FUTURE BATTERY INDUSTRIES CRC

Australian Government
Department of Industry, Innovation and Science

Business Cooperative Research Centres Program

The governance of battery value chains:

SECURITY, SUSTAINABILITY AND AUSTRALIAN POLICY OPTIONS

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Executive Summary

- The battery industry offers significant economic opportunities for Australia. Global demand for batteries is rising rapidly, due to technological transformations in the energy, industrial and transport sectors. Australian governments and businesses have identified building the battery sector as a major national economic imperative.
- Australia's value proposition is as a secure and sustainable partner. Existing battery value chains face significant governance challenges which threaten both their security and sustainability. Australia's geological endowments, trusted governance framework and strong international relationships make it an ideal partner for international efforts to develop more resilient battery value chains.
- Australia will need to upgrade its role within existing global battery value chains. It is already a major up-stream supplier of battery minerals, and end-user of grid-scale batteries. However, it has yet to develop capacity in mid- and down-stream stages of the value chain. As the bulk of value-adding occurs in these stages, Australia's economic opportunity lies in leveraging its competitive advantages to 'move along the value chain' from a mining to processing role.
- To successfully execute this agenda, efforts will need to be informed by an integrated value-chain perspective. Australia is not creating a battery industry de novo, but seeking to augment its existing role within a growing global industry. Policy design by governments, and project development by businesses, must be calibrated to the specific governance features and needs of global battery value chains.
- A value-chain informed strategy should focus on building mid-stream capacity through international partnerships. Domestically, efforts should target Australia's mid-stream processing industries, where the most attractive opportunities lie. Internationally, governments and businesses should actively pursue international trade, investment and technology partnerships with key global players.

Introduction

