strengthening and developing Queensland's battery component manufacturing sector.

Detailed findings of the study in the form of alternative battery technologies, battery industry value-adding potential, industry survey results and insights drawn from the interviews conducted with key industry players, along with the opportunities for strengthening domestic battery component manufacturing, are presented under each chapter of this report. The key findings for building and supporting a robust battery component-manufacturing sector are also presented in separate chapters and summarised in the conclusion.

Driven by the increasing share of clean energy in the country's power generation mix, and in line with the current global trend, the battery storage market in Australia is projected to undergo rapid growth within the current decade. The growth in domestic and global demand for a diverse range of batteries creates multiple opportunities for Australian manufacturers to integrate into the global battery supply chain. These opportunities cover all segments of the value chain; e.g. minerals extraction, raw minerals refining and processing, active materials manufacturing, and battery pack assembly. Battery cell manufacturing and recycling of used batteries are at the early stages of development in Australia.

At present, Australia's competitive advantage stems from its strong performance in the space of mining and exploration, with further opportunities for expanding into downstream activities of refining and processing, as well as developing bespoke battery systems to suit local conditions. Australia already has a highly competitive minerals extraction sector with significant reserves of critical minerals; e.g. lithium, nickel, cobalt, vanadium, graphite, and more. This offers the potential for cost-effective extraction of critical minerals used in battery manufacturing to remain competitive in the global market. Expanding beyond ore extraction into refining and processing of raw minerals presents substantial opportunities for value-add. Australia can capture more value and secure a stronger position within the global battery supply chain through investments and innovations in the space of producing active materials used in battery components.

Australia possesses world-class R&D capabilities for supporting a viable component-manufacturing sector. Investing in next-generation and emerging technologies such as lithium-sulphur and graphene aluminium-ion batteries and focusing on specialised applications (e.g., mining, defence, agriculture) hold promise for developing a competitive advantage. In terms of more mature technologies, Australia has a relative advantage in focusing on producing flow batteries for stationery storage and assembling lithium-ion batteries for special applications, compared to producing lithium-ion batteries for the highly competitive electric vehicles market. In terms of integrating into global supply chains, Australia can consider multiple entry points and pathways outlined (elsewhere) in this report. Priority areas for strengthening component manufacturing in Queensland include strategic investments, including research and development, into developing membrane technologies and materials, high-purity Aluminium, Copper and Lithium foils and selected active materials used in component manufacturing.

Securing off-take agreements with established international players is a key prerequisite for Australian businesses looking to integrate into global supply chains. Prior to entering into these agreements, businesses must demonstrate the technical feasibility and economic viability of full-scale production. This requires navigating a multi-stage qualification process for cell manufacturing, involving laboratory-scale development, proof-of-concept and pilot production, which demands varied levels of investments, technological capabilities and testing and certification systems. Understanding market dynamics, accessing capital, and meeting regulatory requirements are all key factors affecting the capacity of Australian business looking to scale up their operations. Lack of local testing facilities, skilled workforce and access to reliable suppliers, as well as inconsistent regulatory regimes, limited government financial support compared to some international markets and collaborations are all acting as barriers to strengthening domestic manufacturing in Australia.

The study underscored the substantial potential to develop a robust domestic battery component manufacturing industry, for which the country's rich mineral reserves and emerging technological capabilities provide a strong foundation. However, to establish itself as a key player within the global battery supply chain, Australia's technology infrastructure, regulatory setting and investment climate all need to be substantially strengthened. Currently, several countries, particularly those in Asia, dominate the global battery supply chain. To seize the significant economic, environmental, and social benefits presented by the expanding clean energy sector, a number of other countries are already investing heavily into developing domestic battery manufacturing, as well. In Australia, there are already a range of government initiatives, at both state and federal levels, aimed at supporting and promoting the sector. However, all stakeholders should act decisively and collectively to enable domestic component manufacturing to successfully integrate into the global battery supply chain.

To attract capital into the Australian battery-manufacturing sector, it is vital to cultivate a more favourable investment climate. The range of possible enabling measures in this space include targeted government incentives in the form of grants or co-investments, as well as facilitating foreign direct investments, which could mitigate risks and build confidence of the industry. Proactive efforts to streamline regulatory processes and simplifying permitting procedures will further enhance Australia's attractiveness as a destination for investment. Additionally, fostering partnerships between research institutions, universities and the private sector in terms of directing the limited pool of resources available towards advancing the readiness of next generation technologies can help scale up production.

Australia risks being trapped in a vicious cycle where limited capital investment and a fragmented ecosystem hinder the development of a robust domestic battery-manufacturing sector. This creates a self-perpetuating situation where a perceived lack of scale and success discourages further investment, ultimately hampering Australia's ability to capitalize on the growing global market. To break this cycle and create a self-reinforcing, virtuous cycle, a paradigm shift is required. Significant interventions through targeted capital injections, stronger collaborative networks, and risk mitigation measures like loan underwriting are crucial. Such decisive actions will catalyse innovation, attract global partners, accelerate the development of necessary infrastructure, and signal a clear commitment to establishing Australia as a major contender in the global battery industry.

1 | BACKGROUND TO THE STUDY

1.1 Energy transition landscape, the role of stationary energy storage, and batteries for electrification

Australia is rapidly expanding its clean energy capacity, particularly in the solar and wind sectors. Battery Energy storage systems (BESS) play a crucial role in integrating these intermittent energy sources into the grid, ensuring a stable and reliable power supply. Additionally, Australia has one of the most volatile electricity markets in the world (due to the aging coal infrastructure, natural disaster impacts, rapid clean energy growth, and insufficient energy storage and transmission capacity), making energy storage essential for balancing supply and demand, and stabilizing prices [1]. The BESS totalling 757MW were commissioned in Australia in 2023 at a value of AU$995million [2]. BESS installations in 2023 comprised 30% of all projects since 2017 and 53% of the value of all projects since 2017. This growth is driven by the increasing share of clean energy in the country's power generation mix and energy volatility, making battery storage a critical part of secure electricity supply in the National Electricity Market [3].

Australia will need 19 GW of energy storage (BESS, virtual power plants, pumped hydro) capacity for the National Electricity Market by 2030, increasing to 43 GW by 2040 [10]. Investment required to meet this forecast is expected to attract USD$262 billion in investment between 2021 and 2030. The growth in domestic and global demand for a diverse range of batteries creates a significant opportunity for Australian battery manufacturers. The recently announced National Battery Strategy will support Australian manufacturers to make the most of these opportunities [46].

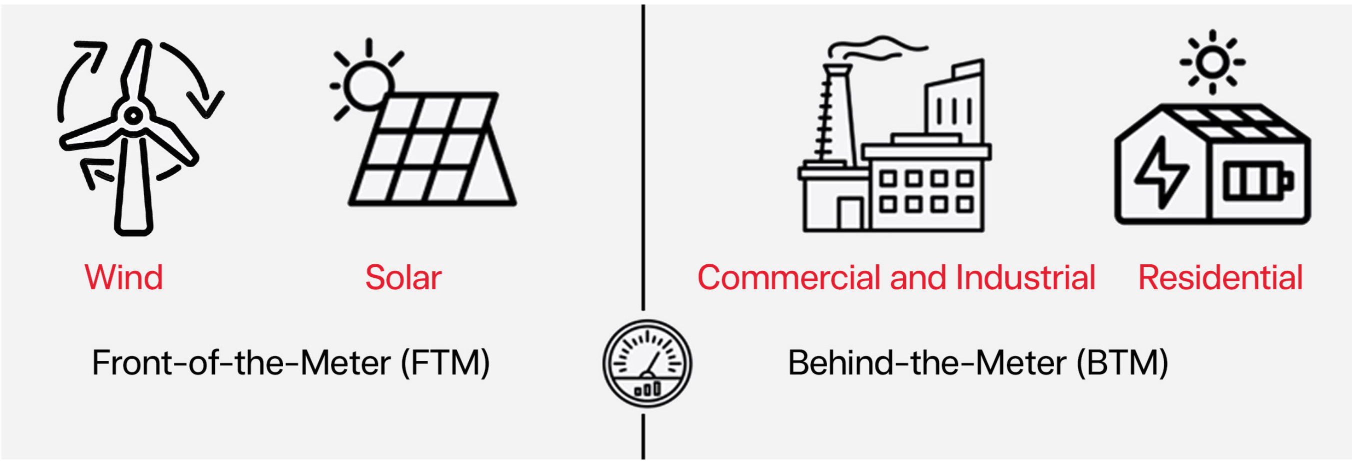
Stationary energy storage using batteries refers to the use of battery systems installed at the fixed locations of the grid, commercial/industrial sites, or residential premises for storing energy. Battery energy storage could be grouped in terms of Front-of-the-Meter (FTM) and Behind-the-Meter (BTM) systems (see Fig 1). FTM storage represents utility-scale systems (located at substations) to leverage economies of scale to benefit the entire grid. It helps to integrate clean energy sources like wind and solar by storing excess power during high generation periods and releasing it during peak demand. BTM storage, by comparison, sits on the customer's side of the meter, at commercial buildings or residential buildings. This allows for peak demand management, backup power for commercial/industrial applications and for residential consumers to take advantage of feed-in tariffs (FTM) by storing solar energy during the day and for subsequent use at night.

Batteries, particularly lithium-ion (Li-ion) and flow batteries, are useful for stationary energy storage. Safer and cheaper lithium iron phosphate (LFP) batteries are most commonly used for utility-scale storage. However, more-energy dense nickel manganese cobalt (NMC) chemistries could also take a part of the market share, despite relatively higher costs [4]. Li-ion batteries are known for their high energy density, making them suitable for a wide range of applications, from small-scale residential systems to large utility-scale installations. In comparison, flow batteries are valued for their ability to store large amounts of energy over extended periods and their long cycle life. Both technologies are well-suited to support the integration of clean energy sources and contribute to the stability and reliability of the grid [3].

Compared to the situation with stationary storage, the rapid rise of the electric vehicle (EV) battery market presents a complex challenge for Australia. The intense competition from established global players makes it difficult for Australia to carve out a significant market share in EV battery manufacturing. However, Australia's strong potential in clean energy and grid stabilisation makes the energy storage market a more suitable focus, providing a unique opportunity to leverage existing strengths and establish a competitive position.

Globally, several countries have started seizing the opportunities of the "battery decade" with a range of targeted initiatives. At present, China dominates the battery manufacturing segment and has strategically secured a formidable position within the global supply chain. The United States is investing heavily in domestic battery production and innovation programs. Europe, through initiatives like the European Battery Alliance, is fostering a comprehensive

Figure 1: Stationary energy storage classification



battery ecosystem, prioritising research, sustainable practices, and a robust domestic industry. Furthermore, the global need for securing supplies of critical minerals is driving a surge of government interventions. Prominent examples include the European Union's Critical Raw Materials Act, and Australia's Critical Minerals Strategy. According to the IEA, there are nearly 200 such policies worldwide, with over half of them implemented in recent years. These policies often reshape trade and investment patterns. Some countries, like Indonesia, Namibia, and Zimbabwe, are restricting the export of unprocessed minerals to boost their domestic industries. This trend of export restrictions has grown significantly since 2009, reflecting the intense global race to secure a competitive position in the booming battery sector.

The dynamic global landscape of energy transition and battery storage offer significant opportunities, as well as a raft of challenges, for countries like Australia aspiring to participate in global supply chains.

1.2 Analysis and evaluation of the Australian battery market; current status, trends, and projections

Currently, the Australian battery market is witnessing significant growth driven by several factors such as increasing uptake of clean energy, reduced reliance on coal power generation, government support, and advancements in battery technologies. Australian Electricity Market Operator's (AEMO) 2022 report estimates that about 90% of the current 21 gigawatts of coal capacity would retire by 2034-35 [10]. This underscores the effort needed to increase the clean energy generation and energy storage capacity.

In the residential sector, there is a growing trend towards home energy storage solutions fuelled by the desire for energy independence and cost savings. Similarly, commercial and industrial sectors are adopting battery storage systems to reduce peak demand charges and enhance energy resilience. Furthermore, grid-connected battery storage projects are being deployed to support the integration of clean energy sources and improve grid stability. In Australia, there has been significant interest in employing batteries for a variety of energy storage applications. In telecommunications, batteries are being used as a backup power source for remote towers and maintaining connectivity in case of grid interruptions [15], whereas, in mining, they are being used for reducing reliance on expensive diesel generators [16]. In agriculture, batteries are being used to power pumps during off-peak hours and powering critical systems in off-grid or weakly connected areas [17]. Furthermore, there are several emerging sectors such as EV charging stations, community-scale microgrids for enhanced resilience [18], and battery systems for defence applications [19].

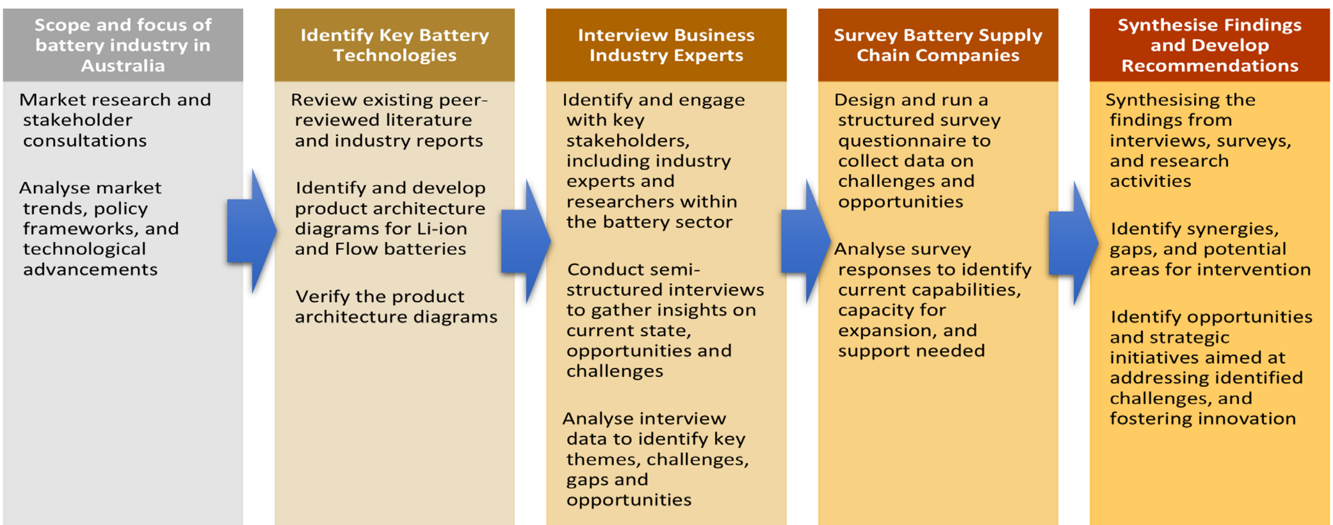
According to AEMO's most likely future scenario on expected energy transition, Australia needs to add energy storage (batteries, pumped hydro, virtual power plants) capacities to the tune of additional 2GW every year till 2030 then to 61GW in 2050 [9]. This implies a 7-fold increase to 2030 and 30-fold increase to 2050. These projections indicate continued expansion in the Australian battery market, with forecasts suggesting substantial investment and deployment in the coming years to meet the energy needs of various stakeholders and contribute to the transition towards a sustainable energy future.

The above analysis and evaluation of the Australian battery market reveals a dynamic landscape across various sectors including residential, commercial, industrial, and grid-connected applications.

1.3 Methodological approach followed

The methodological approach followed in this study involved: (i) evaluating and synthesising the current body of battery manufacturing literature (desk research) to establish the context for the study and conducting a value chain analysis to identify value-add potential; (ii) collecting and analysing empirical data using a mixed-method approach (one-on-one interviews and questionnaire surveys) to establish the current state of battery manufacturing in Queensland; and

Figure 2: Overall methodological approach



(iii) using the findings of (i) and (ii) above for identifying gaps and opportunities in relation to strengthening the Queensland battery component manufacturing sector. A brief outline of the key activities completed is provided in Fig 2.

Considering the scope of previous, comparable studies undertaken in Australia and elsewhere, and following initial stakeholder consultations, the broader scope of the study was set to an extended analysis of the battery component manufacturing in Queensland, with limited coverage of other States, as feasible.

To establish the background for the study, existing literature on market trends and battery technologies was reviewed and summarised. Through this, lithium-ion and flow batteries were identified as the two key battery technologies to focus on, with limited references to the next generation and emerging technologies, as needed. Product architectures for these two technologies were then developed to inform both the value chain analysis and cost analysis, which in turn was used to estimate the potential value-add at each stage of the battery supply chain.

Over 20 interviews with primarily Queensland-based businesses directly involved in some form of battery component manufacturing were conducted to understand their perspectives on the current state of manufacturing. The interviews covered the key aspects of scope of operations, suppliers and markets, future expansion plans, current and anticipated challenges, potential opportunities, and expected policy measures to support domestic supply chain development. A questionnaire survey was also administered among a larger sample of 426 Queensland-based companies, identified as those who could directly or indirectly involved in manufacturing battery components. The survey aimed to gather insights into various aspects, including company operations, scope of work, business growth phases, challenges faced, and responses to government support programs. The descriptive statistics derived based on the 61 responses (15.5% response rate) received are summarised in a separate section of this report.

The findings of the literature review and the results from the empirical data analysis were synthesised to arrive at opportunities for strengthening the battery component-manufacturing sector in Queensland in particular and in Australia more broadly. Based on these analyses, a series of key findings were presented for developing a robust battery component manufacturing sector in Queensland.

2 | INTRODUCTION TO BATTERY TECHNOLOGIES

2.1 Alternative battery technologies, battery chemistries, and applications

Alternative battery technologies encompass a wide array of chemistries and associated manufacturing processes with varying levels of performance in terms of safety, energy density, power and cyclability. These alternative technologies include mature options such as nickel manganese cobalt oxide (NMC), lithium iron phosphate (LFP) and nickel cobalt aluminium oxide (NCA), as well as next-generation options like sodium-ion, lithium-sulphur and lithium-air batteries. Additionally, flow batteries of different chemistries are increasingly considered as a viable alternative for medium-long duration stationery storage applications. Emerging technologies such as solid-state batteries and other forms of metal air batteries are gaining attention for their potential to address the limitations of currently available technologies in terms of energy density, safety, and cost-effectiveness. Understanding the diverse landscape of mature, next-generation, and emerging battery technologies is crucial for identifying suitable applications ranging from portable electronics, stationary energy storage and transportation.

2.2 Mature, next generation, and emerging technologies

In terms of alternative battery technologies, mature, next-generation and emerging options each hold promise for different applications. In the case of the EV sector, while lithium nickel manganese cobalt oxide (NMC) remain the dominant player with a 60% market share, lithium iron phosphate (LFP) batteries are making significant strides, capturing nearly 30% of the market and nickel cobalt aluminium oxide (NCA) also holds a respectable share of around 8% [20]. However, LFPs stand out for their established track record within the short-duration stationery storage market, compared to other chemistries. Estimates suggest that LFP accounts for a significant portion, potentially exceeding 70% of the current stationary storage battery market according to some analyses [5]. As such, LFPs have found widespread use in both electric vehicles and grid-scale energy storage segments, particularly due to their long cycle life and enhanced safety features, as well as cost effectiveness.

In 2022, nearly 95% of all LFP batteries for EV were produced by China. The Chinese manufacturer BYD dominates LFP battery demand with a staggering 50% share of the global market. Tesla has a market share of 15%, indicating a growing preference for LFP batteries. Although currently there is no commercial-scale production of these batteries in Australia, some businesses are assembling lithium-ion battery packs using imported cells, whereas others are developing and testing alternative battery technologies. Established companies like BHP are contributing by producing key Li-ion battery materials like nickel sulphate. For instance, BHP has commenced construction of a nickel sulphate plant at the Kwinana Nickel Refinery, south of Perth [21]. Start-ups like Energy Renaissance are actively pursuing commercial Li-ion battery production, focusing on safe and reliable batteries suited for Australia's climate conditions across various applications [22]. Li-S Energy is also making significant progress with the development of Lithium-Sulphur and has opened a pilot production facility (with 2MWh capacity) at Geelong (VIC) [23]. Li-S claims that their batteries have the potential for much higher energy density, compared to Li-ion, translating to potentially longer-range EVs or smaller, lighter batteries for electronics. Graphene Manufacturing Group (GMG), based in Brisbane (QLD), is developing a novel Aluminium-ion battery with advantages like potentially faster charging times, lower costs, and improved safety. While it is still in the early stages of development, their Aluminium-ion battery represents a promising avenue for future energy storage solutions.

Moreover, longer duration energy storage options like flow batteries are gaining momentum, offering scalable energy storage solutions suitable for grid applications and clean energy integration. Flow batteries, which include chemistries such as zinc-bromine and vanadium redox, are known for their flexibility, rapid response times, and ability to decouple power and energy capacity, making them well suited for applications requiring frequent cycling and high-power output. Published reports suggest that redox flow batteries (RFBs) have demonstrated their potential for commercial-scale production in Queensland. For example, ESI-Asia Pacific, a leading iron flow battery manufacturer, secured a significant deal with Stanwell Corporation for a pilot project utilising long-duration iron flow batteries [6]. Vecco Group is establishing Australia's first vanadium electrolyte manufacturing facility in Townsville. Similarly, the Critical Minerals and Battery Technology Fund (CMBTF) has provided support to the development and construction of a large-scale manufacturing facilities [24].

Emerging technologies hold significant promise for addressing the evolving needs of modern energy storage systems, providing solutions that balance performance, cost-effectiveness, and sustainability across various sectors. For example, solid-state batteries are heralded for their potential to enhance safety and energy density, while metal-air batteries, such as zinc-air and aluminium-air, offer high energy densities and are being explored for use in electric vehicles and grid-scale energy storage.

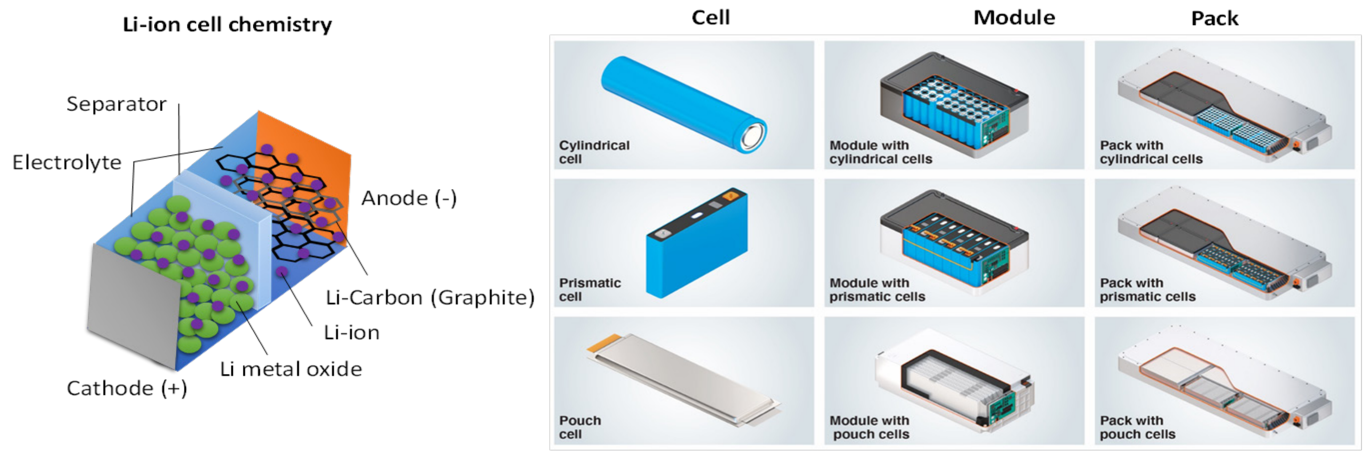
2.3 Generic product architectures for selected battery technologies

Li-ion batteries

A Li-ion battery consists of multiple modules of cells connected and housed in series, parallel or combination series-parallel, serving as the power source. These modules are managed through a low-voltage battery management system responsible for advanced monitoring and controlling of the battery operation. Figure 3 provides a visual representation of the Li-ion cell components, cylindrical, prismatic and pouch cell-based module and pack. Figure 4 illustrates a list of major components of the Li-ion battery pack. Appendix 1a provides a list of the components required for a LiB based energy storage systems. The physical components are depicted using a hierarchical structure incorporating parts, components, sub-assemblies and the final assembly. For LiBs, the raw materials can include active materials, chemicals or other metals or polymers etc. used in producing battery cells, battery modules and battery packs. The product architecture also includes integration into EVs, energy storage systems or consumer products. Cell components can include cathode and anode materials, aluminium foils, copper foils, polymer separators, electrolytes, membranes, and casings.

Redox Flow Batteries (RFBs)

Figure 3: A schematic diagram of Li-ion cell components with visual representation of the cylindrical, prismatic and pouch cell based module and pack



(adapted from https://www.hioki.com/in-en/industries-solutions/manufacturing/rm3545.html)

Figure 4: Major components of a typical Li-ion battery packs

Housing The outer protective shell of the battery pack.	Battery Module A collection of battery cells connected in series and/or parallel.	Low Voltage (LV) System	High Voltage (HV) System	Thermal System Maintains the battery pack at optimal operating temperatures.

• Tray: Holds and organizes the battery modules.
• Cover: Protects the internal components from the environment.
• Sealing: Prevents moisture and dust from entering the pack.
• Reinforcement: Provides structural strength and rigidity.
• Pressure Compensation: Allows for the release of gases produced during normal operation.
• Overpressure Vent: Vents excessive pressure in case of a thermal runaway event.
• Fastener: Secures the cover and other components.
• Label: Displays important information about the battery pack.
• Fire Protection Material: Protects against fire propagation in case of a thermal event.
	• Housing: Protects the cells and provides electrical insulation.
	• Cell Positioning: Ensures proper alignment and spacing of the cells.
	• Cell Contacting: Provides electrical connections between the cells.
	• Filler Material: Fills gaps between cells and provides thermal management.
	• Battery Cell: The basic unit of a Li-ion battery.
	  • Housing: Contains the electrode stack and electrolyte.
	  • Electrode Stack: Consists of alternating layers of positive and negative electrodes.
	  • Electrolyte: A liquid or gel that allows ions to flow between the electrodes.
		• Battery Management System (BMS): Monitors and controls the battery pack, ensuring safe and efficient operation.
		• LV Connector: Connects the battery pack to the vehicle's low voltage system.
		• HV Interlock: Disconnects the high voltage system when the LV system is disconnected.
		• LV Plug: Provides a connection point for LV accessories.
		• Insulation Monitor: Checks the electrical isolation between the high voltage and low voltage systems.
			• HV Plug: Connects the battery pack to the vehicle's high voltage system.
			• Junction Box: Distributes high voltage power to the motor and other components.
			• HV Connector: Connects the junction box to the motor and other components.
				• Interface: Transfers heat between the battery pack and the cooling system.
				• Temper Structure: Distributes heat evenly within the battery pack.
				• Temperature Sensor: Measures the temperature of the battery pack

A RFB consists of the electrolyte contained in tanks, the cell stack including electrodes, gaskets, bipolar plates, sealants, and a membrane which allows ion exchange. A schematic diagram representing RFB components is provided in Fig 5. Battery management is achieved with electrical components and supervisory control and data acquisition (SCADA) for communication. Figure 6 provides a list of major components of a typical flow battery-based energy storage systems. Appendix 1b provides a list of components required for RFBs based energy storage systems.

Figure 5: A schematic diagram of redox flow battery with cell components

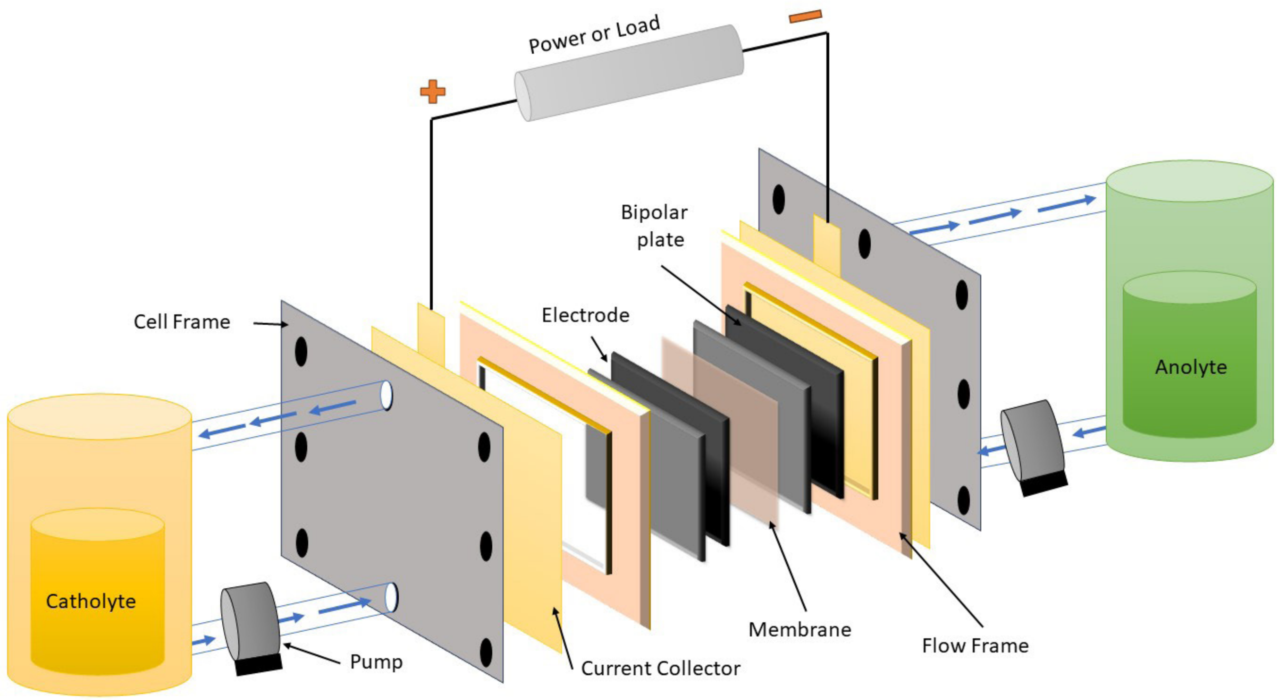
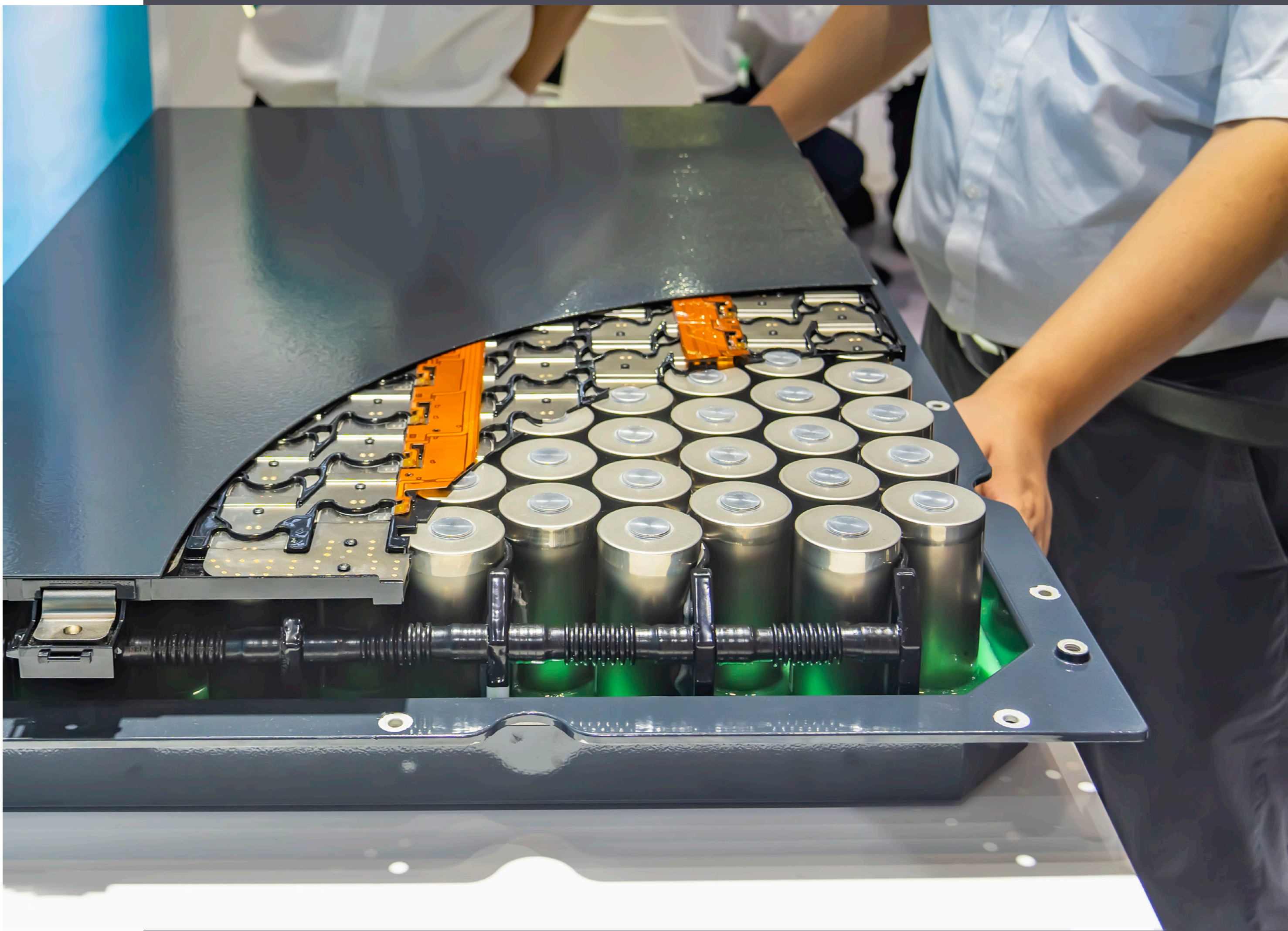


Figure 6: Major components of a typical flow battery-based Energy Storage Systems

Battery The flow battery cell used in the energy storage system.	Battery Venting (Hydrogen Venting) A safety mechanism to prevent overpressure in the system.	Battery Safety (Secondary Containment) Protects against leaks and spills.	Electrical Hardware The physical components that carry and distribute electrical current.	Electrical Components Control and manage the flow of electricity.
• Tanks: Hold the liquid electrolytes (anolyte and catholyte). • Pump: Circulates the electrolytes between the tanks and the cell stack. • Current Collectors: Conductive plates that collect the electrical current produced by the electrochemical reactions. • Electrodes: The surfaces where the electrochemical reactions take place. • Membrane: A separator between the positive and negative electrolytes, allowing ion exchange but preventing mixing. • Bipolar Plates: Conductive plates that connect the cells in the stack in series and provide flow channels for the electrolytes.	• Pressure Relief Valves: Release excess hydrogen gas produced during charging.	• Leak Detection: Sensors and systems to identify electrolyte leaks. • Containment: Trays or bunds to collect any spilled electrolyte.	• Connectors: Join wires and cables. • Distribution Blocks: Distribute power to multiple circuits. • Fuses: Protect circuits from overcurrent. • Lugs: Terminate wires on electrical components. • Wire: Carries electrical current. • Bus Bars: Large, rigid conductors for high currents.	• Power Supplies: Convert AC power to DC power for charging. • Inverters: Convert DC power from the battery to AC power for use. • Contactors: Control the flow of high currents. • Breakers: Protect circuits from overloads and short circuits.
Mechanical Enclosure (Tricon) Houses and protects the battery components.	**Mechanical Hardware** Provides structural support and secures components.	**Mechanical Structure** The overall framework of the system.	**Safety** Protects personnel and equipment.	**SCADA/ Communication** Monitors and controls the flow battery system.
• Enclosure: A protective housing.	• Nuts, Bolts: Secure the components together. • Backplates: Support and mount components. • Cable Trays: Organize and route cables.	• Internal Frame: Provides structural support for the components.	• Gas Sensors: Detect the presence of hydrogen or other hazardous gases. • Interlocks: Prevent unsafe operation by disabling components or systems. • Smoke Detectors: Detect fires.	• Controller: Manages and monitors the system. • Data Converters: Translate data between different formats. • Ethernet Switch: Connects devices to the network. • Modem: Provides internet connectivity. • Antenna: Transmits and receives wireless signals. • Display: Shows system status and data.



3 | VALUE CHAIN ANALYSIS

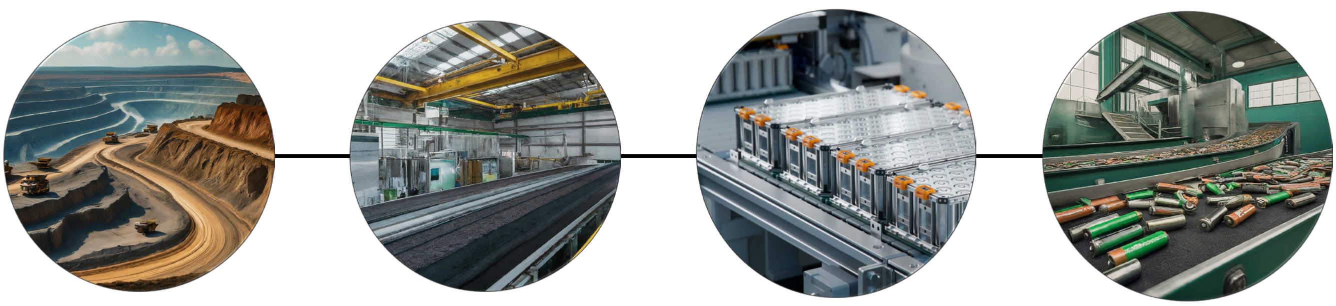
Key Findings

- The global demand for Li-ion batteries is projected to reach 4,700 GWh by 2030. Australian domestic demand is forecast to provide 90 GWh of demand to 2030, including 26 GWh of Queensland demand.
- While currently EVs represent the largest segment of the aggregate battery demand, stationary energy storage systems emerge as the fastest-growing sector.
- Chemicals and active materials represent the bulk of the total cost and weight of LFP battery packs, whereas the membranes represent the highest cost component of flow batteries.
- Cell manufacturing is estimated to represent $121 billion (30%) of the projected Li-ion battery market ($400 billion) by 2030, which offers the highest potential for the value-add across the supply chain. However, cell manufacturing is at a very early stage of development in Australia.
- Active materials manufacturing, valued at $110 billion (27%), represents the second-largest opportunity for value addition. Australia could exploit this opportunity by extending its ore extraction capabilities to cover chemicals refining and materials processing for developing a competitive advantage in the longer run.
- Module and battery pack assembly, accounting for $74 billion (18%), provides opportunities for value addition through design and management of bespoke battery systems to suit local conditions.

3.1 Upstream, midstream, downstream, and recycling segments

The battery value chain represents the multiple stages of value addition involved in transforming raw minerals into final products, including various battery chemistries tailored for specific ESS, EVs and other applications. Value chain analysis helps identify opportunities for value creation and capture by various supply chain partners involved, considering access to resources, capabilities and other infrastructure. It also allows prioritising investments and facilitating supply chain development through appropriate actions. However, compared to other more mature products, mapping the battery value chain poses some challenges due to the ongoing evolution of manufacturing technologies, which is largely driven by the emergence of new battery chemistries [43]. The battery value chain is organised in terms of four segments: upstream, midstream, downstream and recycling, with each of them representing a set of value adding processes as shown in Figure 7.

Figure 7: Segments of the battery value chain



Upstream segment

The upstream segment involves the extraction of raw materials, primarily the minerals essential for battery production. For lithium-ion batteries, the key minerals include lithium, cobalt, nickel, and graphite. Lithium is typically sourced from spodumene or brine, while cobalt and nickel are often extracted alongside other metals. Graphite, used in lithium-ion battery anodes, comes from the natural graphite ore and can also be made synthetically. Most global brine production originates from Argentina, Bolivia, and Chile, with Australia being the primary source of spodumene-based hard rock production [45].

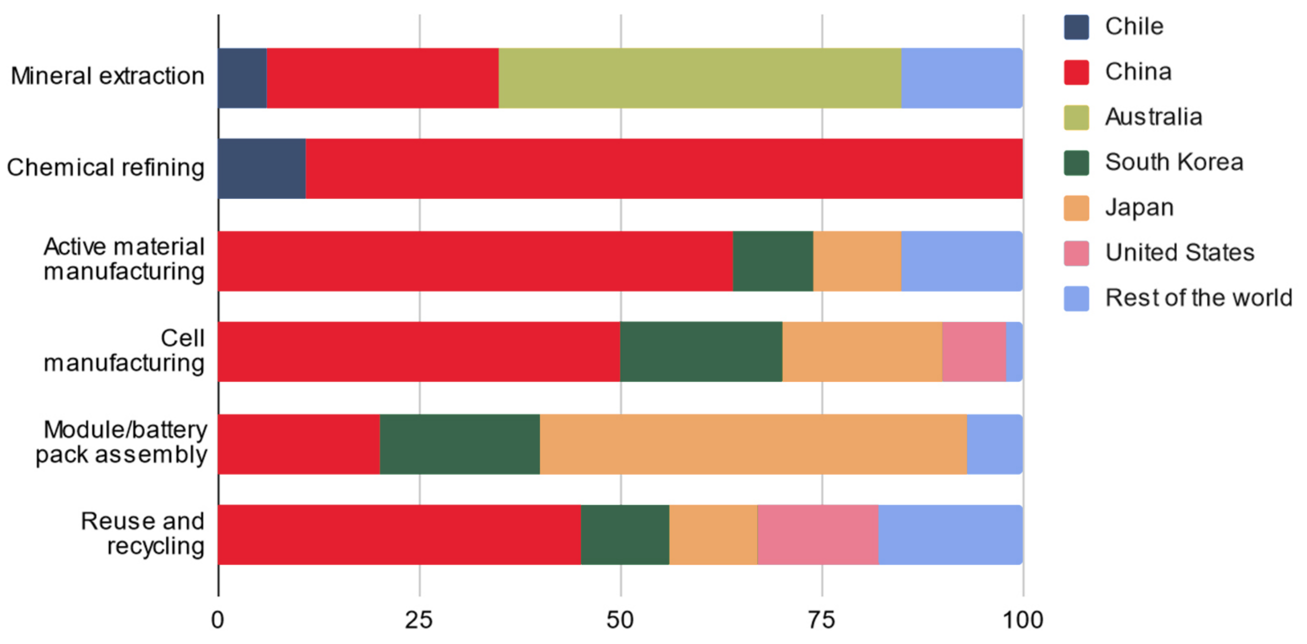
Flow batteries rely on minerals such as vanadium, zinc, iron and bromine. Vanadium, a critical mineral used in vanadium redox flow batteries (VRFBs), is mainly obtained from vanadium-bearing magnetite ores. These ores are commonly found in regions with significant geological formations containing vanadium, including South Africa, Australia, China, and Russia [44]. Zinc is typically mined from underground or open-pit mines in regions with substantial zinc ore deposits, such as Australia, China, Peru, and the United States [44]. Bromine is obtained from brine solutions or as a by-product of industrial processes like seawater desalination or natural gas extraction. Figure 8 provides a country wise production (in %) for each of the segment in the battery value chain. Figure 9 provides an overview of value chain segments for Li-ion and flow Batteries.

Midstream segment

The midstream segment of the value chain involves refining of chemicals and further processing of minerals into battery-grade materials suitable for cell manufacturing [40]. For lithium-ion batteries, lithium- ion brine solutions are converted into carbonates or hydroxides, which undergo further purification processes to produce battery-grade chemicals (e.g LFP, NMC, NCA and LMO). Similarly, cobalt and nickel are extracted from sulphide ores through crushing, grinding, flotation, leaching and purification processes to produce high-purity salts. The refining and chemical processing of minerals for most lithium-ion battery chemistries are taking place in China and other Asian countries such as Japan and Korea.

In the case of flow batteries, high-purity vanadium electrolyte is obtained through crushing, grinding, magnetic separation, roasting, leaching and purification of magnetite ores. High-purity zinc is produced through crushing, grinding, flotation, roasting, leaching, and electrowinning of zinc sulphide ores. Compared to lithium-ion batteries, the refining and processing of materials for flow batteries are not as concentrated in specific regions. Instead, they occur domestically in countries with significant zinc and vanadium resources, such as South Africa, China, Russia, and the United States.

Figure 8: Country wise production (in %) for each segment in battery value chain



Downstream segment

Cell manufacturing plays a central role in producing battery systems for ESS, EV and other applications. Cell manufacturing for Li-ion Batteries involves electrode fabrication, where active materials are mixed, degassed and coated onto metal foils (typically aluminium for cathode and copper for anode) in the form of a slurry prior to drying and calendaring to produce electrodes. This is followed by cell production, where electrodes, separators and electrolytes are assembled into battery cells. These cells are then organized into battery modules and packs, equipped with a battery management system and thermal system, tailored to the end application. Currently, Japan, China and South Korea remain the leading Li-ion cell producers.

Similarly, in the case of flow batteries, cell manufacturing follows comparable principles but with some distinctions. Electrode fabrication is substituted with the preparation of vanadium or zinc electrolyte solutions, which are then assembled into flow battery cells alongside membrane stacks and other components. Formation and testing procedures are implemented to ensure the stability and performance of the flow battery cells, with particular attention paid to maintaining electrolyte purity and optimizing flow dynamics. Flow battery manufacturing is distributed across several countries, including those with significant vanadium reserves (e.g., China, South Africa, Russia).

Recycling segment

Recycling is an important segment of the battery ecosystem that not only helps recover valuable materials for reuse in cell manufacturing, but also reduces the environmental impact of used batteries and conserves natural resources. Some reports suggest that over 90% of the mass of all materials used in the battery could be recovered through well-developed commercial-scale processes [25]. The recycling journey for lithium-ion batteries typically begins with the collection and disassembly of spent battery packs. Components such as electrodes, separators and electrolytes are separated and then processed to recover materials such as lithium, cobalt, nickel and graphite. These materials undergo various treatment methods, including mechanical shredding, pyro-metallurgical processes (such as smelting and refining), and hydrometallurgical processes (such as leaching and solvent extraction), to extract and purify active materials. There is also potential for redeploying used EV batteries for certain stationery storage applications, such as residential solar systems and agricultural energy systems, given their high residual capacity.

For VRFBs, electrolytes can be recycled through processes such as precipitation and solvent extraction to obtain high-purity vanadium compounds suitable for reuse. In zinc-bromine flow batteries, zinc and bromine electrolytes are treated separately to recover zinc metal and bromine compounds. Not much recycling of VRFBs are happening in Australia

Australia recycles only 10% of its lithium battery waste, collecting and shredding batteries locally before exporting them overseas [66]. Shipping spent batteries is risky due to potential fires, and onshore recycling is critical for retaining valuable resources, building industries, and developing a circular economy. Sending batteries abroad means that Australia misses the opportunity to recover valuable materials like lithium, graphite, cobalt, nickel, and manganese. Overall, material recovery and reuse will contribute to reducing the need for virgin resources minimising waste and resource conservation.

Figure 9: Overview of value chain segments for Li-ion battery and flow batteries

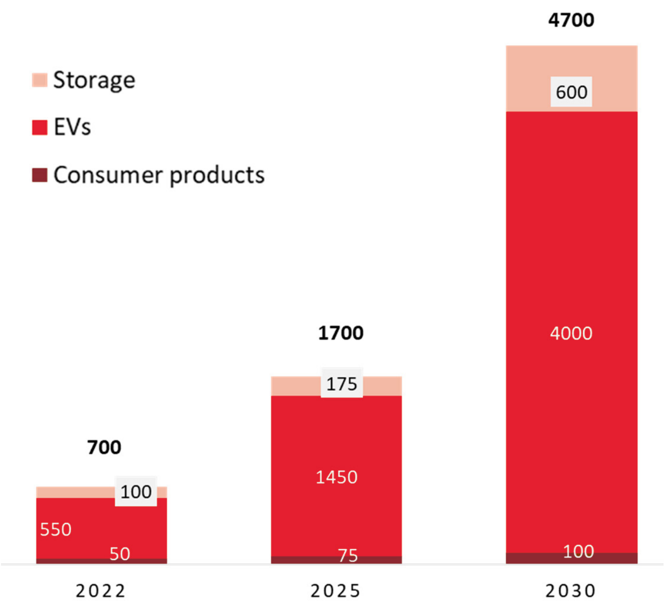
	UPSTREAM	MIDSTREAM		DOWNSTREAM			RECYCLING
	Mineral extraction	Chemical refining	Active materials manufacturing	Cell manufacturing	Module/battery pack assembly	Application	Reuse and recycling
LITHIUM-ION BATTERIES	Lithium Cobalt Manganese Graphite Titanium Silicon	Lithium hydrooxide Nickel sulphate Cobalt sulphate High purity alumina	Cathode (LFP, NMC, NCA, LMO) Anode (Graphite, Silicon, Titanium) Separator Electrolyte	Cathode fabrication Assembly of cathode, anode, electrolyte, separator	Cells orgaised in to module and packs Integration of battery management & thermal system	EVs Consumer electronics On-grid/off-grid ESS	Disassembly of packs Recovery, treatment and purification of cell components Reuse of recovered material
FLOW BATTERIES	Zinc Bromine Iron			Cells are stacked to form module/stack Manifolds and piping installation followed by sealing and encapsulation		energy storage system	sepearated and purified Recovered materials reused
Major Players	Flow battery manufacturing is distributed across several countries (Austria, Canada, Japan, and UK), including those with significant vanadium reserves (e.g., China, Russia, South Africa)						

Sources: [47-49]

3.2 Cost analysis and mass breakdown of Li-ion and flow batteries

Notwithstanding the significant disparities among the individual estimates reported, the global demand for batteries is expected to grow substantially over this decade. For example, a study commissioned by FBI CRC has reported an increase of 9-10 folds in the global battery demand over 2020 level to reach 2,300-2,600 GWh in 2030 [48]. In contrast, the other reports based on the McKinsey Battery Insights model have projected the demand for Li-ion batteries along to reach 4,700 GWh by 2030 [37]. These variations in demand estimates could largely be attributed to the way each model has accounted for the impact of exogenous factors such as technological advancements, policy responses and price fluctuations. Figure 10 illustrates the global battery demand (in GWh). While electric vehicles represent the largest segment of the aggregate battery demand, stationary storage emerges as the fastest-growing sector. Australian domestic demand is growing at a comparable rate and is forecast to provide 90 GWh of demand to 2030, including 26 GWh of Queensland demand that could potentially be served by the local producers.

Figure 10: Global battery demand (in GWh)

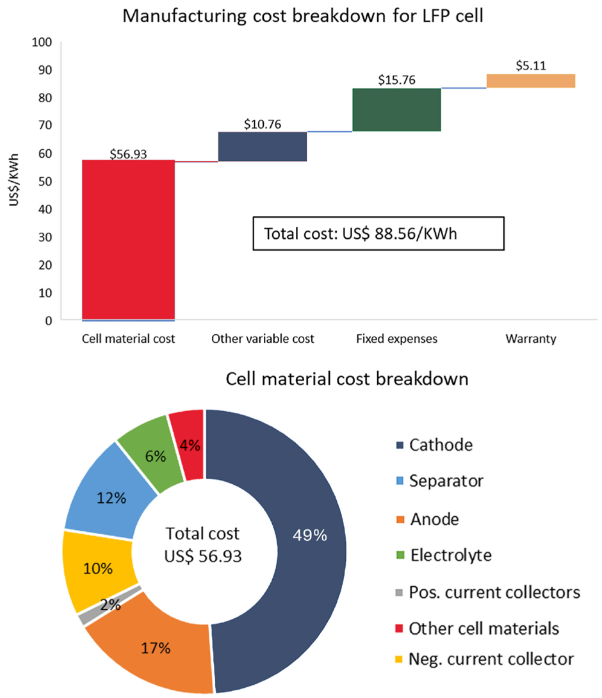


Since 2010, advancements in battery chemistry, manufacturing processes and energy storage systems have led to the development of batteries with higher energy density, longer cycle life, and reduced material costs. Innovations in material sourcing, recycling, and alternative chemistries have further contributed to cost reductions for materials such as lithium, cobalt, nickel, and vanadium.

Cost and mass breakdown of a LFP Cell

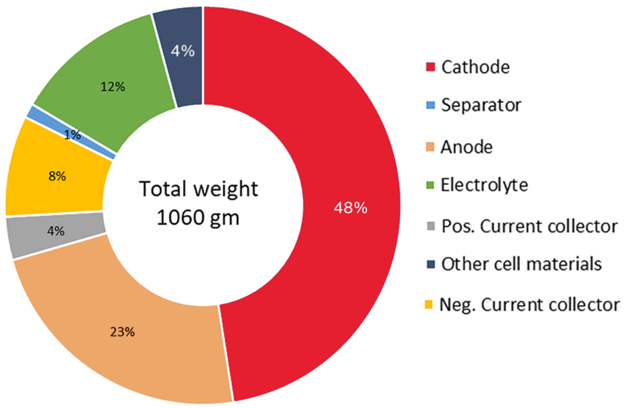
As of 2022, the average total cost of a LIB cell was US$ 86-96 per kWh, which is over 90% lower than the price of LIB cell in 2010. The cell material cost accounts for 65% of the total cost of an LFP cell, with the active materials used in electrodes contributing 66% of the total cell material cost (Fig 11). In terms of mass/volume, electrodes constitute about 71% of the total cell weight (Fig 12). Other components such as electrolyte, copper, and aluminium foil make up the remaining 29% of the total mass. The total cost of these components accounts for 34% of the total cell material cost.

Figure 11: Cost breakdown of a LFP cell



Source: Analysis from Batpac 5.1 (BatPaC 5.1 is the fifth version developed in 2022, it utilises a baseline plant with a 50 GWh per year capacity to determine costs. Validation of cost was conducted through literature, online databases, and direct communications as well with materials suppliers, cell manufacturers, and original equipment manufacturers. Since its 2007 inception, the model has undergone continuous peer and private reviews for accuracy and reliability.

Figure 12: Mass breakdown of LFP cell



Source: Analysis from Batpac 5.1
Note: Total mass is in grams

Cost and mass breakdown of an LFP Pack

Chemicals and active materials represent a considerable portion of the total battery pack cost and weight. In a typical LFP battery pack, these cell materials constitute 65% of the total weight (see Fig. 13) and contribute to just over 50% of the total pack cost (see Fig. 14), whereas module and pack components make up 35% by weight, accounting for only 12% of the cost (see Fig. 14). Notably, out of the pack and module parts, 36% consists of Aluminium [51-52]. This underscores the potential contribution of active materials and other cell/pack materials in terms of value addition and cost reduction as their price can have a substantial impact on the total cost of the battery pack.

Figure 13: Mass breakdown of Li-ion battery packs

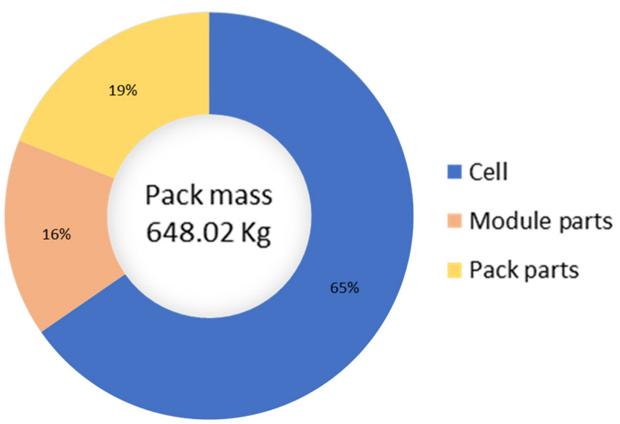
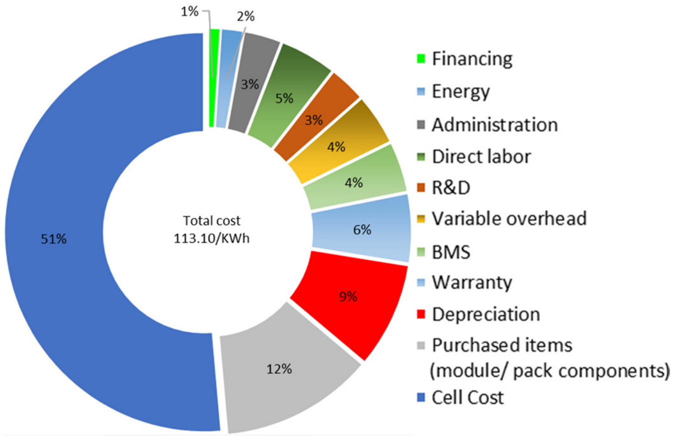


Figure 14: Cost breakdown of Li-ion battery packs

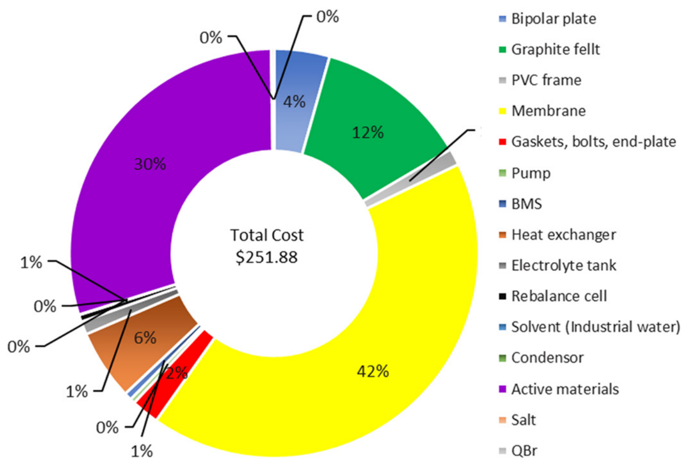


Source: Analysis from Batpac 5.0 Total cost of LIB: US$ 120.64/KWh

Cost breakdown of vanadium RFBs

In the case of vanadium redox flow batteries (VRFBs), the membrane stack constitutes the highest cost (42%) followed by active materials (30%) and graphite felt (12%) (Fig. 15).

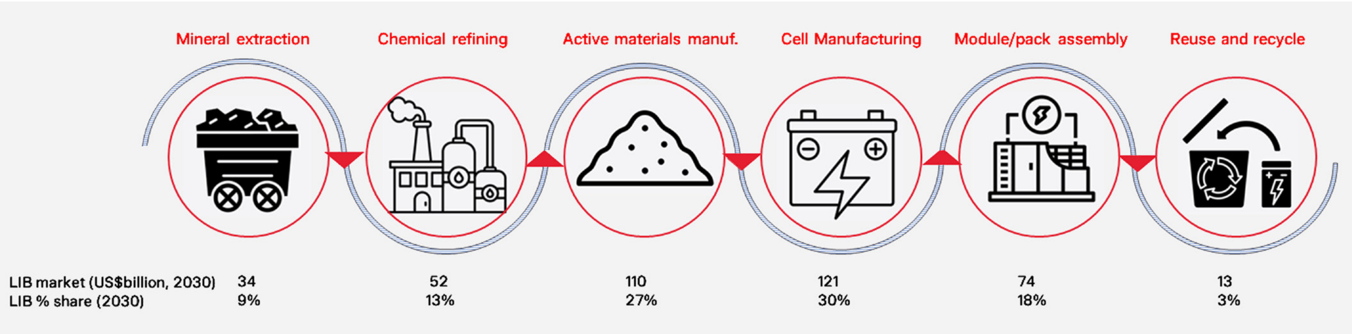
Figure 15: Component cost breakdown of VRFBs



Note: Total battery cost: 252/KWh Source: [39][41-42]

3.3 Value-add potential based on cost analysis and extant studies

Figure 16: Global value addition market size in different segment of value chain

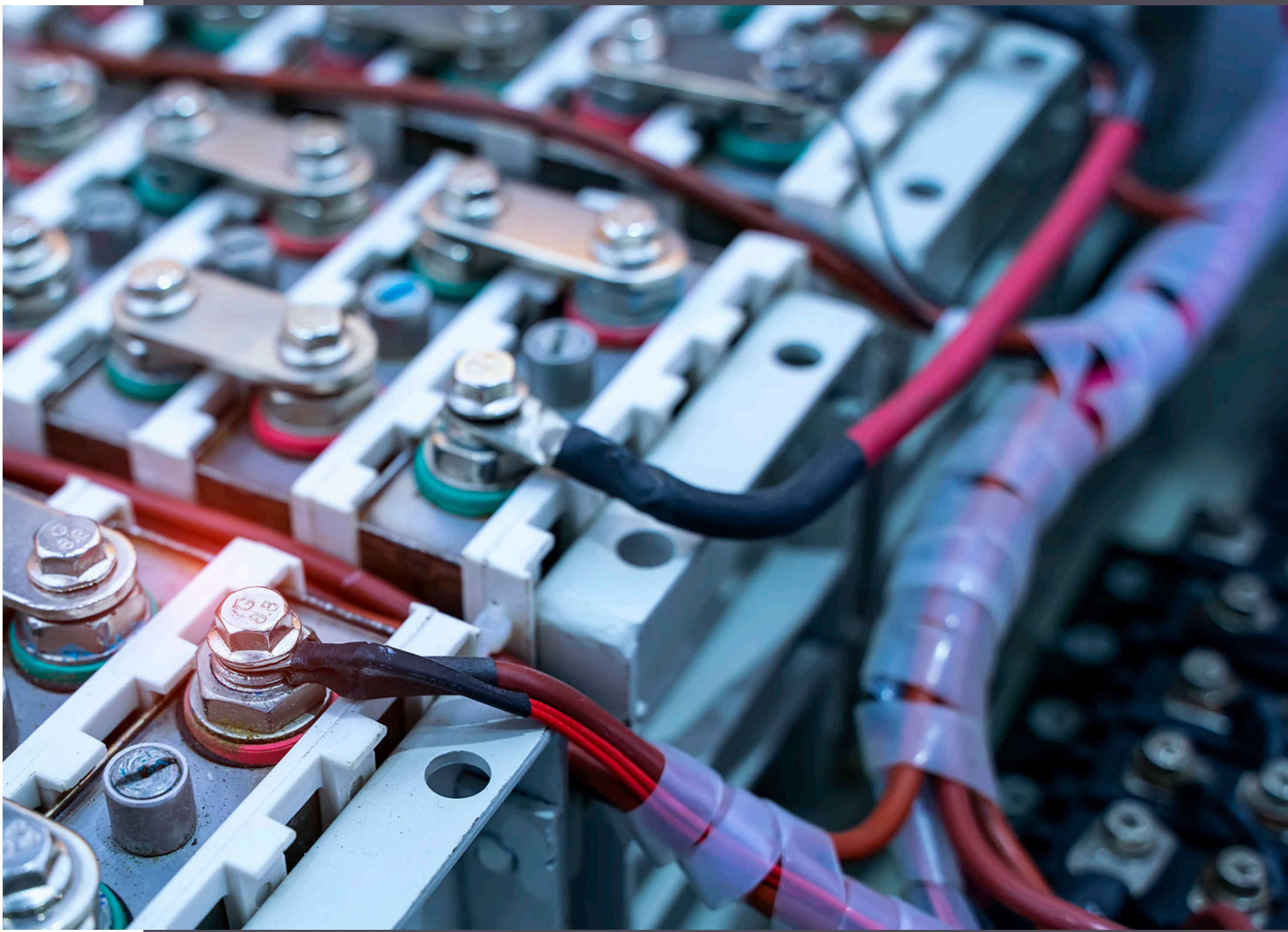


Source: Market share numbers are from [37-38]

The Li-ion battery market is expected to generate $400 billion in revenue by 2030, highlighting significant opportunities for value capture across the supply chain (see Fig 16). Mineral extraction, with an estimated market size of $34 billion (9%), offers prospects for Australian businesses to sustain their current market share. This includes extracting minerals like lithium, phosphorus, nickel, and manganese for established battery applications, as well as minerals such as sodium, aluminium, graphite, zinc, and others for emerging battery chemistries and technologies. Similarly, chemical refining, projected to reach a market value of $52 billion (13%) by 2030, highlights the opportunities for innovation in refining and further processing. Notably, efforts to refine material purity and to better quantify the impact of impurities on battery performance can significantly enhance the quality and cost competitiveness of active materials respectively, thereby improving battery performance, longevity, and cost. This represents a significant opportunity for value addition and value capture for Australian businesses. Active materials manufacturing, valued at $110 billion (27%), represents the second-largest opportunity for value addition. Advancements in manufacturing processes, alongside the development of novel materials, can maximize energy density and power, serving as crucial avenues for driving innovation and cost reduction across the value chain.

Cell manufacturing is estimated to represent $121 billion (30%) by 2030, which offers the highest potential for the value-add. Strategic investments in state-of-the-art manufacturing facilities for automation, process optimization, material innovation, and rigorous quality control measures hold the potential to enhance production efficiency and consistency within this sector, thereby contributing to overall cost reduction and competitiveness. Module and battery pack assembly, accounting for $74 billion (18%), provide opportunities for value addition through design and management. Additionally, the innovative integration of modular designs with standardized components can streamline disassembly and recycling processes, reducing end-of-life waste and fostering sustainable practices. Recycling, projected at $13 billion (3%), holds promise for value addition through resource recovery and reuse. Advanced recycling technologies can facilitate the efficient extraction and reuse of valuable materials from used batteries, thereby reducing the industry's reliance on virgin resources and minimizing environmental impact.

The Greenbushes mine is an open-pit mining operation in Western Australia and is the world's largest hard-rock lithium mine. It is located to the south of the town of Greenbushes, Western Australia.(Shutterstock)



4 | INDUSTRY PERSPECTIVES: SUMMARY FINDINGS DRAWN FROM INTERVIEW DATA

Key Findings

- Australian businesses are involved in value-adding activities across the entire battery supply chain but are at varied levels of maturity, with ore extraction and battery pack assembly representing the highest levels of intensity. Active materials processing and recycling are both at early stages of development in Australia.
- Given that there is no cell manufacturing in Australia, component manufacturing is limited to the supply of certain locally produced parts for the thermal system, housing and battery management systems etc.
- Securing off-take large scale agreements with the established international players is a key prerequisite for Australian businesses looking to integrate into global supply chains.
- Startup companies must demonstrate the technical and economic feasibility of full-scale production via a multi-stage qualification process involving laboratory-scale development, proof-of-concept and pilot production.
- Understanding market dynamics, accessing capital, and meeting regulatory requirements are all key factors affecting the capacity of Australian businesses looking to scale up their operations.
- Access to testing facilities, skilled workforce, and reliable suppliers, as well as inconsistent regulatory regimes, limited support, and the absence of comprehensive collaborations are all acting as barriers to strengthening domestic manufacturing in Australia.
- There are multiple pathways for Australian businesses seeking to integrate into the global battery supply chain, depending on their current state and the opportunities available for value addition.

As part of this study, over 20 businesses directly involved in battery components manufacturing were interviewed to gain insights into the three key aspects: current state of battery component manufacturing in Queensland, the challenges faced by the industry, and the opportunities for integrating into the global battery supply chain. To understand the broader context of their business operations, the participants were also asked to provide as much information as possible about the supply chain partners they currently work with, the stages of the value chain they focus on, and the market segments they serve. The key findings resulting from the analysis of interview data are presented in this section.

4.1 Current state of battery component manufacturing

The businesses interviewed span across all three stages (i.e. upstream, mid-stream and downstream) of the battery supply chain and involved in the following activities.

- Developing and testing battery chemistries and processes for manufacturing cathode active material or graphene-based anode material, and electrolytes using minerals/metals mined in Australia and/or overseas.
- Assembling complete battery systems with imported cells and components, and other locally sourced parts.
- Developing and supplying battery management systems or parts for multiple domestic and overseas markets.
- Battery recycling with ambitious plans for supplying recycled material for cell manufacturing.

> *“You produce lithium-ion batteries and battery packs close to the end market because they are large volume, low density, transformed products… so if you don’t have a very big electric vehicle manufacturing industry close by, it is not something you should be doing.”*
>
> *ID 1 (Active Material Manufacturer, QLD)*

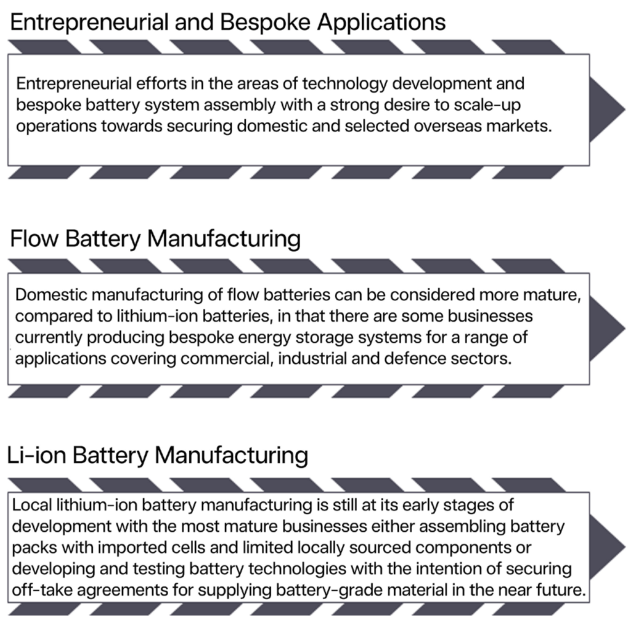
Nearly all of these companies consider themselves as small players on a global scale, but plan to scale up their operations in the next 3-5 years. Some of the businesses are currently serving the domestic market and limited overseas markets whereas others are aiming to secure off-take agreements with global supply chain partners.

The product and service range they currently offer or intend to offer include: (i) electrolytes for flow batteries, cathode-active material or graphene-based anode material; (ii) design, assembly and/or supply of battery systems, including off-grid energy storage systems and community batteries; and (iii) bespoke battery management systems for low-voltage and high-voltage applications. However, none of the companies interviewed are actively pursuing li-ion battery cell manufacturing in Australia.

Current or potential applications of these products and services include: low-voltage or high-voltage stationery storage systems with applications for commercial, industrial and defence sectors; and remote area (off-grid) ruggedized batteries for hot climates and cyber-secure applications, as well as mobility and specific vehicle types.

Overall, the state of battery component manufacturing in Queensland (and more broadly in Australia) can be characterised in terms of its entrepreneurial efforts in the areas of technology development and bespoke battery system assembly with a strong desire to scale-up operations towards securing domestic and selected overseas markets (see Fig 17). In relative terms, domestic manufacturing of flow batteries can be considered more mature, compared to lithium-ion batteries, in that there are some businesses currently producing bespoke energy storage systems for a range of applications covering commercial, industrial and defence sectors. There is at least one Australian company operating their flow battery production facility overseas and serving both domestic and limited overseas markets. By comparison, local lithium-ion battery manufacturing is limited to assembling battery packs with imported cells and some locally sourced parts or developing and testing battery technologies with the intention of securing off-take agreements for supplying battery-grade material in the near future. Businesses within both sectors are facing a raft of challenges, particularly in relation to scaling up their operations and integrating into global battery supply chains, which are outlined in the next section.

Figure 17: Current state of battery manufacturing in Australia



4.2 Challenges faced by the battery component manufacturing sector

Understanding and navigating battery technology market and industry dynamics was identified as one of the major challenges faced by the businesses operating in this rapidly expanding, technology-driven sector (see quote below for an elaborate account of one business). Market access is informed by the understanding of the battery technology market, including identifying potential customers and their needs. A key success factor for any business entering the battery manufacturing industry is securing off-take agreements with global supply chain partners. Given that only a few large-scale cell manufacturers currently dominates the Li-ion battery industry, securing off-take agreements is a major challenge for Australian businesses, particularly when their competitors are operating in environments where there are government subsidies, policies favouring domestic manufacturing and access to large markets. Technology-intensive facilities used for the development, testing and certification cycles, that precede cell production requires significant capital investments in terms of both set-up costs and operational expenditure. However, return on these investments is not guaranteed until off-take agreements are signed-off with key supply chain partners. As such, unlike in the US, more risk-averse Australian investors are reluctant to fund these projects, making it challenging for the domestic businesses to scale-up their operations past the demonstration stage of technology development. Moreover, with developing government support compared to some international markets, and lower R&D spend in Australia, businesses are forced to self-fund some lab-scale development of battery technologies, which further extends the development cycle. According to some interviewees, as a result, Australian IP tends to go offshore where it can find more risk tolerant capital.

> *So, the biggest challenge I'd say we've had is developing markets… there is a market for this battery technology in Australia and it is a large market and we see a large opportunity that goes along with having a supply chain that's locally operational and feeding a local market as well as an export market… But having that understanding and knowledge and perspective on what that looks like and yeah, I guess educating and converting that into purchases... so that would probably be the major challenge… once you get that market developed, some of the other risks and challenges become easier… accessing capital becomes easier once you've got a well-defined market that you can show a path into."*
>
> *ID 2 (Mining and Electrolyte Refiner, QLD)*

> *Every other developed country in the world, you will get substantial government funding… you'll get up to 40% of the equity given to you as a government grant or as an investment or infrastructure allowance or a tax break… there isn't an exception in the world where this sort of industry goes ahead without significant government co-investment."*
>
> *ID 3 (Component Manufacturer)*

Challenges associated with testing and certifying battery products locally in Australia were noted as critical by multiple businesses. The absence of accredited testing labs for safety certificates, specifically for International Electrotechnical Commission (IEC) standards like IEC 62619, was seen as a major obstacle, as the products need to be sent overseas for testing, causing delays and increased costs. The IEC 62619 standard outlines safety requirements and testing procedures to ensure that lithium batteries used in these applications are safe, reliable, and perform as expected. By adhering to this standard, manufacturers can demonstrate that their Li-ion batteries meet rigorous safety standards, providing users confidence in their performance and safety in industrial applications. The reliance on foreign testing facilities, particularly in China and Europe for certification also results in a loss of competitive advantage due to leakage of proprietary know-how. Existing testing facilities, such as the QUT Advanced Battery Facility, can support local battery testing needs but is limited in scale and capacity. The capacity of testing operations is being expanded currently through the establishment of QUEST Hub, which, in collaboration with QUT and industry, will double the capacity of battery testing and research services. CRC research projects are also currently operating to grow testing capacity such as the National Battery Testing Centre (NBTC) research project, but these projects have certain limitations, particularly in budget, which does not allow for the accommodation of commercial-scale testing (in terms of capacity as well as variety of tests that can be performed). The funding structure and standards set by entities like future battery industry cooperative research centre (FBI-CRC) also limits access to local testing facilities for companies not originally part of the CRC. For example, some businesses that have sought to collaborate with current FBI-CRC partners to access the facilities at NTBC have also met with obstacles, as existing members could veto new entrants, making it difficult for companies to participate and benefit from these facilities.

> *Partnerships and collaborations, I think from a research point of view, is super important if we can continue to create bodies where we can have companies access for testing and analysis of their products, whether it's for an Australian standards point of view or understanding material properties that they're using in their products … It's not specifically at the universities, but in collaboration with industry, sort of industrial hubs or research hubs."*
>
> *ID 4 (Component Manufacturer)*

Supply-related challenges faced by the component manufacturing sector largely revolves around the over-reliance on overseas suppliers (due to lack of domestic suppliers), which results in delays due to disruptions and long procurement lead times, as well as having to buy in large quantities leading to significant inventory holding costs and high working capital requirements. Generally, most businesses use a mix of international and local suppliers for materials, parts and components, including battery management systems, with a focus on quality and meeting industry-specific requirements. However, Australian businesses are small-scale operations and their bargaining power is limited in negotiating price and other terms of contracts with international suppliers. Particularly, as most of the suppliers are from China, and European factories are primarily supplying to Europe, some Australian business perceive that they are at the mercy of the Chinese manufacturing industry. Securing the right suppliers who could deliver materials, parts and components to meet specific requirements was identified as another challenge, whereas long lead times associated with procuring equipment is also of particular concern.

> *We need aluminium foil…really thin foil… about 15 to 20 Micron thin but very high precision… plastic polymer material for separators and then we need, you know … there's another chemical, so there's those are the types of material we need… those are the types of products that we're continually looking for suppliers for… we've got to find the company that will supply us the one that works the best and can supply good quality continually…and most of these companies actually are overseas…. …I would love to get an Australian supplier for that."*
>
> *ID 5 (Electrode Material and Potential Cell Manufacturing Company, QLD)*

Lack of transparency in suppliers' manufacturing processes and inconsistent quality standards adopted by diverse suppliers, when coupled with the limited availability of and access to Australian testing and certification facilities, make it difficult for Australian businesses to identify and connect with reliable overseas suppliers.

For example, difficulties in sourcing specific components such as DC-based electrolyte pumps tailored to their application was cited by at least one of the businesses interviewed. Limited scale hindered the attraction of multiple suppliers for critical components. The organization struggled to diversify the supply of specialised materials, partly driven by the small scale and bespoke nature of their battery chemistry. Scaling up operations faced challenges due to historically small markets and limited access to capital, with the Australian risk appetite differing from the United States. Accessing capital through the Australian Stock Exchange provided less funding compared to competitors. Additionally, the evolving battery market required adapting to changing customer demands.

Businesses' perspectives of the regulatory environment in Australia vary somewhat depending on the areas of their focus. While some businesses noted that although the regulatory setting in Australia is not perfect, it is better than in US. Others saw that the existing rules and regulations need to be updated. For example, the technical requirements (specifications) of Energy Queensland were observed to be far more stringent than in anywhere else in Australia. They were perceived as inherently conservative (concerned and focused on reliability, performance) partly due to lack of understanding of the standards. Adopting new technologies, especially in the absence of standardised industry practices, has been challenging, as power authorities and transmission companies have diverse rules, creating complexities in developing new products. Varying regulations across different Australian states and lack of standardised industry practices make it challenging to scale efficiently, as well.

The importance of government regulations to ensure safe and compliant battery replacements, preventing potential risks such as house fires and supporting the clean energy agenda was also recognised. Table 1 summarises the challenges identified in this section and potential actions to address them.

Table 1: Summary of challenges faced by the industry and potential actions to address them

Challenge Category	Specific Challenges
Market Access & Competition	Difficulty securing off-take agreements due to limited large players and lack of government subsidies compared to some international markets
Investment & Scaling	Risk-averse investors reluctant to fund projects beyond the demonstration phase
Testing & Certification	Absence of accredited test labs for safety certificates, specifically for IEC standards like IEC 62619, necessitates sending products overseas for testing.
Collaboration & Access to Facilities	Obstacles in accessing facilities like NTBC due to existing members' veto power
Supply Chain & Procurement	Difficulty finding suppliers who meet specific requirements and long lead times for equipment
Regulations & Standards	Varying regulations across states, lack of standardized practices, and conservative technical requirements from power authorities (e.g. AS4777)
Workforce & Skills	Lack of advanced training programs in battery manufacturing and difficulty recruiting skilled workers

4.3 Pathways for integrating into the global battery supply chain

Considering that some Australian businesses are already assembling battery systems and others have demonstrated a strong desire to move into full-scale production of battery-grade material in the near future, several possible pathways for integrating into global supply chains are identified in this section.

First Pathway

Given that most of the raw materials used in battery manufacturing are currently mined (or can be potentially mined) in Australia and/or in nearby countries, many businesses saw the opportunity to add further value through refining these raw materials/concentrates into high purity chemicals/metals and the production of battery-grade material. This means moving downstream the battery supply chain, and a few companies are already developing and testing various technologies and processes required for the production of battery-grade material, despite not being able to secure off-take agreements with global supply chain partners yet.

Setting up facilities for refining or full-scale production of battery-grade material requires substantial capital investments that need to be secured through multiple domestic and international sources. Most of the businesses recognise that such investments are most likely to come in the form of foreign direct investments or in collaboration with established international companies willing to set up operations in Australia, thereby highlighting the critical role that can to be played by the government in facilitating such arrangements.

Second pathway

However, for those businesses who are already assembling battery systems, whether it is Li-ion batteries or flow batteries, the opportunities are for establishing niche markets in Australia and selected overseas countries, and enhancing the local content of the products and services they offer. In particular, for Li-ion batteries, currently the market is dominated by a few large global players. The scale of Australian businesses operating in this space does not allow them to complete head-on against these large players. Therefore, targeting areas where Australia can differentiate itself allows businesses to avoid direct competition with those global suppliers.

Businesses operating in this segment of the supply chain have already identified certain applications such as bespoke battery systems to cater to special needs (e.g. safety-critical areas), larger vehicles for mining and agricultural sectors, grid-scale storage, low voltage installations and micro grids, ruggedized batteries suitable for hot climates and cyber-secure environments and high-energy density batteries for electric aviation, including high-altitude drones and defence applications, having the greatest potential for success.

Additionally, focusing on battery systems, including battery management systems, for long-duration stationary energy storage is expected to provide an advantage in being able to produce value-added products in proximity to the market. Some businesses also pointed out that the evolving nature of the sector during its early adoption phase provides a favourable environment for multiple technologies to succeed in securing a sizeable market share.

This means strengthening the capabilities of domestic suppliers of raw materials, parts, and components, as well as battery management systems, which in turn will help the businesses operating within the midstream segment of the battery supply chain, leading to reduced costs/lead times and improved reliability/safety. Building domestic capabilities will also reduce dependency on materials, parts and components procured from overseas and associated market risks, while enabling service elements such as maintaining and warranting products over time. More broadly, developing sovereign capabilities within this sector will see Australia securing a stronger and more sustainable position in the global battery supply chain, thereby enhancing its resilience against potential disruptions or threats to national interests.

Third Pathway

A potentially crucial, but least explored, option is strengthening local component manufacturing through battery recycling. Despite the limited number of Australian businesses actively involved in battery recycling, there is significant potential for value-add via recycling of used batteries, while at the same time enhancing Australia's credentials in supporting sustainable manufacturing. Competencies gained in this area could be leveraged to strengthen the midstream segment of the supply chain, as well. At least one of the Australian businesses interviewed is currently engaged in recycling, which involves collecting, sorting, discharging and safe processing of used batteries into their components (e.g. copper, aluminium and plastic) and separating high-value black mass and mixed metal dust. This way, cathode nano-material extracted out of the used batteries could be fed back into the midstream segment of the battery supply chain.

5 | INDUSTRY PERSPECTIVES: RESULTS FROM THE ANALYSIS OF SURVEY DATA

Key Findings

- In the case of Li-ion batteries, the development of active materials for cathodes and anodes is currently limited to early-stage startups and small-scale R&D facilities. No production facilities for electrolytes currently exist in Australia. Expanding production in these areas would necessitate investments in infrastructure and technology.
- In the case of RFBs, Queensland has capabilities in several key areas, including the development of SCADA/communication systems, safety components, mechanical hardware, and electrical components. However, membrane production is currently limited to R&D, and electrolyte mineral mining and production are in the early stages of development. Electrode and current collector materials are mainly imported from overseas.
- Over 60% of the businesses surveyed reported that they are able to transition skills/capabilities from traditional industries to cater to the emerging battery manufacturing sector.
- Main challenges to local manufacturing include: high cost of local components, limited skilled workforce, and resource limitations, as well as lack of reliable suppliers, ongoing orders, raw material availability, adequate R&D support/tax incentives, and access to new technology or capital.
- The support required to facilitate transition to battery component manufacturing include: networking opportunities, battery industry education, access to a reliable supplier database, briefings on available government support, facilitating collaboration with researchers, and access to manufacturing hubs, as well as workshops on capability development, industry transitioning, tax and R&D incentives, and mentoring.

5.1 ICN database analysis for Queensland battery manufacturing capabilities

The components identified in the product architectures for Li-ion batteries in Appendix 1a and redox flow batteries (RFBs) in Appendix 1b, were matched to capabilities in the Queensland Governments's Australian Battery Supply Chain Database to identify companies in Queensland with stated capacity to supply those components. A survey questionnaire was sent to each of these companies to verify their capabilities in battery component manufacture. The outcomes of the returned surveys indicate the following:

Li-ion batteries

The assessment of Queensland's manufacturing capabilities for Li-ion battery components reveals a mixed landscape (see Table 2). There is potential in several areas, particularly in the assembly and production of less complex components. This includes housing elements, reinforcement features, and some thermal system components. Additionally, local manufacturers show promise in assembling components using both local and imported content.

However, challenges exist in areas that require specialised materials or complex manufacturing processes. Notably, Australia lacks local production of electrolytes. The manufacturing of key materials like cathode and anode is currently limited to early-stage startups and small-scale R&D facilities. Expanding production in these areas would necessitate investment in infrastructure and technology.

While existing facilities can handle the low-volume manufacture of basic components, scaling up to meet high-volume demand may require additional investment in automation and specialised machinery. Tooling costs and design complexity also pose challenges for local manufacturers, particularly for intricate components like junction boxes and HV plugs. More information on specific components and capabilities is provided in Appendix 2.

Table 2: Overview of manufacturing capabilities for Li-ion battery components

Category	Key Component(s)	Manufacturing Capability	Facility Availability	Notes
Housing	Tray, Cover, Sealing, etc. (11-17 companies with capabilities)	High	Exists	Local manufacturing is feasible with potential for automation in large-scale production.
Reinforcement	Fiber, Rib Design (6 companies with capabilities)	High	Exists	Primarily a design feature, existing facilities can implement.
Pressure Compensation	Special membranes, Valves (24 companies with capabilities)	Assembly using imported content possible	Requires investment	Automation likely needed for mass production.
Thermal System	Sensors, Temper Structure, etc. (5-12 companies with capabilities)	Assembly using local/ imported content possible	Exists	Relies on imported components; large-scale production may need automation.
High Voltage (HV)	Connector, Junction Box, etc. (10-17 companies with capabilities)	High (except for complex designs)	Exists (some complex)	Tooling costs a major factor for local production of complex parts.
Low Voltage (LV)	Insulation Monitor, Plugs, etc. (5 companies with capabilities)	Assembly possible, volume production needs investment	Exists	Many off-the-shelf components available.
Battery Management	Electronic Components (6 companies with capabilities)	Some companies capable, volume needs investment	Exists	Existing facilities adequate.
Battery Module	Filler, Cell Contacting, etc. (3-8 companies with capabilities)	High	Exists	Many materials locally sourced, existing facilities capable.
Electrode Stack and Electrolyte	Electrolyte, Separator, Cathode, Anode (3-7 companies with capabilities)	None for electrolyte, separator Limited for cathode and anode materials	Small-scale R&D level with some pilot facilities	No local electrolyte production, some startups/ early stage businesses for cathode and anode materials. Existing facilities at R&D scale, expansion requires investment.
Cell Housing	Pouch, Prismatic, Round (15 companies with capabilities)	Varied (materials, tooling cost)	Exists	Manufacturing capability exists, but tooling cost and design complexity can be barriers.

Flow batteries

Australian industry appears to have marginally better capabilities to supply components for flow batteries than for Li-ion batteries. Queensland demonstrates strong capabilities in several key areas of flow battery manufacturing, including SCADA/communication, safety components, mechanical hardware, and electrical components (see Table 3). Many of these items can be sourced locally. While capable of manufacturing mechanical structures for existing designs, new designs may require collaboration with R&D organisations.

While some electrical components are imported, most can be manufactured locally. QLD also has the capability to produce essential safety systems and shows promise in the development of flow battery components. However, membrane production is currently limited to R&D, and electrolyte mineral mining and production are in the early stages of commercial development. Also, electrode and current collector materials are mainly imported from overseas suppliers with no local manufacturers.

Membranes are one of the most expensive components in flow batteries and there are only a few suppliers of these worldwide. There are few initiatives focussed on research into developing membranes to bring costs down.

Overall, Australia possesses a promising capacity for flow battery manufacturing, with potential for growth in flow battery technology through further development and investment. More detailed information on specific components and capabilities is provided in Appendix 3.

Table 3: Overview of manufacturing capabilities for flow battery components

Category	Key Components	Manufacturing Capability in Australia	Facility Availability	Notes
SCADA/ Communication	Display, Antenna, etc. (10-12 companies with capabilities)	High (using local and imported components)	Exists	Local design and build possible.
Safety	Smoke Detector, Interlocks, etc. (4-8 companies with capabilities)	Local and imported components available	Exists	Existing facilities meet requirements.
Mechanical Structure	Structure, Frame (4-10 companies with capabilities)	Likely possible for existing designs	Possibly exists	New designs may require collaboration with R&D organizations.
Mechanical Hardware	Cable Trays, Backplates, etc. (9-10 companies with capabilities)	High (some imports)	Exists	Most items can be manufactured locally.
Mechanical Enclosure	Tricon (2 companies with capabilities)	Proprietary product, Australian supplier	Australian warehouse	Proprietary product with local supply.
Electrical Components	Breakers, Contactors, etc. (7-11 companies with capabilities).	Some local, some imported, capability exists	Exists	Local manufacturing capability exists for most components.
Electrical Hardware	Busbars, Wire, etc. (8-10 companies with capabilities)	Local suppliers, some imports	Exists	Existing facilities can supply most items.
Battery Safety	Secondary Containment (6 companies with capabilities)	High	Exists	Local companies capable of producing.
Battery Venting	Hydrogen Venting (NA)	Possibly, depending on design	Could meet needs	Capability may exist depending on design.
Flow Battery	Membrane, Bipolar Plates, Electrode, Current collector, Electrolyte	Limited for membranes, electrode, current collector, bipolar plates, other components in development	Limited R&D/Early Commercial	Membrane capability limited to R&D, some components (electrolytes) in commercial development.

5.2 ICN questionnaire survey results

To understand the obstacles facing battery component manufacturers in Queensland and Australia, we engaged ICN QLD to conduct a targeted survey. Using component requirements from lithium-ion and redox flow battery architectures (detailed in Appendices 1a and 1b), we matched these needs with the capabilities of companies listed in ICN QLD database, resulting in a focused survey distributed to 426 identified businesses. This section analyzes the 61 responses received, offering crucial insights into the operational characteristics, challenges, and experiences with support programs within both the flow battery and lithium-ion battery sectors.

Demographic information

Fig 18 shows selected demographic information such as annual turnover and the number of employees of the companies surveyed in each of the two categories, flow batteries and Li-ion batteries. Fig 19 shows the businesses by component type as identified in Section 2.3. Most of the businesses in both the flow battery and Li-ion battery segments are producing electrical, mechanical and thermal management components of the battery system.

Figure 18: This dashboard summarises survey participation (Number of companies surveyed and responded), components (by category, total number of components), business size by number of employees

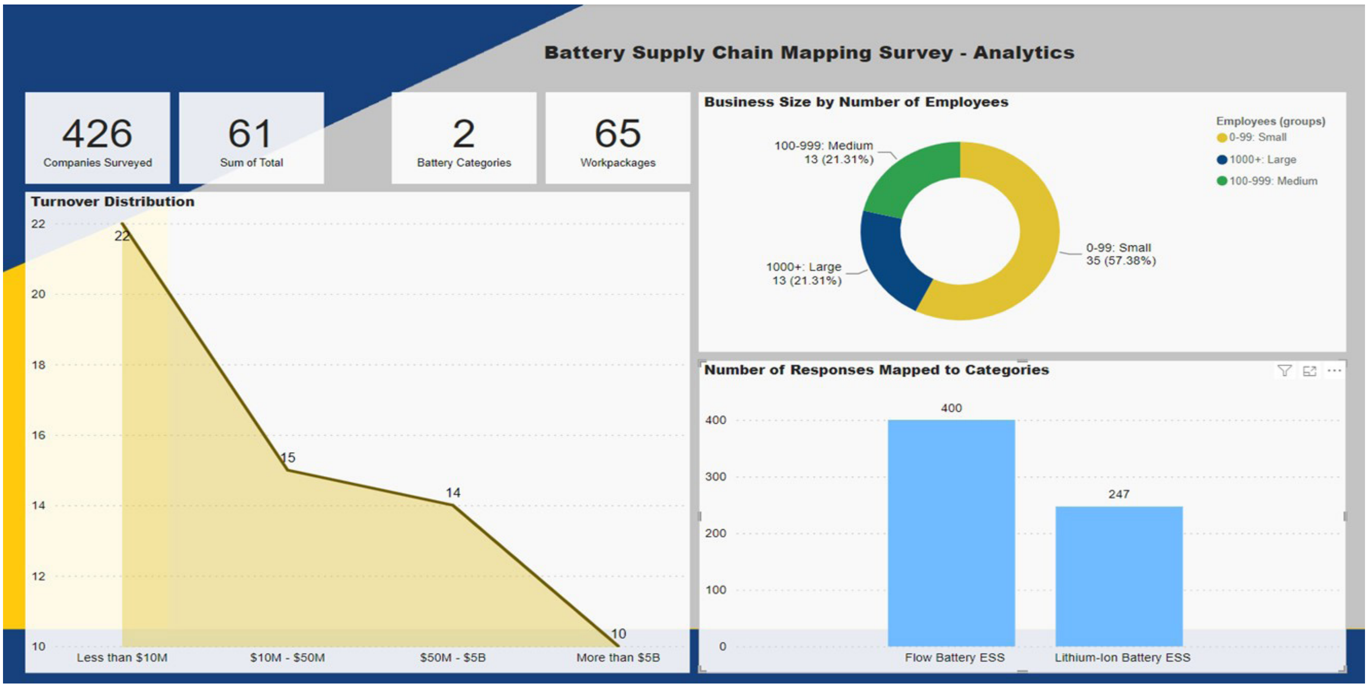


Figure 19: This dashboard focuses on components responses categorised by type of battery ESS. Separate column charts for each category show the number of responses received for each component.

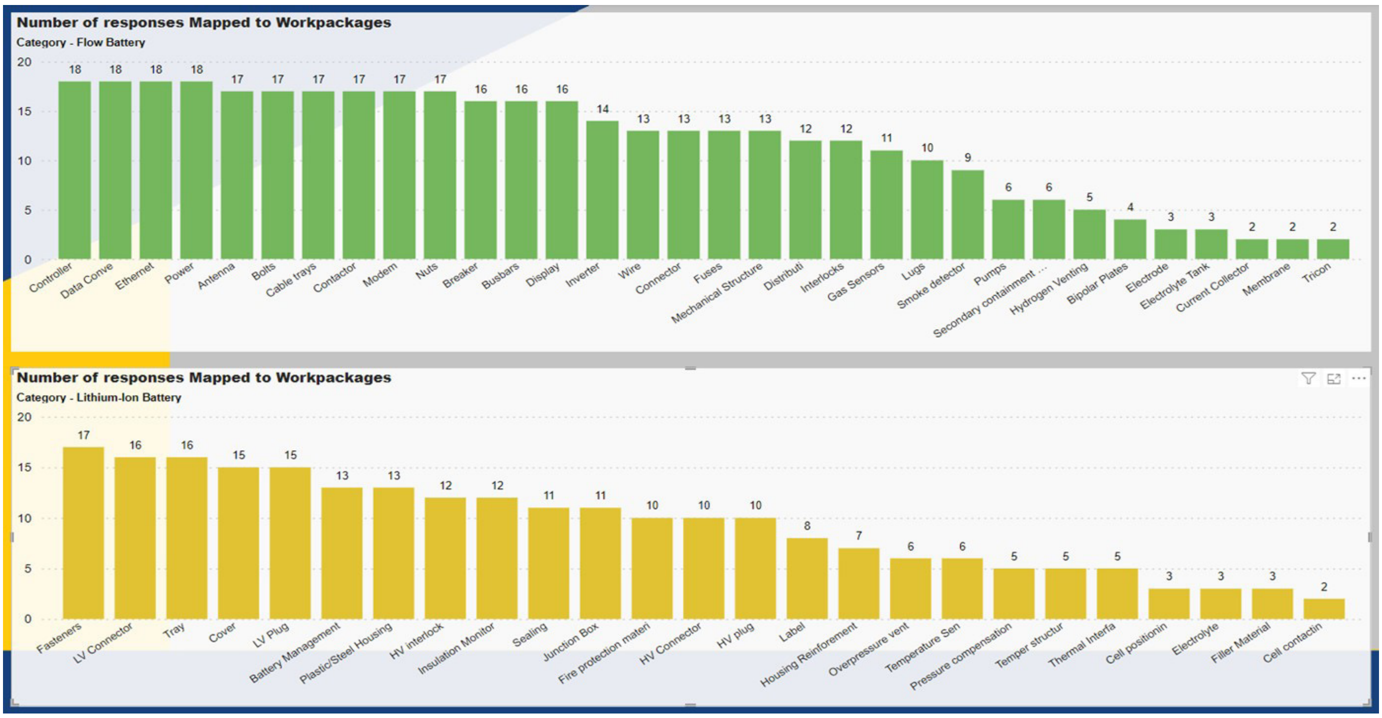
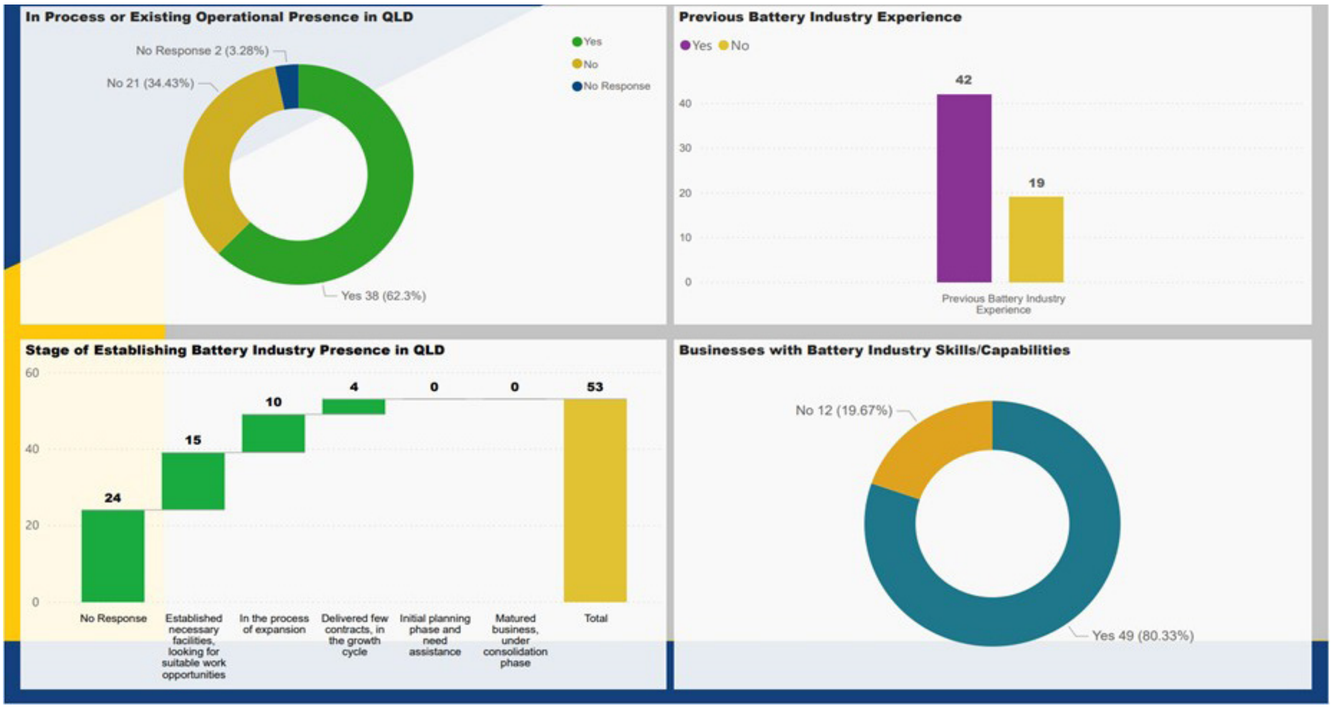


Fig 20 reveals that most businesses have existing presence in QLD or are in the process of setting up operational presence in QLD. Also, nearly 65% of the businesses who have responded have previous battery industry experiences (lead acid). Furthermore, around 19% of the businesses have no battery industry specific skills and capabilities.

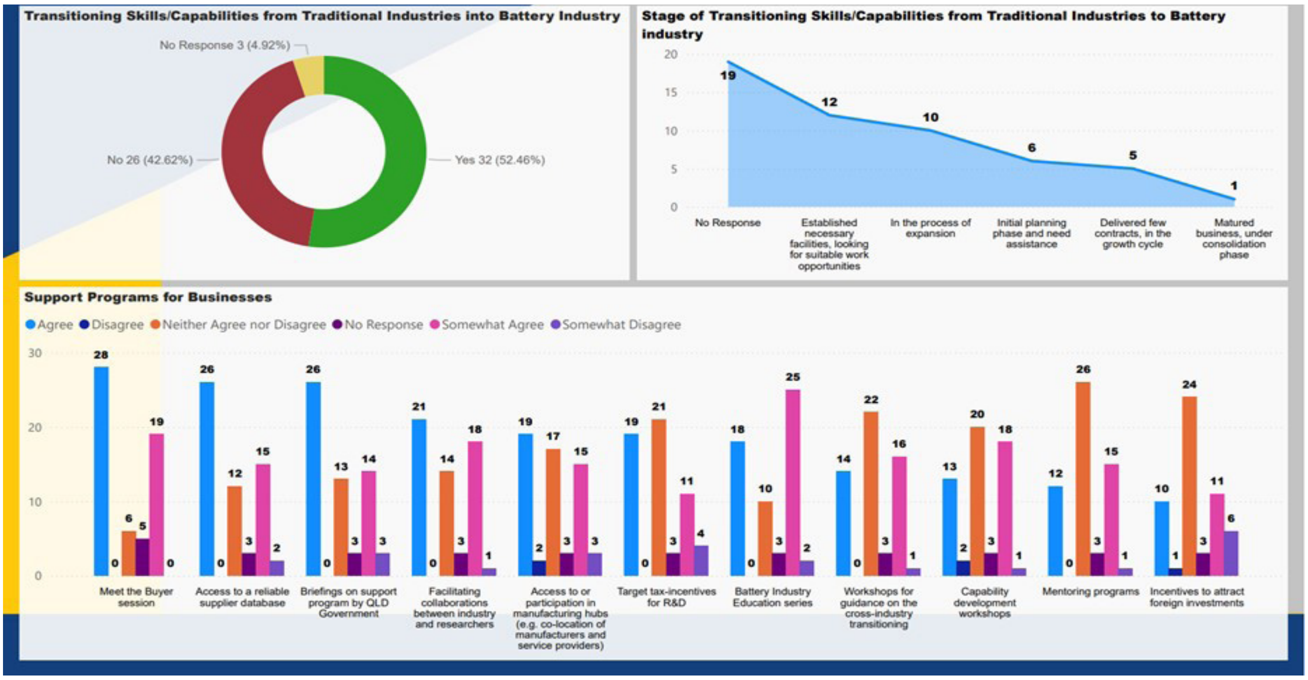
Figure 20: This dashboard shows battery industry exposure in Queensland. Pie charts depicts the number of businesses having a presence in QLD and possessing battery industry skillsets and capabilities. Column charts show the number of businesses having prior battery industry experience and the stage at which they are establishing a presence in QLD.



Requirements to help transition to supply components for battery industry

Fig 21 reveals that approx. 63% of the businesses surveyed are able to transition skills/capabilities from traditional industries to battery industry, as well as the responses to government support programs available to them.

Figure 21: This dashboard explores the skills transition and government support programs. A pie chart shows responses on transitioning skills from traditional industry to battery industry, with a separate count of companies at various stages of transition. A clustered column chart visualises agreement/disagreement on the government support programs available for businesses.



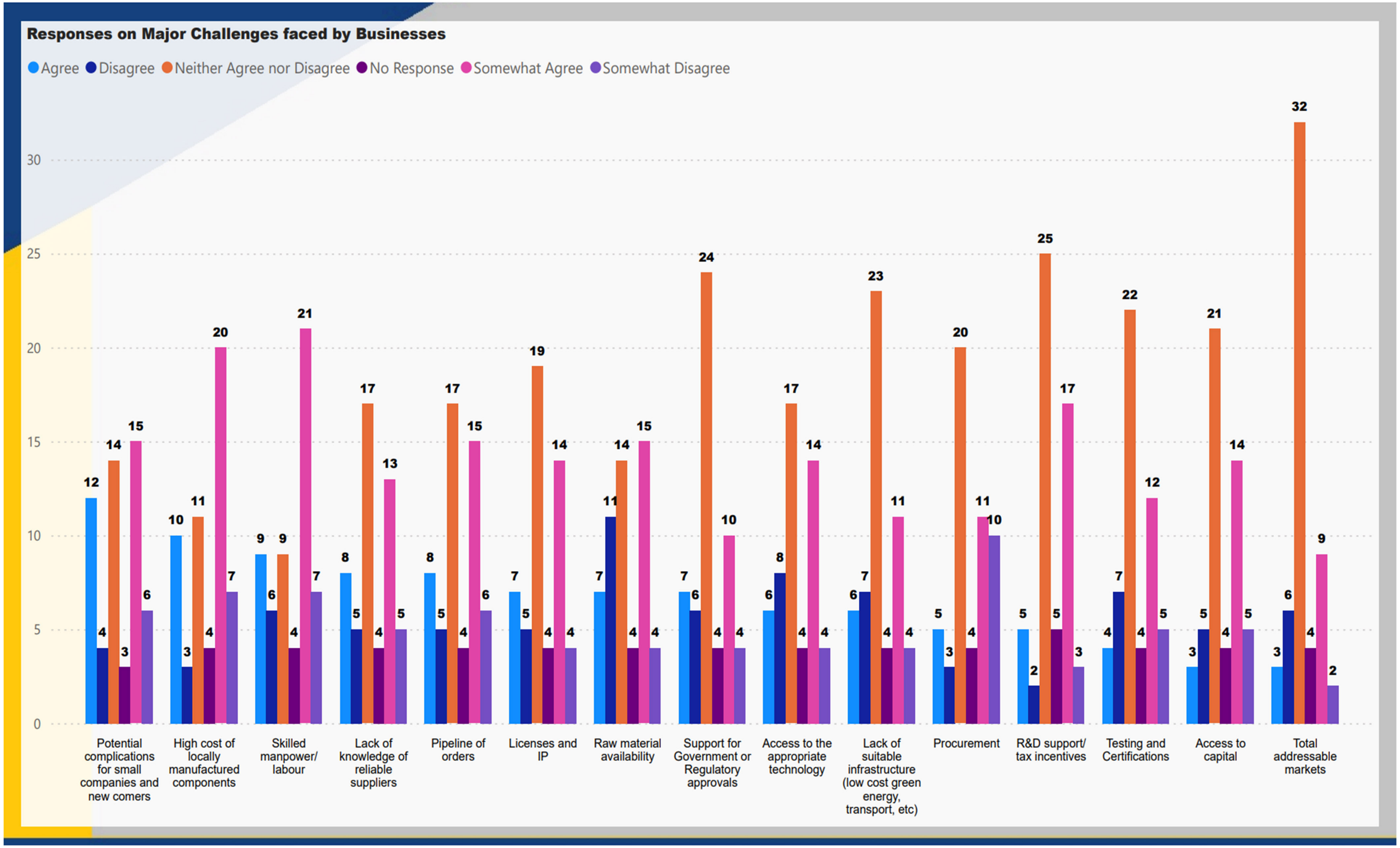
The responses also indicate that businesses would benefit from the battery industry opportunities. This is as a result of a lack of robust networks connecting manufacturers to battery-tech startups and researchers for them to become more informed. Based on the responses, there is a need to increase manufacturers' knowledge about the opportunity and what is required from manufacturers through access to battery component manufacturing industry and research networks. Table 4 summarises challenges faced and support required for the existing and transitioning businesses. The Queensland Battery Industry Strategy (QBIS) has proposed several actions towards addressing these challenges since 2024.

Table 4: Summary of respondents' views on challenges faced and support required for the existing and transitioning businesses

Category	Challenges faced by businesses
Market Access & Competition	**Existing**: Access to markets (20%) Pipeline of orders (38%)
	Transition*: -
Investment & Scaling	**Existing**: Access to capital (30%) Small company limitations (47%) R&D support/tax incentives (36%)
	Transition: Incentives to attract foreign investment (36%) Target tax incentives for R&D (49%)
Access to Facilities	**Existing**: Testing and certification (28%) Low-cost green energy, transport, etc. (29%)
	Transition: Access to manufacturing hubs (57%)
Collaboration & Networking	**Existing***: -
	Transition: Facilitating collaboration with researchers (65%) Meet the buyer sessions (79%) Briefings on support from QLD Government (66%)
Supply Chain & Procurement	**Existing**: Procurement (28%) Lack of network of reliable suppliers (39%) High cost of local components (51%) Raw material availability (37%)
	Transition: Access to reliable supplier database+(68%)
Regulations & Standards	**Existing**: Regulatory hurdles (29%) Licenses and IP (23%)
	Transition*: -
Workforce & Skills	**Existing**: Skilled workforce (50%) Access to technology (36%)
	Transition: Transitioning support (50%) Capability development (52%) Battery industry education (71%) Mentoring programs (45%)

* no challenges in a particular category were identified in the survey response; + Australian battery supply chain database was launched in 2024 to discover and engage with potential suppliers and partners throughout the battery value chain

Figure 22: This dashboard focuses on key challenges faced by the businesses, and the prevalence of various threats and challenges.



Challenges faced in the local manufacture of battery components

While survey responses, as illustrated in Figure 22, highlight areas where manufacturers seek greater clarity regarding battery manufacturing opportunities in Queensland, these insights provide a valuable roadmap for targeted government initiatives. Following are a set of challenges faced by the manufacturers.

Analysis of challenges for local manufacturing

High Cost of Locally Manufactured Components

The majority (51%) of respondents indicated that sourcing materials and components within the country is expensive, impacting profit margins and potentially making businesses less competitive in the global market. This is quite relevant for both Li-ion and flow batteries, where several key and expensive components are sourced from overseas (e.g. membranes, cathode and anode active materials, foils).

Skilled Workforce/Labour

One half of the businesses surveyed indicated that the shortage of skilled workers hinders growth and innovation. Businesses may struggle to find qualified employees with the right technical skills, leading to increased training costs or difficulty in meeting the demand. Therefore, training and educational programs could be developed by universities and other institutions in collaboration with the industry to develop battery manufacturing specific skills.

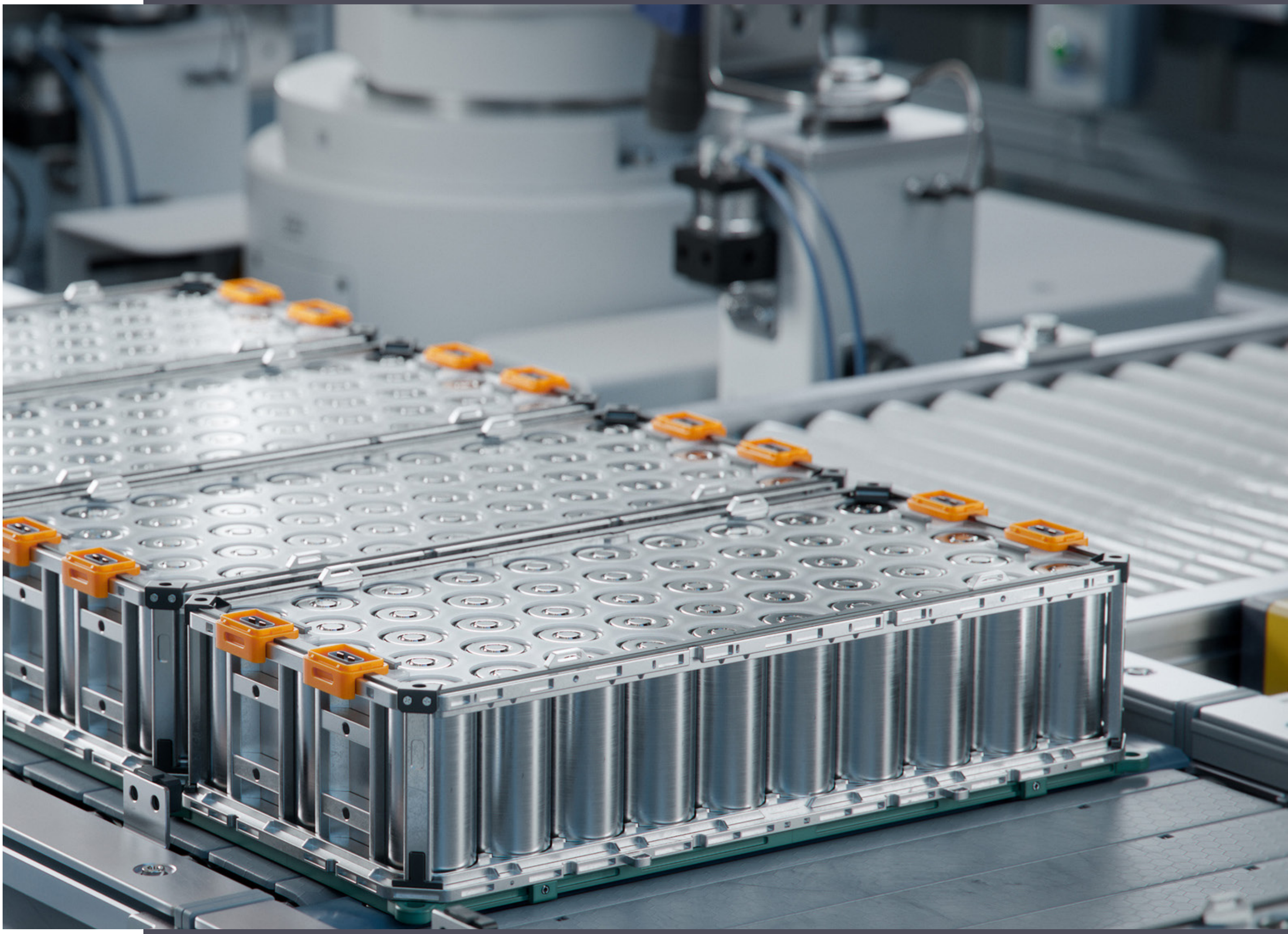
Potential Complications for Small Companies and Newcomers

Nearly, half (47%) of the respondents indicated that smaller and newer businesses perceive that they lack the resources and established networks of larger competitors, making it harder for them to enter the market, secure funding, and navigate regulatory hurdles. This was confirmed in the interviews as well where a few participants mentioned the need for having government appointed facilitators to provide appropriate support for businesses to fulfill the requirements for getting necessary approvals (e.g. support in filling up the forms, identifying key requirements, matching them with key government priorities etc). In addition, 29% of survey respondents saw regulatory approvals as another challenge. The specific challenges were not stipulated by respondents. Navigating complex regulations and obtaining necessary approvals can be time-consuming and costly, particularly for early stage businesses that are less familiar with the processes.

R&D Tax Incentives and Access to Capital

R&D tax incentives and access to capital were both identified as major challenges. The lack of sufficient R&D incentives and support can discourage innovation. Businesses might not have the financial means to invest in new technologies or product development. Similarly, securing funding is often a major hurdle for businesses, especially startups and small enterprises. Limited access to capital can restrict growth opportunities and make it difficult to invest in new projects or expand operations. These challenges, specially access to capital, were also identified in our interview analysis. Therefore, additional R&D incentives and support is required to keep innovating and growing battery component manufacturing sector.

The survey results reveal a range of opportunities and challenges. While many businesses, particularly those involved in flow and Li-ion batteries, see the potential for growth and are able to transfer skills from traditional industries, they also face significant hurdles. These include, high costs for locally manufactured components, a shortage of skilled labour, difficulties accessing capital, and navigating regulatory processes. Smaller companies and newcomers to the industry are particularly vulnerable due to limited resources and networks. Despite these challenges, businesses express support for government initiatives aimed at developing the domestic supply chain, such as information sharing, collaboration opportunities, and R&D funding. These findings highlight the need for continued government support and skills development to foster a thriving battery industry in Queensland. In direct response to these identified needs, QBIS has identified and provided plans for supporting the battery industry.



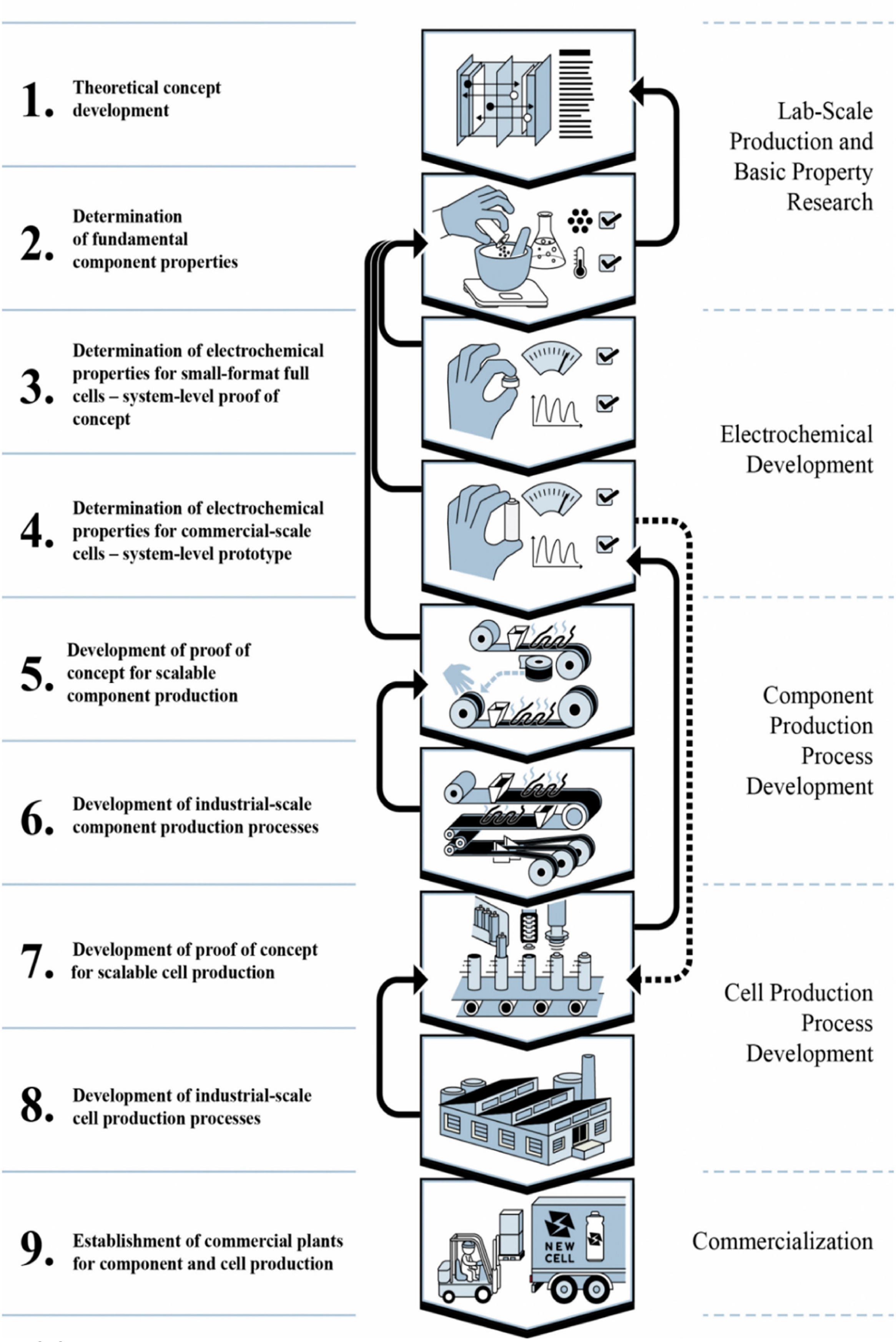
6 | OPPORTUNITIES FOR STRENGTHENING DOMESTIC MANUFACTURING

Key Findings

- Australia can leverage its strong position in ore extraction, along with its well-developed infrastructure, to expand its market share of critical minerals used in battery manufacturing through sustained investments.
- Australia has the potential to become a key player in the mid-stream segment of the value chain to create and capture more value and expand market share through new investments and innovations. This includes refining and processing of selected raw minerals to produce high-value battery grade materials and electrolytes (e.g. high-purity Alumina and Aluminium, Lithium, Vanadium, membrane materials).
- For cell manufacturing to achieve and sustain competitiveness at the global level, the domestic battery eco-system needs to be substantially developed. Given the limited capacity for any individual business in Australia to setup a gigafactory, a more realistic intermediate step would be to establish a niche low-volume cell manufacturing industry: e.g. to produce high-performance cells for defence, mining and space applications.
- Leveraging its world class R&D capabilities, Australia could focus on commercialisation of emerging technologies such as producing silicon anodes, enhancing phosphate-based cathodes, and improving the purity of iron and vanadium electrolytes, which offer opportunities for producing differentiated products.
- In the longer run, Australia has the opportunity to develop highly specialised batteries, including high-performance Li-ion batteries, unique graphene aluminium-ion batteries, and flow batteries, each offering distinct advantages over traditional Li-ion batteries.
- Battery pack assembly sector could sustain its competitive advantage by continuing to develop innovative solutions, including bespoke configurations and battery management systems, to suit local conditions or specific requirements and avoid direct competition against imported products.
- To build a viable domestic battery recycling sector, Australia needs to invest in reverse logistics infrastructure, streamline regulatory regimes and achieve scale economies.
- In the space of research and training, opportunities exist to strengthen the battery manufacturing ecosystem by stronger, comprehensive collaborations among key partners to offer targeted training programs that meet the future needs of the emerging active materials and cell manufacturing sectors.

A typical battery pack consists of multiple sub-assemblies, components and parts that are made of a mix of refined materials, including high-purity metals, chemical compounds and polymers. While the minerals used for certain battery materials can only be extracted in locations where adequate reserves are available, most of the parts and components could potentially be manufactured in any location around the world. However, successful integration into global battery supply chains is largely driven by the ability of a business to enter into off-take agreements with major buyers such as EV manufacturers. Prior to entering into these agreements, businesses must demonstrate the technical feasibility and economic viability of full-scale production. This requires navigating a multi-stage qualification process involving laboratory-scale development, proof-of-concept and pilot production (see Fig 23), which demands varied levels of investments, technological capabilities and testing and certification systems.

Figure 23: Battery component readiness level framework



Source: [61]

Given that battery chemistries and associated manufacturing processes keep evolving, the development and testing of battery technologies involve long-lead times and substantial sunk costs, as well as large capital investments for scaling up production. This means, understanding and developing markets remains a key challenge faced by potential new entrants to the battery manufacturing industry. In particular, access to capital remains a major challenge for local businesses. Having recognised the broader economic, social and environmental benefits offered by the growing battery market, many countries around the world are actively pursuing opportunities to participate in the global battery supply chain. China, which currently dominates the global battery supply chain, has facilitated the early development of their supply chain through direct and indirect public investments and regulatory measures that promote the adoption of batteries. Aspiring economies like in USA and EU have also already committed substantial public funds to support local supply chain development and encourage industry collaborations.

Numerous initiatives undertaken at both the state and federal levels, as well as the strong interest shown by the industry to invest in developing battery grade materials, indicate that Australia is also looking to seize the opportunities presented by the expanding domestic and international battery market, albeit moving at a slower pace than other comparable countries.

The major opportunities for strengthening the domestic manufacturing at each segment of the battery ecosystem, as informed by this study, are presented in this section.

6.1 Mining and ore extraction

Australia possesses significant reserves of critical minerals such as vanadium, nickel, cobalt, graphite, and aluminium (some of which are still not fully exploited), used in both mature and next generation battery technologies. Currently, Australia accounts for over 50% share of the global market for lithium. About 28% of the global vanadium reserves are also located in Australia. Additionally, Australia holds significant reserves of nickel, cobalt, bauxite and copper (refer to Table 5 for the list of mineral mining activities in Australia). With its long history of ore extraction and well-developed infrastructure, Australia is well positioned to maintain its competitiveness in mining critical minerals for Li-ion batteries and further expand its market share of other selected battery minerals through sustained investments. It will offer ongoing opportunities for cost-effective production of a variety of high-quality battery materials and electrolytes.

6.2 Refining and processing into battery grade materials

Refining and processing of raw materials is currently dominated by China (over 75% of the global market share), with only a few other countries such as Chile, Japan and Korea (combined market share of over 15%) having a somewhat significant presence within this segment. Value chain analysis shows that substantial opportunities for value capture are found in refining and processing of active materials, which represents 40% of the total value-add across the supply chain. Furthermore, active materials, primarily lithium and nickel for Li-ion batteries and vanadium for flow batteries, are pivotal in determining battery pack prices and will play a crucial role in reducing materials and logistics costs. Vanadium is instrumental in determining flow battery prices due to its extensive utilisation in electrolytes.

As shown in Table 6, this segment is gathering momentum with a number of projects either currently in progress or are planned to commence in the near future.

Table 5: Battery related minerals mining in Australia

Mineral	Production	Major Mines in Australia	Approx. World Market Share	Total Ore Reserves (As of Dec 2022)*	Notes
Manganese	5.0-7.0 million tonnes	Groote Eylandt	~15%	109 Mt	Primarily from Groote Eylandt mine
Phosphate	0.5 - 1 million tonnes	Phosphate Hill	< 5%	157 Mt	Smaller scale compared to other minerals
Bauxite (Aluminium)	~ 100 million tonnes	Weipa, Gove, Huntly and Willowdale, Boddington	~30%	1634 Mt	Dominant global position
Zinc	1 - 1.5 million tonnes	Mt Isa, Century, Dugald River, George Fisher	~5%	21.12 Mt	Several significant mines
Cobalt	5-10 kilo tonnes	Murrin Murrin, Ravensthorpe Nickel Operation	5-10%	614 kt	By-product of nickel mining
Lithium	250 to 350 kilo tonnes LCE	Greenbushes, Mt Cattlin, Pilgangoora, Wodgina	~55%	4794 kt	Rapidly expanding production
Nickel	200 - 250 kilo tonnes	Mt Keith, Murrin Murrin, Cosmos, Nova	~7%	8.6 Mt	Significant global producer
Graphite	< 10,000 tonnes (small-scale)	Uley Graphite	< 1%	5 Mt	Production increasing, exploration active
Vanadium	< 10,000 tonnes (small-scale)	Windimurra	< 1%	2971 kt	Potential for future growth

https://www.ga.gov.au/aimr2023/australias-estimated-ore-reserves

Table 6: Refining projects in Australia for different battery materials

Mineral	Company	Materials Refined (Focus)	Notes on Production
Lithium	Wesfarmers https://www.wesfarmers.com.au/	Lithium hydroxide	Kwinana refinery (under construction)
	Tianqi Lithium https://www.tianqilithium.com.au/	Lithium hydroxide	Kwinana refinery (operational, joint venture with IGO)
	Covalent Lithium https://covalentlithium.com/	Lithium hydroxide	Kwinana refinery (development stage)
Nickel	BHP Nickel West https://www.bhp.com/	Nickel sulfate	Major producer for the battery industry
	Queensland Pacific Metals (QPM) https://www.qpmetals.com.au/	Nickel sulfate	TECH Project (planned)
	Mincor Resources	Nickel sulfate (potential)	Plans to transition to battery-grade nickel, leveraging operations
	Pure Battery Technologies https://purebatterytech.com/	Nickel sulfate	Queensland company, start-up chemical plant in Germany, long term plans may include battery precursor material plant in Townsville
Cobalt	Clean TeQ https://www.cleanteq.com/	Nickel sulfate, cobalt sulfate (potential)	Syerston Project (development stage)
	Queensland Pacific Metals (QPM)	Cobalt sulfate	TECH Project (planned)
	https://www.qpmetals.com.au/ https://australianmines.com.au/	Nickel sulfate, cobalt sulfate	Sconi Project (development stage)
Manganese	Consolidated Minerals Limited https://www.consmin.com.au/	Manganese (various forms)	Limited refining in Australia, focus on ore export
Phosphate	Incitec Pivot https://www.incitecpivot.com.au/	Fertilizers (derived from phosphate rock)	Significant fertilizer producer, not dedicated battery focus
Aluminium	Alcoa https://www.alcoa.com/	Alumina, Aluminium	Multiple refineries, major aluminium producer
	Rio Tinto https://www.riotinto.com/	Alumina, Aluminium	Multiple refineries, major aluminium producer
	Alpha HPA https://alphahpa.com.au/	High Purity Alumina (HPA)	Specializes in ultra-high purity alumina for various applications
	Lava Blue https://lavablue.com.au/	High Purity Alumina (HPA)	Developing in ultra-high purity alumina process
Graphite	EcoGraf https://ecograf.com.au/	Spherical graphite	Battery anode material plant in Western Australia
	Syrah Resources https://www.syrahresources.com.au/	Graphite (active anode material)	Processing in the US, potential future expansion in Australia
	Axon Graphite https://company-announcements.afr.com/asx/nvx/ 4cac5d12-f144-11ee-bbf5-9ecdadde1113.pdf	Spherical Purified Graphite Battery Anode Material	Novonix and Lithiem Energy merger graphite assets combined in new company, Axon Graphite

Mineral	Company	Materials Refined (Focus)	Notes on Production
Vanadium*	TNG Limited https://tngltd.com.au/	Vanadium pentoxide (potential)	Mount Peake Project (development stage)
	Critical Minerals Group	Vanadium mining	Lindfield Project
	Multicom Resources	Vanadium pentoxide (potential)	Saint Elmo Project (development approved and construction commenced)
	Vecco Critical Minerals Project	Vanadium pentoxide (potential)	Julia Creek (development stage)
	Vecco Group	Vanadium electrolyte plant from an imported vanadium	Townsville
	Australian Flow Batteries https://www.afb.energy/	VRFBs	Perth
	VSUN https://vsunenergy.com.au/	Vanadium electrolyte from imported materials	Perth
Zinc	Sun Metals https://www.sunmetals.com.au/	Zinc	Refinery in Townsville

* *most the vanadium refining projects listed above are yet to commence local production in Australia*

In addition to the active materials used, aluminium represents over 30% of the total mass of a Li-ion battery pack and over 20% of the total cost of the battery. Despite Australia being the largest producer of bauxite, domestic refining and smelting remains low. This presents Australia another opportunity to leverage its strengths for processing battery-grade aluminium. Alpha HPA, an Australian company, has recently (Apr, 2024) secured funding for full-scale production of high-purity alumina at their Gladstone based site making it one of the largest single site ultra-high-purity alumina refineries in the world [36]. Similarly, in flow batteries, the membrane stack represents the highest cost element and Australian businesses are currently experiencing difficulties with sourcing membranes, in terms of both lead-time and cost, due to the limited number of reliable suppliers they have access to. This is a significant gap in the battery supply chain that Australia could potentially exploit. The current level of activity within midstream battery component is summarised in Table 7.

Table 7: Battery component development projects

Component	Company	Focus/Materials	Location	Recent News (Product Development)
Anode	AnteoTech	Silicon-enhanced composite anodes	Brisbane, QLD	Successful development of long-life battery technology:
Cathode	VSPC	CAM for LFP and LMFP	Brisbane, QLD	Commercial testing of materials is done and plan for expansion through scale-up of its pilot facility
Anode	Novonix	Synthetic Graphite	Chattanooga, US (potential Australian expansion)	Production ramp-up in the US, potential for Australian expansion
Anode	Sicona Battery Technologies	Silicon-carbon composite anode materials	Wollongong, NSW	Announced plans to invest in US.
Anode	Talga Group	Natural graphite mining, anode processing	Vittangi, Sweden (potential Australian expansion)	Anode qualification progress, European and potential Australian operations
Electrolyte	Calix	Electrolyte additives, solvents	Bacchus Marsh, VIC	Research collaborations and focus on battery materials
Electrolyte	Boron Molecular	Ionic liquid electrolytes	Adelaide, SA	Progress in electrolyte research and development

Component	Company	Focus/Materials	Location	Recent News (Product Development)
Other	GMG	1. Graphene manufacturing; 2. Battery cell development	Brisbane, QLD	Graphene aluminium-ion battery development
Membrane	ESI -AP and UQ	Membranes for Iron flow battery systems	Brisbane QLD	ESI -AP and UQ's Dow Center have started working on the development of membranes for Iron flow battery systems but they have a desire to commercially develop this to support other manufacturers and close the supply chain gap
Membrane	Fortescue (FFI)	FFI Ionix, a subsidiary of Fortescue Future Industries (FFI), is a leading developer and manufacturer of advanced ion-exchange membranes for green hydrogen production. These membranes can be adapted to be used in flow battery applications.	Delaware (US) (potential expansion in their Electrolyser facility in Gladstone (QLD))	FFI Ionix specializes in Anion Exchange Membranes (AEM) and other cutting-edge membrane technologies. They have established commercial-scale manufacturing facilities in USA to meet the growing demand for its membranes

6.3 Cell manufacturing to module and pack assembly

Cell manufacturing represents 30% of the total value-add across the battery supply chain, which is estimated to be over USD120 billion globally. Currently cell production is led by China (63% market share) with South Korea and Japan each having 23% and 6% market share, respectively. There are several Australian businesses currently in the process of developing and testing cell manufacturing processes, at varied levels of technology readiness. The recent establishment of Li-S Energy's new dry room production facility in Geelong, Australia marks a significant step towards developing its cell manufacturing capabilities for lithium-sulphur batteries. GMG has developed a unique Graphene Aluminium-Ion battery technology that utilises graphene to enhance the performance and stability of aluminium-ion batteries. However, given that Australian business are at the early stages of developing battery chemistries and manufacturing processes, the opportunities for expanding into full-scale production of cells in the immediate future are quite limited. Instead, Australia could focus on capturing more value by producing selected refined materials such as high-purity Alumina and Aluminium, leveraging higher-grade and more readily available reserves. Moreover, for cell manufacturing to achieve and sustain competitiveness at the global level, the domestic battery ecosystem needs to be substantially developed from where it is now.

Additionally, there are multiple opportunities for the domestic manufacturing sector to develop its capabilities to supply other critical components that go into battery pack assembly. For example, the global EV battery housing market is projected to reach $11.74 billion by 2031 from $3.67 billion in 2021. EV battery housing consists of a frame, underride guard, connection profile, and cover, along with upper and lower support. Housing materials need to meet multiple requirements such as high fatigue strength, sealing, high yield strength, anti-vibration, heat management, and corrosion protection to the battery pack. Australia's strengths in advanced materials research, including polymers, and capabilities in steel and aluminium production could potentially be harnessed to exploit commercial opportunities in this sector.

Alternatively, with its strong R&D capabilities, Australia could focus on emerging technologies and high-performance materials such as producing silicon anodes, which offer differentiated performance compared to graphite anodes, developing vanadium-based cathodes, enhancing phosphate-based and nickel-based cathodes and improving the purity of iron and vanadium electrolytes. Currently, a number of universities are actively pursuing fundamental research aimed at developing emerging technologies such as sodium-ion, potassium-ion, lithium-sulphur electro-chemistries for improving the fundamental safety performance of Li-ion battery materials, cells and packs.

Li-ion batteries hold a significant share of the global market, but, moving forward, graphene aluminium-ion batteries may gain traction due to their advanced performance attributes. Flow batteries also stand to increase their market share because of their longer cycle life and the potential to enhance battery capacity by adjusting electrolyte quantities without additional capital expenditure. Moreover, pack assembly drives demand for cell manufacturing while reducing logistics costs for integration, service, and maintenance industries. While Li-ion and potentially graphene and aluminium-ion batteries are well suited for mobility applications, there is a growing market for stationary storage, that could potentially be served by Vanadium redox flow batteries. Thus, in the longer term, Australia has the opportunity to develop highly specialised batteries, including high-performance Li-ion batteries, unique graphene aluminium-ion batteries, and flow batteries, each offering distinct advantages over traditional Li-ion batteries.

The global battery pack assembly represents 18% of the total value add across the supply chain. There are already a number of Australian businesses involved in battery pack assembly, using imported cells and both imported and locally sourced parts and battery management systems. While some business are supplying to utility companies, others are targeting specific markets such as defence, mining, agriculture and telecommunications. Some of these businesses serving niche markets are also offering customised battery systems to suit local conditions. This segment presents opportunities for new entrants to capture more value by developing innovative solutions, including bespoke configurations and battery management systems, to suit local conditions or specific requirements and avoid direct competition against imported products.

6.4 Recycling

Recycling is identified as a significant segment (3% of total value add) of the battery value chain from both value recovery and sustainability perspectives. Recycling involves collection, transportation, disassembly, materials separation and recovery. In some cases, used EV batteries are used for residential and other short-duration stationery storage applications, as well. Currently most of the material recovery from recycling takes place in China (45%) with USA, Japan and South Korea sharing another 35% of the feedstock. There are only a few Australian businesses actively engaged in battery recycling with their operations limited to collection, transportation, disassembly, sorting, and black mass recovery. Black mass is then sent to other locations where active materials processing takes place. Given the limited feedstock available in Australia and different regulations in regards to transportation, storage and handling, current recycling rates of used batteries in Australia remains low. Potential opportunities in the recycling space, therefore, need to be targeted at achieving scale economies and resolving logistics related hurdles. This will pave the way for feeding recycled materials back into the mainstream supply chain either at onshore or offshore nodes, depending on the state of domestic supply chain development. The newly established ARC Training Centre for Battery Recycling is expected to comprehensively address the full range of challenges associated with battery recycling. The proposed measures include building advanced manufacturing capability for recycling mixed battery materials, promoting 2nd-life re-use, redesigning high performance batteries towards a battery circular economy, and advancing a regulatory landscape supportive of battery recycling.

6.5 Research and development

Future Battery Industries Cooperative Research Centre (FBI-CRC) is Australia's flagship research program. In March of 2024, round 25 of the CRC program also saw the submission of the Minerals to Megawatts CRC program, a national consortium of industry and university partners seeking to fortify Australia's energy security by establishing and growing resilient supply chains for battery materials, cells and systems. CSIRO's energy storage and battery technologies group also undertakes significant battery research, including material characterisation and testing of Li-ion and lithium metal batteries.

Apart from the research undertaken by FBI-CRC and CSIRO, several major publicly funded programs, such as ARENA and Economic Accelerator program, support battery-related R&D projects. Additionally, many of the Australian universities undertake battery-related research, either independently or as part of collaborative research programs, covering multiple areas such as materials science, electrochemistry and manufacturing processes. Some of these institutions have facilities for testing of battery cells and packs of varied types and sizes.

CSIRO battery research capabilities include material characterisation (chemical, physical and electrochemical); preparation of electrodes (commercial and novel anodes and cathodes); electrolyte design (organic and ionic liquids-based); fabrication of different battery architectures (i.e. coin cells, pouch cells, flexible cells) and testing battery performance of commercial and novel electrolytes and electrode materials. Their dedicated battery laboratory has facilities and equipment for testing single cells at low currents to battery packs that are used for vehicles or grid storage.

QUT's Energy Storage Research Group undertakes battery research on technologies, standards and safety, and works locally and nationally to deliver major capability building projects in energy storage at QUT's Advanced Battery Facility (ABF). The ABF also has unique capabilities to fabricate and test pilot-scale quantities of custom Li-ion cells. These projects to date represent over $60million in co-investment from industry, research institutions and government to develop facilities for fundamental research, testing and qualification services in battery materials and systems across the entire battery value chain. QuestHub, houses facilities and equipment at the QUT Banyo Pilot Plant Precinct for testing multiple types and sizes of battery systems under real-world conditions and supports industry-driven research translation and commercialisation efforts through co-location of industry and academic experts.

The University of Queensland has significant research capabilities across the entire value chain, including battery mineral extraction, metallurgy, electrochemistry, nanotechnology, materials science, process engineering and electrification. Centres like the Sustainable Minerals Institute (SMI), UQ Material Performance (UQMP), Centre for Microscopy and Microanalysis (CMM), Centre for Advanced Materials Processing and Manufacturing (AMPAM), Advanced Robotics Manufacturing Hub (ARMHub), Industry 4.0 Energy Testlab, and the Structural Fire Engineering Group are all actively engaged in supporting companies to commercialise and deploy batteries.

The Battery Research and Innovation Hub of the Deakin University is a purpose-built facility for battery design and development, encompassing research, pilot-scale manufacturing and the commercialisation of energy storage technologies. Specialising in advanced battery design, fabrication and testing, the facility includes a pilot production line to manufacture advanced batteries and battery components, complementing pouch cell prototyping, a cell and pack testing lab, and advanced cell diagnostics, materials characterisation and failure analysis. Their research focus on advancing existing technologies such as Li-ion, as well as sustainable alternatives such as sodium batteries.

ANU Research School of Chemistry has a facility that undertakes research into new battery storage technologies including Li-ion, sodium-ion and potassium-ion, hybrid capacitors and super-capacitors. It supports the characterisation, development and performance testing of battery materials, electrolytes and devices.

The Centre for Clean Energy Technology at the University of Technology Sydney is working on electro-materials for applications in lithium-ion batteries, lithium-air batteries, sodium-ion batteries and lithium–sulphur batteries.

Monash University researchers in Australia have developed a new lithium-sulphur battery design. They claim that it requires less lithium, with more energy per unit volume, lasts longer, and can be produced for half the price of the dominant Li-ion technology.

These sample projects highlight Australia's world-class capabilities in battery research across the full R&D spectrum. While the majority of research undertaken by the independent researchers at the university level remains to be on emerging technologies, there are significant collaborative efforts in moving towards the commercialisation of next generation technologies, as well. The analysis of industry perspectives and published reports points to the opportunities for greater collaboration across research institutions, government agencies and industry partners to address the major challenges faced by the industry. These challenges revolve around the demonstration of the commercial potential of next generation battery technologies. This is particularly significant given the current battery manufacturing landscape, where the majority of minerals refining, active materials processing and cell production is taking place overseas, concentrated only in a few countries. By supporting truly collaborative research targeting commercialisation of next generation technologies, Australia could develop sovereign manufacturing capabilities and help mitigate supply chain vulnerabilities, as well as address product quality and safety issues, which are critical to serving niche markets and meeting unique Australian conditions.

As the domestic battery eco-system is in its infancy, Australian businesses assembling battery packs largely rely on overseas suppliers for active materials, parts and components, which poses a range of issues in relation to development lead times, quality assurance and product testing and certification. In particular, the proprietary processes used for developing active materials and cell manufacturing in China is reported to be quite diverse in terms of their adherence to industry standards. This poses significant procurement challenges for Australian businesses, in terms of supplier evaluation and selection, as well as quality assurance. Additionally, given limited independent testing facilities in Australia, businesses developing new battery technologies are facing significant difficulties with product certification. As such, there is an urgent need for expanding the current facilities or establishing new facilities that can be accessed by local businesses for testing and certification of their products and processes.

6.6 Education and training

Currently there are two major ARC training centres in Australia; one for future energy storage technologies, and the other for battery recycling.

The ARC Training Centre for Future Energy Storage Technologies is a $11.3million initiative with 11 participating organisations across government, industry and universities. The Centre provides skills and training in advanced manufacturing across the energy storage supply chain; from materials through to devices and into integrated commercial products, to facilitate next-generation energy storage technologies. It will design and manufacture new energy storage devices and components, including advanced Li-ion, super capacitors and solid state Li and Na batteries, with improved power, capacity and safety.

The ARC Training Centre for Battery Recycling will provide industry-centric solutions for the problems associated with battery recycling across the entire value chain, covering waste battery collection, transportation, storage, materials recovery and reuse. This Training Centre aims to transform Australia's battery and resource industries by building advanced manufacturing capabilities for recycling mixed battery materials, promoting 2nd-life re-use, redesigning high performance batteries towards a battery circular economy, and advancing the supporting regulatory landscape. The research will address the challenges associated with battery recycling, deliver industrial demonstrations and promotion policies, and create a dynamic skilled workforce. Outcomes are expected to shape a distinctive battery recycling model that shifts Australia to zero battery waste to landfill; establish a profitable and self-sustaining onshore industry chain; and help ensure the future of Australia's energy security.

Apart for these two dedicated training centres, most of the universities pursuing battery-related research provide postgraduate training and early career researcher development opportunities across a range of discipline areas relevant to the battery industry. For instance, the Battery Research and Innovation Hub of the Deakin University also provides post-secondary education and training opportunities in battery production and process engineering. Similarly, The Centre for Clean Energy Technology at UTS offer to transform PhD students and early career researchers into highly skilled professionals in the fields of electrochemistry, and electro-materials for battery technologies and applications.

There are opportunities in the education and training space for collaboration among the universities, industry and government agencies to develop more targeted training programs that takes into account current and future industry needs.

A summary list of opportunities identified in the study is presented in Table 8.

6.7 Options for supply chain development

Compared to China and other countries aspiring to be part of the global battery supply chain, domestic battery component manufacturing sector in Australia is largely underdeveloped. Apart from mineral extraction, which has about 50% share of the global market, other segments of the battery value chain are almost non-existent in Australia. This means, on the one hand, there are many opportunities for expanding into other segments of the value chain. On the other hand, this situation presents a challenge as to what segments of the supply chain Australian businesses should prioritise in terms of maximising value capture, particularly considering the significant entry barriers such as advanced technological capabilities, large capital requirements and high investment risks.

There are three major options for strengthening Australia's participation in the global battery supply chain. The first option is expanding downstream into raw materials refining and active materials processing, which comes across quite logical given the country's substantial minerals reserves, strong mining infrastructure and well-developed capabilities.

Table 8: Opportunities for battery manufacturing

Opportunity Area	Specific Opportunities
Raw Material Mining	Consolidate and leverage the current market position through ongoing extraction of vanadium, lithium, nickel, cobalt, graphite, iron, aluminium to further strengthen value addition and value capture
Refining/ Processing	Seek to become a key player in refining/processing of battery-grade materials (V, Li, Ni, Graphite, Al, Fe)
	Build on the current success with the development and refinement of vanadium electrolyte for flow batteries: • Vecco Group opened Australia's first vanadium electrolyte production facility in Townsville, Queensland, in June 2023. The company has plans to expand its electrolyte production in Townsville, as well as in the USA and Europe. Vecco Group has entered into a non-exclusive partnership with Sumitomo Electric to create an end-to-end vanadium flow battery supply chain in Australia, leveraging Vecco's vanadium mining and electrolyte production capabilities and Sumitomo Electric's expertise in battery systems. • Australian Vanadium Limited (AVL) is one of the leading companies in this space, having recently launched its new vanadium electrolyte manufacturing facility in Western Australia. The facility is capable of producing high-purity vanadium electrolyte for use in VFBs.
	Explore the potential for processing of battery-grade Al, Cu, and Li foils by extending the current capacity and capabilities.
	• Alpha HPA has recently secured funding for full-scale production of high-purity alumina at Gladstone site. Such initiatives are further needed to develop local manufacturing of aluminium foils and other battery components including enclosures for battery industry. • Currently, there is only a few suppliers for these materials globally (e.g. Fumatech, DuPont, Ionomr Innovations Inc.).
Cell Manufacturing to module and pack assembly	Prioritise the local production of selected refined materials (e.g., foils (Al, Cu, Li), high purity alumina, cathode precursors, anode materials) with a view to integrating into global cell manufacturing supply chains in the future
	• Strengthen capacity for increasing local share of component procurement - supply components for battery pack assembly (e.g. housing for pack, cell casing, foils)
	Serve niche domestic and selected overseas market with products tailored to specific applications and local conditions
	• Develop bespoke battery systems for specialised (e.g. safety-critical) and/or larger vehicles for mining and agricultural sectors, grid-scale storage, low voltage installations and micro grids, ruggedized batteries suitable for hot climates and cyber-secure environments and high-energy density batteries for electric aviation, including high-altitude drones and defence applications. • Companies such as Li-S energy, GMG, Energy Renaissance has the capabilities and interest to establish facilities for cell manufacturing with assistance from Australian Battery Industrialisation Centre (ABIC), Queensland Battery Industry Strategy (QBIS) and other government initiatives.

Opportunity Area	Specific Opportunities
Recycling	Achieve economy of scale in battery recycling • Focus on tracing of battery materials for recycling and reuse improving circularity of key minerals • Build the reverse logistics infrastructure and streamline regulations – there is currently limited battery recycling taking place in Australia
Research & Development Testing and Certification capabilities	Leverage industry-research institutes collaboration for speeding up the development of next-generation battery technologies (Li-S, Na-ion, Graphene Al-ion etc) • Expansion/establishment of independent testing facilities in scale as well as the variety of tests that can be performed (e.g. IEC 62619, IEC 62485-5, AS IEC 62619) or establish similar facilities like TÜV Rheinland for testing and certifications in Australia • Large organisations typically purchase batteries in the megawatt-hour (MWh) range. However, producing an MWh-sized battery for testing purposes is a significant financial and resource burden for smaller startups. To address this challenge, startup manufacturers and buyer organisations need to work together to consider expanded testing data on smaller kilowatt-hour (kWh) battery units in their purchasing decisions. This approach is faster, more cost-effective, and still provides buyers with valuable insights into technical specifications, performance, and production quality, ultimately ensuring the same level of confidence as MWh-scale testing.
Education/Training	Collaborate across the tertiary education sector (vocational and university) to fill the skills gap • Develop targeted training programs aligned with industry needs (e.g. short courses, vocational programs in cell assembly, applied battery science, applied electrochemical knowledge as well as applied chemical engineering). ABIC, QBIS and Manufacturing Skills Queensland can assist in creating these training programs run by QUT, UQ, GU, and others
Supply Chain Development	Prioritise investments based on potential for value capture • Expand into raw materials refining and processing – has the greatest potential for value add and can build on existing capacity • Enter mid-stream with cell manufacturing – has the medium potential for value add but difficult to secure off-take agreements • Enter downstream with pack assembly and move backward – has moderate potential for value add but low barriers to entry

There are several large businesses that have already started or planning to set up raw materials refining projects indicating that this is the most likely path that industry will take in the immediate future. However, given the large capital requirements associated with setting up refining and processing plants, the success of expanding into this segment largely depends on the ability to attract investments. Otherwise, this segment is considered relatively low-risk and high-return, given that refining and processing accounts for over 40% of the total value-add across the supply chain.

Entering the supply chain mid-stream (i.e. cell manufacturing) is the second option, which is the next most attractive segment in terms of value adding potential representing 30% of the total value-add across the supply chain. However, cell manufacturing requires not only substantial capital, but also mastery of technology, as well as a well-developed battery eco-system. Commercial success of cell manufacturing also depends on the businesses ability to enter into off-take agreements with global players. Additionally, given the evolving nature of battery chemistries and associated processing technologies, there are significant investment risks applicable to this sector. Therefore, the success of cell manufacturing largely depends on the ability to attract established international players to set up local plants or more risk-tolerant local/overseas investors to support Australian entrepreneurs.

The third option is entering the supply chain downstream (pack assembly) and move backwards progressively into cell manufacturing as the domestic component manufacturing sector strengthens. This segment carries an 18% share of the total value-add across the supply chain and perhaps holds the greatest promise for Australian businesses, given the low entry barriers and demonstrated success of a number of businesses already operating in this space. However, given the limited availability and high costs of local components, as well as lack of access to reliable and high-quality overseas suppliers, local businesses may not be able to compete head-on against cheaper overseas products in this sector. That being said, the businesses currently operating in this sector has successfully navigated these challenges by targeting niche markets with products and services catering to specific applications and meeting local conditions.

Additionally, recycling and reuse of used batteries could be scaled up so that the recovered material can be fed back into component manufacturing.

7 | PRIORITY AREAS FOR STRENGTHENING DOMESTIC COMPONENT MANUFACTURING

Key Findings

- Membranes, a vital component of flow batteries, account for up to 40% of the total battery system cost, and currently there are only a few membrane manufacturers around the world.
- Given the high costs and poor environmental credentials of the existing membrane materials, there is currently a growing research effort directed at developing cost-effective and environmentally-friendly alternatives.
- Aluminium is widely used in different Li-ion battery components, including current collectors and battery enclosures, accounting for approximately 15%-30% of the total weight of a battery pack.
- Australia's abundant mineral resources, and the substantial and growing global battery market, present a compelling opportunity for Australia to capture greater value within the midstream segment of the battery value chain, by producing battery grade Aluminium, Copper and Lithium foils.
- Active materials represent approximately 27% of the overall Li-ion battery market value. By developing domestic active material manufacturing capabilities, Australia can capture a significantly larger portion of the value created across the supply chain. This translates into increased revenue potential, greater control over supply chain security and resilience, and the ability to tailor battery designs to suit local conditions and niche applications.

7.1 Membranes

Flow batteries are an enabling technology for long-duration energy storage (LDES), a crucial component of grids powered by intermittent renewable sources. The membrane within a flow battery is vital, serving as a separator that facilitates the selective transport of ions necessary to complete the electrochemical circuit. Traditionally, perfluorinated sulfonic acid (PFSA) membranes, with Nafion being the most prominent brand, have been widely used due to their high conductivity and chemical stability. While PFSA membranes offer reliable performance, they bring along several concerns. Their high cost (often exceeding USD $200 per square meter) can account for up to 40% of the overall flow battery system costs, hampering widespread commercialisation of flow batteries. Additionally, the environmental consequences of PFSA use are troubling. Due to their extreme stability, PFSAs are often referred to as "forever chemicals," as their breakdown in the environment is extremely slow [7]. This persistence raises concerns over bioaccumulation and potential human health risks [8]. The risk of PFSA leakage during battery operation or disposal further underscores the need for alternative membrane materials that are both effective and environmentally responsible. These concerns have propelled intensive research into developing cost-effective and environmental-friendly alternative membrane materials that maintain or surpass the performance of PFSA membranes.

The flow battery market is experiencing robust growth, with projections estimating its value to reach between USD 1.25 and USD 1.6 billion by 2030 [1, 5]. The total addressable market (TAM) for flow battery membranes naturally scales with this expansion. Importantly, expertise in developing flow battery membranes offers potential synergies with the expertise required for developing related clean energy technologies. Both fuel cells and electrolyzers rely on robust separators

> ESI-AP, UQ Dow Center: ESI-AP is developing advanced membrane technology for iron flow batteries, aiming to commercialize their innovations, if supported. UQ's expertise in electrochemical processes positions them as potential key research partner in the transition towards renewable energy.
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> FFI Ionix: A US based company acquired by Fortescue Future Industries is a leader in ion-exchange membrane (AEM) technology. FFI Ionix has established a robust manufacturing infrastructure, specializing in high-performance AEMs that are vital components for green hydrogen production. FFI has opened a new electrolyser facility at Gladstone QLD which will source their membranes from FFI Ionix. These membranes can also be used for the flow battery technology.
>
> QUT QUEST Hub: Through the QUEST Hub program, QUT is actively fostering innovation in the energy storage sector by establishing a small-scale membrane manufacturing facility of size 1m2 area. This initiative will support the flow battery industry in Queensland by providing locally-produced, high-quality membrane components and driving advancements in energy storage technology.

with targeted ion conductivity. By adapting manufacturing and materials development, membrane producers can potentially create solutions that serve multiple applications. This cross-pollination broadens the technical and commercial value of membrane innovations, making membranes a critical component for both energy storage (flow batteries) and energy generation (fuel cells, electrolyzers). With 40%

of VRFB cost attributable to the membrane, recent capital cost estimations of VRFB as US$350/kW [50], and AEMO forecasts [10] for LDES requirements by 2030 (excluding pumped hydro) of approximately 5GW, an estimate of the value of domestic supply of membranes for RFBs could be extrapolated to be US$700 million, with further upside for fuel cell and electrolyzer applications. This is a local manufacturing opportunity worth pursuing with suitable incentives for interested proponents.

The search for high-performance, sustainable, and cost-competitive flow battery membranes represents an active and vital area of materials science and electrochemical engineering. The initial feasibility study for the commercial development of flow battery membranes in Australia highlights promising potential. However, further analysis with more comprehensive market data and in-depth technical assessments is required to make a definitive determination on commercial viability.

7.2 Aluminium foil

Aluminium plays a critical role in lithium-ion batteries (LIBs), accounting for approximately 15% - 30% of the total weight proportion [51-52]. It is widely used in different Li-ion battery components, including current collectors and battery enclosure. The aluminium foil market is estimated to grow from US$27.6 billion in 2024 to US$44.8 billion in 2034 [53]. According to TrendEconomy [54], Australia exports US$3.5 million of aluminium foil but imports US$115 million annually. Aluminium foil prices tend to vary substantially, however, the agents 'Made in China' and 'MSE supplies' report a value of ~US$103,500/t [34,55] and an article in the Shanghai Metals Market [56] suggests that for every GW of Li-ion battery, 750t of aluminium foil is required. This translates to a market value of around US$77.25m for every GW of Li-ion battery manufactured. While the global market is significant, China has the capacity to service it. However, with Queensland bauxite, alumina, aluminium and HPA capabilities, there is significant opportunity to develop a domestic market for battery-grade aluminium foil manufacturing in Queensland, in addition to supplying for all other battery component requirements.

Rio Tinto: While not based in Queensland, Rio Tinto is one of the world's largest aluminium producers and operates refineries in other parts of Australia. They could potentially supply aluminium suitable for foil production.

Alpha HPA: While not a refiner, Alpha HPA is a Queensland-based company that produces high purity alumina, a key ingredient in aluminium smelting. Their product could be used by other companies to produce high-quality aluminium for foil.

Liberty House Group: This company has shown interest in developing a green aluminium smelter in Gladstone, Queensland, which could eventually produce aluminium suitable for foil production.

Queensland Alumina Limited (QAL):QAL is a major alumina refinery located in Gladstone, Queensland. While they don't produce aluminium directly, their alumina is used in smelters elsewhere to produce aluminium.

Current collector

The most significant use of aluminium in all Li-ion batteries is in the current collector for the cathode (positive electrode). A review of current collectors revealed that, in a typical Li-ion battery cell, ~6.9 wt% of a cell is made of Al foil [26]. It acts as a conductive path for electrons to flow between the electrodes and the external circuit. Aluminium offers a good balance between weight and conductivity at a relatively low cost compared to other conductive materials like copper. This is crucial for keeping Li-ion batteries lightweight and affordable. Typically, high-purity aluminium foil (usually > 99.5% pure) and around 16 microns thick is used for current collectors due to its excellent electrical conductivity and formability [27].

Cell and pack housing

Aluminium can also be used for the battery enclosure (for both cell and pack), providing structural integrity and protecting the internal components from the environment. Aluminium offers a good compromise between strength, weight, and cost compared to materials like steel. Lightweight Al hard casings have been proposed in several applications of Li-ion batteries [28]. It helps maintain a lightweight battery while providing adequate protection. Here, machinability and formability are key considerations. Alloy grades like 1xxx and 3xxx series aluminium are commonly used for enclosures due to their good strength-to-weight ratio and ease of fabrication [29,30,31].

Other components (limited use)

Aluminium may be present in some other Li-ion battery components in trace amounts, such as certain conductive additives or anti-corrosion coatings.

Separator coating

Within lithium-ion batteries, high purity alumina (HPA) (grade 4N/5N) is used to coat the battery separator. This improves the stability and safety of the battery by increasing thermal resistance and preventing unwanted chemical reactions, while also enhancing battery power and charging speeds. The use of high-purity HPA (4N and 5N) is crucial as impurities can negatively affect both LED performance and battery lifespan.

Australia is the world's largest producer of bauxite, representing 31% of the global production in 2016, the second largest producer of alumina (17%) and the sixth largest producer of aluminium (3%) [32-33]. Queensland is a major player in aluminium production, due to its abundant deposits of bauxite, the aluminium ore. The large bauxite resources at Weipa (>3000 Mt) in Queensland is amongst the world's highest grade deposits, averaging between 49% and 53% Al2O3 .

Australia's abundant aluminium resources present a significant opportunity to capture greater value within the battery supply chain and beyond. While the country excels in bauxite mining and alumina production, upgrading domestic refining capabilities to produce high-purity aluminium (above 99.5%) is crucial. This specialised aluminium is essential for manufacturing battery components like current collectors in the form of ultra-thin foils (around 16 microns thick), as well as robust enclosures. As demonstrated earlier, the value of aluminium increases dramatically with each stage of processing: a ton of high-purity aluminium foil commands a price 44 times higher than standard aluminium (see Table 9). Investing in the infrastructure and expertise for advanced aluminium refining would position Australia well to address emerging battery market needs and diversify its offerings within this high-value sector.

In April 2024, Alpha HPA secured funding for full-scale production of over 10,000 tonnes of high-purity alumina products per year at their Gladstone based site making it into one of the largest single site ultra-high-purity alumina refineries in the world [36]. Such initiatives are further needed to develop local manufacturing of aluminium foils and other battery components including enclosures for battery industry.

7.3 Copper foil

Australia possesses the resources and capabilities to become a major player in the global copper foil market for Li-ion batteries. As the world's leading exporter of copper, accounting for approximately 10% of the global production, Australia holds vast reserves estimated at over 80 million tonnes. This provides a secure supply of raw material for copper foil manufacturing, a critical component in Li-ion batteries. The demand for these batteries is projected to grow significantly, driven by the increasing adoption of EVs and ESS. The Australian government has also demonstrated its commitment to developing a domestic battery industry by allocating over $1 billion in funding for battery-related projects. Estimates for the global Cu foil market vary between US$14.4 billion in 2021, projected to grow to $25.64 billion in 2031 [57], and from other sources [58] US$7.4 billion in 2023 to US$14.8 billion in 2033. According to American Copper [59], for every GW of LiB, 334t of Cu foil is required. Agent 'Made-in-China' cites a value of around US$120/kg copper foil. This translates to a market value of around US$40.08 million for every GW of Li-ion battery manufactured. With Queensland copper refining capabilities, there is reasonable opportunity to develop a domestic market for copper foil for anode manufacturing and potentially for next generation battery chemistries, as well.

> Copper Refineries Pty Ltd (Glencore): They have electrolytic copper refinery in Townsville, North Queensland. Using Glencore's proprietary IsaKIDD process, the refinery produces up to 300,000 tonnes a year of 99.995% pure copper cathode—the primary raw material used to produce copper wire, cabling and many other products.

Australia's potential in copper foil production is further strengthened by its skilled workforce, technical expertise in metallurgy, and strategic location. The country's proximity to Asian markets, which account for over 70% of global Li-ion battery production, offers a logistical advantage for exporting copper foil and mitigating supply chain risks. Additionally, Australia's focus on sustainable mining practices and clean energy sources aligns with the growing emphasis on environmental responsibility in the battery industry.

However, significant challenges remain in this sector. Establishing copper foil production requires substantial capital investment, and the global market is dominated by established Asian manufacturers. Furthermore, the energy-intensive nature of copper foil production could be a hurdle due to Australia's relatively high energy costs. Nevertheless, with the right investments, policy support, and technological advancements, Australia could capitalise on its strengths and overcome these challenges to become a key player in the copper foil market.

7.4 Lithium foil

Australia, the world's leading lithium producer, possesses a unique opportunity to become a key player in the lithium foil market for Li-ion batteries. With substantial lithium reserves, the country has a secure supply of raw material for Li foil manufacturing. This thin lithium metal sheet serves as the anode in emerging high-energy-density battery chemistries such as lithium-sulfur and solid-state batteries. The demand for these advanced batteries is projected to surge as the world seeks more efficient energy storage solutions for EVs and clean energy systems. Manufacturing lithium foil in Australia faces challenges. Currently, Australia mines lithium ore but lacks the refining and processing infrastructure to produce lithium metal, a crucial input for lithium foil production. Additionally, working with lithium metal is complex due to its reactivity, necessitating

Table 9: Production and export volumes for Bauxite, Alumina and Aluminium

Commodity	Production (million tonnes Mt)	Export Income ($million)	Value ($/t)
Bauxite	98.5	1284	~38
Alumina	18.9	8308	~347
Aluminium	1.53	5281	~2,300
Al foil (>99.5%)	-	-	~103,500

Source: Office of the Chief Economist (Resources and Energy Quarterly, Mar 2024)[35]; MSE Supplies website [34] large-scale dry room facilities for safe production. Furthermore, establishing the costly extrusion rolling equipment required for foil manufacturing poses a significant financial hurdles.

Estimates for the global Lithium foil market include US$750m in 2023, projected to grow to $1.63 billion in 2030 [60]. There is no data available on lithium foil trade. With lithium spodumene deposits and hydroxide processing located primarily in West Australia, the opportunity for lithium foil manufacturing is less obvious for Queensland. Although with Queensland's existing manufacturing bases in Gladstone and Townsville, Queensland could become a destination for a lithium foil manufacturer, if supported.

7.5 Active materials development

Active materials are the core elements within Li-ion batteries. These are the primary determinants of battery performance characteristics like energy density, power output, lifespan, and safety. They include the cathode (positive electrode), anode (negative electrode) and electrolyte. Manufacturing high-quality active materials requires specialised processes and expertise. Currently, the global active materials market is dominated by Asian countries, particularly China, South Korea, and Japan. This concentration poses supply chain risks and limits value capture for countries like Australia, despite its abundant reserves of critical battery minerals.

> Li-S Energy currently imports lithium foil from overseas and it has the potential in developing or expanding into domestic lithium foil production (with its large-scale dry room production facility and the use of Li foil in its Li-S batteries).

Active material manufacturing involves several stages: (i) precursor synthesis: producing metal (e.g., nickel, cobalt, manganese) compounds with specific chemical and structural properties tailored for battery applications; and, (ii) active material formulation - combining precursor materials, conductive additives, and binders to create the final electrode material. This stage critically influences performance characteristics. Each stage demands precise control over material properties, purity, and consistency. Advanced characterisation techniques and stringent quality control are essential for ensuring reliable battery performance.

Active materials represent approximately 27% of the overall Li-ion battery market value (see previous discussions in the Value Chain Analysis section). By developing domestic active material manufacturing capabilities, Australia can capture a significantly larger portion of the battery value chain. This translates into increased revenue potential, greater control over supply chain security and resilience, and the ability to tailor battery performance to suit local conditions and niche applications.

Cathode active materials (CAM)

There is considerable variation in the CAM chemistries available for Li-ion batteries. CAMs with high nickel content, manganese and cobalt (NMC) are favoured because of their high energy densities while lithium iron phosphate (LFP) CAMs are cost-effective. These CAM chemistries are expected to dominate demand for the next decade.

Average CAM prices in 2023 varied between US$20,000 and 25,000/t. With CAM demand in 2023 estimated to be 1,960 kt, the market is estimated by Fraunhofer to be US$49 bn.

> VSPC (a subsidiary of Lithium Australia Ltd): VSPC is actively engaged in developing advanced cathode active materials for Li-ion batteries, with a focus on Lithium Ferro Phosphate (LFP) and Lithium Manganese Ferro Phosphate (LMFP). These materials are known for their long cycle life, safety, and thermal stability. Currently in the pilot stage, VSPC is working on finalizing their production process and exploring the development of a demonstration plant in Queensland.
>
> Feline Pty Ltd: This company is focused on developing and manufacturing advanced lithium-ion batteries (LIBs) with superior performance and safety features. They are currently developing a novel LIB cell format architecture with low internal impedance to reduce heat generation during discharge, enabling high-power draw without compromising cell performance. Feline Pty Ltd is working on producing prototype cells for testing in maritime applications by the Defence Science and Technology Group (DST).
>
> GMG is actively pursuing the development of its unique Graphene Aluminium-Ion battery technology that utilises graphene to enhance the performance and stability of aluminium-ion batteries and is planning an Automated Battery Pilot Plant for the manufacture of its Graphene Aluminium Ion Battery.
>
> QPM: The company is focused on refining cobalt sulphate and nickel sulphate cathode precursor material from imported materials. They have secured offtake agreements for 100% of their nickel and cobalt sales for the life of the project, and their major offtake partners are General Motors, LG Energy Solutions, and POSCO. Their TECH (Townsville, QLD) project has been recognised as "Prescribed Project" (economically & socially important to a region).
>
> AustVolt: This Western Australian company is focused on developing Australia's first commercial-scale cathode precursor manufacturing plant for NMC batteries, which are primarily used in electric vehicles (EVs). They are also collaborating with a US company to establish CAM manufacturing capabilities in Houston, USA. AustVolt's strategic location in Western Australia allows them to leverage the state's abundant mineral resources to create a fully integrated lithium battery supply chain, connecting the mine to the market.

Recent low nickel prices have significantly reduced costs, such that currently CAM prices are closer to US$10,000/t. However, there is little clarity about how long nickel prices will remain subdued. Consequently, there is variation in predictions for future CAM prices but expectations of around US$ 15,000 - 20.000/t by 2030 are common. With demand for CAM in 2030 forecast to be 6,839kt, the value of the market in 2030 could reach between US$102 and US$136 bn [62].

China dominates the CAM market with 66% share, followed by South Korea with 19% and Japan at 7%.

Despite the inherent potential, Australia's active materials manufacturing sector is in its early stages. A few companies, such as VSPC, Feline, GMG are developing cathode active materials (CAM), and QPM and Austvolt are developing cathode precursor materials, but the broader ecosystem necessary for large-scale production remains underdeveloped.

Anode active materials (AAM)

The four largest manufacturers of Anode Active Materials (AAM) are in China and account for over 50% share of the global market. Japan has a market share of 16% with South Korea having a 9% share.

Average costs for AAM in 2023 are estimated by Fraunhofer to be US$8,500/t. With a global AAM demand of approximately 875 kt, the global market is estimated to be US$ 7.4 bn in 2023. In 2030, prices are projected to decrease to US$ 7,500/t but with an increase in demand to 2,570kt, the global market in 2030 for AAM is forecast to be US$19.3bn [62].

Graphite for AAM is primarily supplied by China, but China's export restrictions levied in 2023 [63], has led to greater interest in developing natural graphite resources as input to anodes [64] as well as more interest in alternate anode chemistries including silicon [65]. These commercial developments offer opportunities for Queensland based Axon Graphite Limited and Anteotech, with both its silicon anode technology development and silicon enhancements to anodes.

Electrolytes

Since the commercialisation of Li-ion batteries, LiPF6 has been used as the electrolyte. The market is growing in proportion to the demand for batteries. Various additives are used in LiPF6 to increase conductivity, service life and chemical compatibility.

The total demand for electrolyte per year is estimated by Fraunhofer to be 350 kt in 2023. Price has stabilised over the last few years at about US$8,000/t . The value of the global electrolyte market in 2023 is estimated to be about US$ 3.5 bn. Forecasts for 2030 are for demand of 1,775kt at a price of US$8000/t which equates to a $14bn market.

China currently supplies around 70% of the global demand followed by Japan 16% and South Korea 12%.

Queensland has a number of chemical manufacturers that could supply into this global opportunity, of which Cleveland Bay Chemical Company has already signalled an interest in partnering with battery-tech proponents to develop bespoke electrolyte formulations.

Active materials manufacturing represents a high-value opportunity for Australia to strengthen its position in the global battery industry. While challenges exist, a focused, long-term approach with investment in R&D, infrastructure, and partnerships can position Australia as a key contributor in this critical sector.

8 | CONCLUSIONS AND KEY FINDINGS

8.1 Conclusions

According to the research and considering the current focus of the industry [47-49], currently, Australia's competitive advantage stems from its strong performance in the space of ore extraction, with further opportunities for expanding into downstream activities of refining and processing, as well as developing bespoke battery systems to suit local conditions.

This study underscored the substantial potential for Australia to develop a robust domestic battery component manufacturing industry, for which the country's rich mineral reserves and emerging technological capabilities provide a strong foundation. However, to establish itself as a key player within the global battery supply chain, Australia's technology infrastructure, regulatory setting and investment climate all needs to be substantially strengthened. Currently, several countries, particularly those in Asia, dominate the global battery supply chain. To seize the significant economic, environmental and social benefits presented by the expanding clean energy sector, a number of other countries are already investing heavily into developing domestic battery manufacturing, as well. As such, Australia should act swiftly and decisively to enable domestic component manufacturing.

Based on a comprehensive analysis of the current state of domestic manufacturing, as well as the challenges faced by the industry and potential opportunities presented, a suite of key findings are made in this report aimed at establishing Australia as a key player in the battery component manufacturing landscape. As summarised in Table 10, the opportunities for strengthening domestic component manufacturing include a range of value-adding options that offer different outcomes in term of value capture, considering the current state of supply chain performance. While resource abundance provides a solid foundation, Australia needs to overcome a range of hurdles in relation to its value-adding capacity, R&D efforts, investment attraction, and workforce development to fully capitalise on the booming battery sector.

To attract both domestic and international capital into the Australian battery-manufacturing sector, it is vital to cultivate a more favourable investment climate. This involves addressing challenges like the limited track record of attracting local and foreign investments and the perceived higher risks associated with investments into emerging technologies. The range of possible enabling measures in this space include targeted government incentives, as well as facilitating foreign direct investments, which could build confidence of the industry. Furthermore, third party testing capacity is also needed to support benchmarking and product performance validation to build investor confidence in emerging technologies and attract investment to local businesses. Proactive efforts to streamline regulatory processes and simplifying permitting procedures will further enhance Australia's attractiveness as a destination for investment. Additionally, fostering partnerships between research institutions, universities and the private sector in terms of directing the limited pool of resources available towards advancing the readiness of next generation technologies can help scale up production.

Australia risks being trapped in a vicious cycle where limited capital investment and a fragmented ecosystem hinder the development of a robust battery manufacturing sector. This creates a self-perpetuating situation where a perceived lack of scale and success discourages further investment, ultimately hampering Australia's ability to capitalise on the rapidly growing market. To break this cycle and create a self-reinforcing, virtuous cycle, a paradigm shift is required. This may involve significant government interventions and stronger collaborative networks between industry and research. Such decisive actions will catalyse innovation, attract global partners, accelerate the development of necessary infrastructure, and signal a clear commitment to establishing Australia as a major contender in the battery industry. A summary of key findings derived from the insights developed through this study, which are aimed at overcoming the barriers and challenges faced by the industry, as well as exploiting and enabling the opportunities presented are provided below.

8.2 Key findings

1. Value chain analysis

- The global demand for Li-ion batteries is projected to reach 4,700 GWh by 2030. Australian domestic demand is forecast to provide 90 GWh of demand to 2030, including 26 GWh of Queensland demand.
- While currently EVs represent the largest segment of the aggregate battery demand, stationary energy storage systems emerge as the fastest-growing sector.
- Chemicals and active materials represent the bulk of the total cost and weight of LFP battery packs, whereas the membranes represent the highest cost component of flow batteries.
- Cell manufacturing is estimated to represent $121 billion (30%) of the projected Li-ion battery market ($400 billion) by 2030, which offers the highest potential for the value-add across the supply chain. However, cell manufacturing is at a very early stage of development in Australia.
- Active materials manufacturing, valued at $110 billion (27%), represents the second-largest opportunity for value addition. Australia could exploit this opportunity by extending its ore extraction capabilities to cover chemicals refining and materials processing for developing a competitive advantage in the longer run.
- Module and battery pack assembly, accounting for $74 billion (18%), provides opportunities for value addition through design and management of bespoke battery systems to suit local conditions.

2. Industry perspectives: summary findings drawn from interview data

- Australian businesses are involved in value-adding activities across the entire battery supply chain but are at varied levels of maturity, with ore extraction and battery pack assembly representing the highest levels of intensity. Active materials processing and recycling are both at early stages of development in Australia.
- Given that there is no cell manufacturing in Australia, component manufacturing is limited to the supply of certain locally produced parts for the thermal system, housing and battery management systems etc.
- Securing off-take large scale agreements with the established international players is a key prerequisite for Australian businesses looking to integrate into global supply chains.
- Startup companies must demonstrate the technical and economic feasibility of full-scale production via a multi-stage qualification process involving laboratory-scale development, proof-of-concept and pilot production.
- Understanding market dynamics, accessing capital, and meeting regulatory requirements are all key factors affecting the capacity of Australian businesses looking to scale up their operations.
- Access to testing facilities, skilled workforce, and reliable suppliers, as well as inconsistent regulatory regimes, limited support, and the absence of comprehensive collaborations are all acting as barriers to strengthening domestic manufacturing in Australia.
- There are multiple pathways for Australian businesses seeking to integrate into the global battery supply chain, depending on their current state and the opportunities available for value addition.

3. Industry perspectives: results from the analysis of survey data

- In the case of Li-ion batteries, the development of active materials for cathodes and anodes is currently limited to early-stage startups and small-scale R&D facilities. No production facilities for electrolytes currently exist in Australia. Expanding production in these areas would necessitate investments in infrastructure and technology.
- In the case of RFBs, Queensland has capabilities in several key areas, including the development of SCADA/communication systems, safety components, mechanical hardware, and electrical components. However, membrane production is currently limited to R&D, and electrolyte mineral mining and production are in the early stages of development. Electrode and current collector materials are mainly imported from overseas.
- Over 60% of the businesses surveyed reported that they are able to transition skills/capabilities from traditional industries to cater to the emerging battery manufacturing sector.
- Main challenges to local manufacturing include: high cost of local components, limited skilled workforce, and resource limitations, as well as lack of reliable suppliers, ongoing orders, raw material availability, adequate R&D support/tax incentives, and access to new technology or capital.
- The support required to facilitate transition to battery component manufacturing include: networking opportunities, battery industry education, access to a reliable supplier database, available government support, facilitating collaboration with researchers, and access to manufacturing hubs, as well as workshops on capability development, industry transitioning, tax and R&D incentives, and mentoring.

4. Opportunities for strengthening domestic manufacturing

- Australia can leverage its strong position in ore extraction, along with its well-developed infrastructure, to expand its market share of critical minerals used in battery manufacturing through sustained investments.

- Australia has the potential to become a key player in the mid-stream segment of the value chain to create and capture more value and expand market share through new investments and innovations. This includes refining and processing of selected raw minerals to produce high-value battery grade materials and electrolytes (e.g. high-purity Alumina and Aluminium, Lithium, Vanadium, membrane materials).

- For cell manufacturing to achieve and sustain competitiveness at the global level, the domestic battery eco-system needs to be substantially developed. Given the limited capacity for any individual business in Australia to setup a gigafactory, a more realistic intermediate step would be to establish a niche low-volume cell manufacturing industry: e.g. to produce high-performance cells for defence, mining and space applications.

- Leveraging its world class R&D capabilities, Australia could focus on commercialisation of emerging technologies such as producing silicon anodes, enhancing phosphate-based cathodes, and improving the purity of iron and vanadium electrolytes, which offer opportunities for producing differentiated products.

- In the longer run, Australia has the opportunity to develop highly specialised batteries, including high-performance Li-ion batteries, unique graphene aluminium-ion batteries, and flow batteries, each offering distinct advantages over traditional Li-ion batteries.

- Battery pack assembly sector could sustain its competitive advantage by continuing to develop innovative solutions, including bespoke configurations and battery management systems, to suit local conditions or specific requirements and avoid direct competition against imported products.

- To build a viable domestic battery recycling sector, Australia needs to invest in reverse logistics infrastructure, streamline regulatory regimes and achieve scale economies.

- In the space of research and training, opportunities exist to strengthen the battery manufacturing ecosystem by stronger, comprehensive collaborations among key partners to offer targeted training programs that meet the future needs of the emerging active materials and cell manufacturing sectors.

5. Priority areas for strengthening domestic component manufacturing

- Membranes, a vital component of flow batteries, account for up to 40% of the total battery system cost, and currently there are only a few membrane manufacturers around the world.

- Given the high costs and poor environmental credentials of the existing membrane materials, there is currently a growing research effort directed at developing cost-effective and environmentally-friendly alternatives.

- Aluminium is widely used in different Li-ion battery components, including current collectors and battery enclosures, accounting for approximately 15%-30% of the total weight of a battery pack.

- Australia's abundant mineral resources, and the substantial and growing global battery market, present a compelling opportunity for Australia to capture greater value within the midstream segment of the battery value chain, by producing battery grade Aluminium, Copper and Lithium foils.

- Active materials represent approximately 27% of the overall Li-ion battery market value. By developing domestic active material manufacturing capabilities, Australia can capture a significantly larger portion of the value created across the supply chain. This translates into increased revenue potential, greater control over supply chain security and resilience, and the ability to tailor battery designs to suit local conditions and niche applications.

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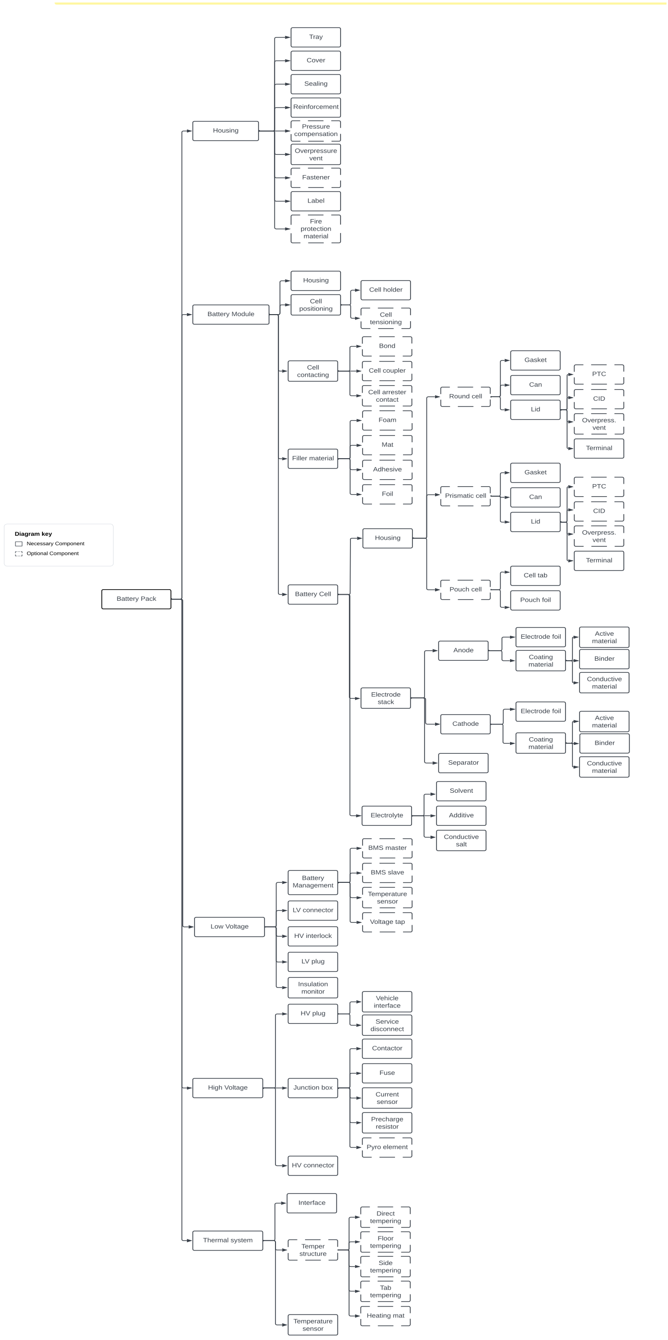
Appendix 1 | Product architecture diagrams

Appendix 1a | Li-ion battery architecture diagram



Li-ion battery architecture explanation:

Components for a Li-ion battery are broadly grouped as follows:

Housing: this protects the battery from damage and delays the spread of fire. It is generally constructed from stainless steel to create the structural load capacity between the components.

Battery module: is the energy source for the battery. It is made up of:

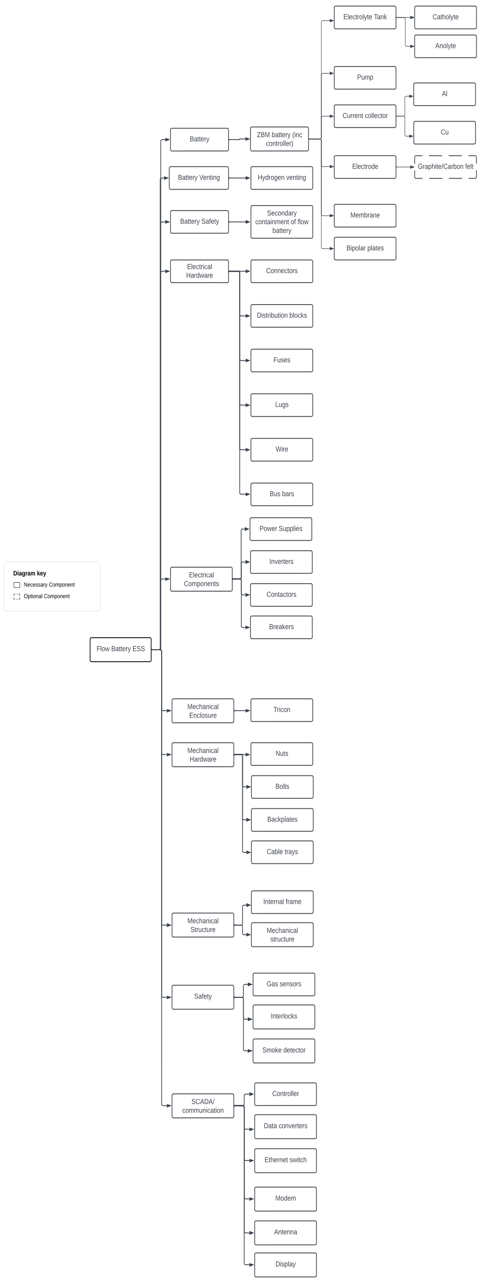
- Battery cells comprising the cathode, anode and electrolyte;
- Cell contacts to collect current;
- Cell positioning to secure the cells;
- Filler materials for temperature control.

Low voltage battery management system: to control and manage voltage, current, temperature control, fault detection, cell balancing and data storage.

High voltage interface to vehicle

Thermal system: to interface with temperature sensors.

Appendix 1b | Flow battery architecture diagram



Flow battery architecture explanation:

Components for a RFB are broadly grouped as follows:

Battery: is the energy source and is made up of the electrolyte tank, current collector, membrane, pumps and bipolar plates.

Battery venting: to vent hydrogen from the chemical reaction.

Electrical hardware and components: required to collect current

Mechanical components: for cell stack.

Safety: including sensors, interlocks and smoke-detectors.

Battery Management System: requires SCADA / Communication

Appendix 2 | Update on the battery industry status in Queensland

Appendix 2a | Li-ion battery industry status

Category	Components (total companies)	Process Comment	Core Capability Comment	Facilities Comment
Housing	Tray (17)	Trays can be manufactured from metal or plastic using a variety of techniques depending on the shape requirements and the production volume. For example, large volumes may justify the cost of dies for plastic injection moulding or metal stamping.	A number of Australian companies either have current capability in this field or could easily gear up if justified economically.	Current facilities exist with the capability to manufacture this component.
	Cover (11)	As for tray.	As for tray.	As for tray.
	Sealing (12)	Sealing can be achieved using elastomeric materials such as rubber or silicone in the form of gaskets, or by application during assembly. Plastic or metal welding could also be used.	Many Australian companies are familiar with these production processes.	For large volume production this process is likely to be highly automated necessitating investment in new machinery.
	Reinforcement (6)	Reinforcement can be achieved by the incorporation of fibres in plastics, or by design using ribs or shapes to increase rigidity.	Many Australian companies are familiar with these processes.	This is a design feature which could be implemented with existing facilities.
	Pressure compensation valves (24)	Pressure compensation may be achieved by the used of specialised membranes allowing gas to escape but preventing contamination from outside, or by incorporating an over-pressure valve.	Australian companies have the ability to assemble using imported content.	For mass production, automation of assembly is likely, necessitating investment in new machinery.
	Overpressure vent (6)	Normally incorporated in the design of the housing. Depending on the design this may require the use of techniques such as laser cutting or precision machining.	Many Australian companies are familiar with these techniques.	Existing facilities could cope with this requirement.
	Fastener (39)	Depending on the design, fasteners include screws, bolts, clips or inbuilt features.	These are locally made and imported.	Local supply from existing facilities is possible but some items are likely to be imported in order to bring costs down.
	Labels (14)	Can be incorporated in the design or applied later.	These are locally made and imported.	Local supply from existing facilities is possible but some items are likely to be imported in order to bring costs down.
	Fire protection material (4)	The design may utilise fire-resistant or flame-retardant materials or use coatings to achieve the desired result.	Australian companies have the ability to assemble using local and imported content.	This is a design feature which could be implemented with existing facilities.
Thermal system	Temperature sensor (12)	Thermocouples, thermistors, and infrared sensors may be utilised. These are generally imported except for some specialised components manufactured in R&D establishments.	Australian companies have the ability to assemble using local and imported content.	Existing facilities could cope with this requirement but using imported components.

Category	Components (total companies)	Process Comment	Core Capability Comment	Facilities Comment
	Temper structure (7)	The temper structure refers to the embedment in the battery design, of heating elements whose function is to regulate the temperature and prevent overcooling which can lead to loss of performance and trigger processes which reduce battery life.	Australian companies have the ability to assemble using local and imported content.	For large volume production this process is likely to be highly automated necessitating investment in new machinery.
	Thermal Interface material (5)	The thermal interface material ensures that heat does not build up in a component but is transferred to other components through the interface material.	Australian companies have the ability to assemble using local and imported content.	For large volume production this process is likely to be highly automated necessitating investment in new machinery.
High Voltage	HV connector (10)	Connector with plug and socket ends to transmit high voltage current from cells.	Many Australian companies are able to manufacture these.	Facilities exist which can manufacture these.
	Junction box (17)	A junction box is a convenient method of connecting two or more cables. In a battery system it will often contain a number of electronic components to regulate current flow, safety switches, and other important functions.	While many Australian companies would have the capability of manufacturing the junction box, the design may be quite complex requiring precision shaping and forming processes.	Depending on complexity, the cost of tooling up to manufacture this will be a large factor in determining if local facilities will participate.
	HV plug (11)	The HV plug connects an external source to the battery.	While many Australian companies would have the capability of manufacturing the plug, the design may be quite complex requiring precision shaping and forming processes.	Depending on complexity, the cost of tooling up to manufacture this will be a large factor in determining if local facilities will participate.
Low Voltage	Insulation monitor (5)	The monitor detects leakage currents. It contains electronic components such as semiconductors mounted on a printed circuit board and enclosed in a mountable box	Some Australian companies could assemble such a device, but volume production may require considerable investment.	Existing facilities can manage this.
	LV plug (12)	There will be a number of LV plugs and connectors in the battery.	Many connectors will be off-the-shelf items available in world-wide supply chains.	Local supply from existing facilities is possible but some items are likely to be imported in order to bring costs down
	HV interlock (5)	The interlock is a safety device preventing high voltage from becoming a hazard.	Some Australian companies could manufacture such a device, but volume production may require considerable investment.	Depending on complexity, the cost of tooling up to manufacture this will be a large factor in determining if local facilities will participate.
	LV connector (5)	There will be a number of LV plugs and connectors in the battery.	Many connectors and plugs will be off-the-shelf items available in world-wide supply chains.	Local supply from existing facilities is possible but some items are likley to be imported in order to bring costs down.
	Battery Management (6)	The battery management system (BMS) consists of a number of electronic components mounted on printed circuit boards and assembled in mountable enclosures. The manufacturing process is highly automated for volume production.	Some Australian companies could manufacture the BMS but volume production may require considerable investment.	Existing facilities can manage this.

Category	Components (total companies)	Process Comment	Core Capability Comment	Facilities Comment
Battery Module	Filler material (3)	Filler materials are used to separate the various components in the housing. Their function can be to insulate, shield, stiffen, or protect components.	Materials are available from a wide variety of locally manufactured and imported content suppliers.	Existing facilities can manage this.
	Cell contacting (6)	The cell contacting system ensures that individual cells are all connected in a rigid unit with effective contact points between cells. Precision manufacturing is required to contain cells and resist movement which could be caused by motion and vibration.	A number of Australian manufacturers have the capability to manufacture the system.	Existing facilities can manage this.
	Cell Housing – Plastic (16)	The cell housing contains the cells and cell contacting system.	A number of Australian manufacturers could manufacture this but tooling could be expensive.	Existing facilities can manage this.
	Housing - Steel (7)	Steel structure to add strength to the housing.	Depending on the design this may require complex and expensive tooling.	Existing facilities can manage this.
	Cell positioning (8)	The cell positioning system complements the cell contacting system to maintain a rigid unit.	Depending on the design this may require complex and expensive tooling.	Existing facilities can manage this.
	Electrolyte (0)	The electrolyte facilitates the flow of electrons to the anode.	There are no companies producing electrolytes for Li-ion batteries in Queensland or in Australia.	No commercial facilities available. Deakin University and University of Queensland - Researchers from these universities have developed a safer, non-flammable electrolyte for sodium-ion batteries.
	Electrodes are manufactured in several stages during which a current collector (aluminium foil for cathode, and copper foil for anode) is coated with a slurry of an active material (lithium salt for cathode, and graphite for anode) and then dried and calendered to form separate rolls of cathode and anode sheet. In the case of prismatic cells, the sheets are then cut to length and stacked, with a separator between, in a repeating cycle of anode, separator, cathode etc. Various processes are used by different manufacturers and for mass production, these are highly automated. There is one factory in the Newcastle region manufacturing lithium batteries in large volumes.			
	Electrode Stack Separator (0)	The separator is generally polyethylene or polypropylene sheet.		
	Electrode Stack Cathode (4)	The underlying cathode material is aluminium foil and cathode active material (CAM).	There are a few early-stage startup businesses producing CAM for batteries. No business producing Al foil for batteries.	Existing facilities are at small scale R&D manufacturing level (VSPC, GMG). Need support for expansion including specialised equipment.
	Electrode Stack Anode (2)	The underlying anode material is copper foil and graphite.	There are a few early-stage startup businesses producing anode materials for batteries. No business producing Cu foil for batteries.	Existing facilities are at small scale R&D manufacturing level (for Li-ion and Na-ion batteries).
	Housing: 1. Pouch Cell (15)	Depending on the specific design these would be manufactured from a variety of materials.		

Appendix 2b | Flow battery industry status

Category	Components (total companies)	Process Comment	Core Capability Comment	Facilities Comment
SCADA/Communication	Display (11)	The Supervisory Control and Data Acquisition (SCADA) system allows operators to monitor and control the flow battery plant operations, based on the state of charge and the demand.	Many local and international companies can design, build, and install SCADA systems in Australia using a variety of local and imported components	Australia has the facilities to design and build SCADA systems.
	Antenna (20)			
	Modem (12)			
	Ethernet switch (5)			
	Data converters (45)			
	Controller (10)			
Safety	Smoke detector (8)	Ensure safe operation of the flow battery system.	Local and imported components are supplied from Australia.	Existing facilities can supply these.
	Interlocks (7)			
	Gas Sensors (4)			
Mechanical Structure	Mechanical Structure (4)	The mechanical structure and internal frame system is specifically designed and may therefore require several specified manufacturing processes which have been developed by global companies.	For an existing design of flow battery, It is likely that Australian companies have the capability to manufacture these, but there will exist many experienced global companies. A start-up company in Australia could develop new processes possibly in conjunction with and R&D organisation such as a university or CSIRO.	Existing facilities could possibly supply these.
	Internal frame (10)			
Mechanical Hardware	Cable trays (10)	The mechanical hardware is used in the assembly of the flow battery system.	Many Australian companies manufacture mechanical hardware. Some common items such as some nuts and bolts will be imported.	Australia has the facilities to manufacture most mechanical hardware.
	Backplates (9)			
	Bolts (14)			
	Nuts (16)			
Mechanical Enclosure	Tricon (2)	This is a proprietary product manufactured by Schneider Electric, a German company with manufacturing plants worldwide.	Australian supplier.	Australian warehouse.
Electrical Components	Breakers (7)	Electrical components are used in the assembly of a flow battery plant system	Some components will be manufactured by local companies and some items will be imported. The capability exists to manufacture these locally.	Australia has the facilities to manufacture most components.
	Contactors (10)			
	Inverters (11)			
	Power Supplies (20)			
Electrical Hardware	Busbars (8)	A variety of electrical hardware is used the assembling the flow battery system.	Australian companies can supply these. Some components may be imported.	Existing facilities can supply these.
	Wire (8)			
	Lugs (15)			
	Fuses (9)			
	Distribution blocks (15)			
	Connectors (10)			

Category	Components (total companies)	Process Comment	Core Capability Comment	Facilities Comment
Battery Safety	Secondary containment of flow battery (6)	The secondary containment system ensures that any leaks of corrosive materials which escape the main enclosure are prevented from causing a hazard.	Australian companies have the capability to produce this system.	Existing facilities would meet this requirement.
Battery Venting	Hydrogen venting (NA)	In some design of flow battery there is the possibility of generation of hydrogen to dangerous levels (> 4 % in air). A hydrogen monitoring and venting system is used to safely dilute this gas.	Depending on the design Australian companies may have the capability to provide this system.	Existing facilities could meet this requirement.
Flow Battery	Membrane (NA)	Section 7.1 of this report discusses flow battery membranes and the ongoing studies into commercial development in Australia.	Limited capability exists in an R&D context.	R&D facilities are currently being utilised. No commercial scale business found producing membranes in Australia.
	Bipolar Plates (6)			
	Electrode (5)			
	Current Collector (0)			
	Pump (12)			
	Electrolyte + Tank (16)			

CONTACT

Dr Nagesh Shukla
Department of Management,
Griffith Business School,
Griffith University, Nathan
QLD 4111

Email: n.shukla@griffith.edu.au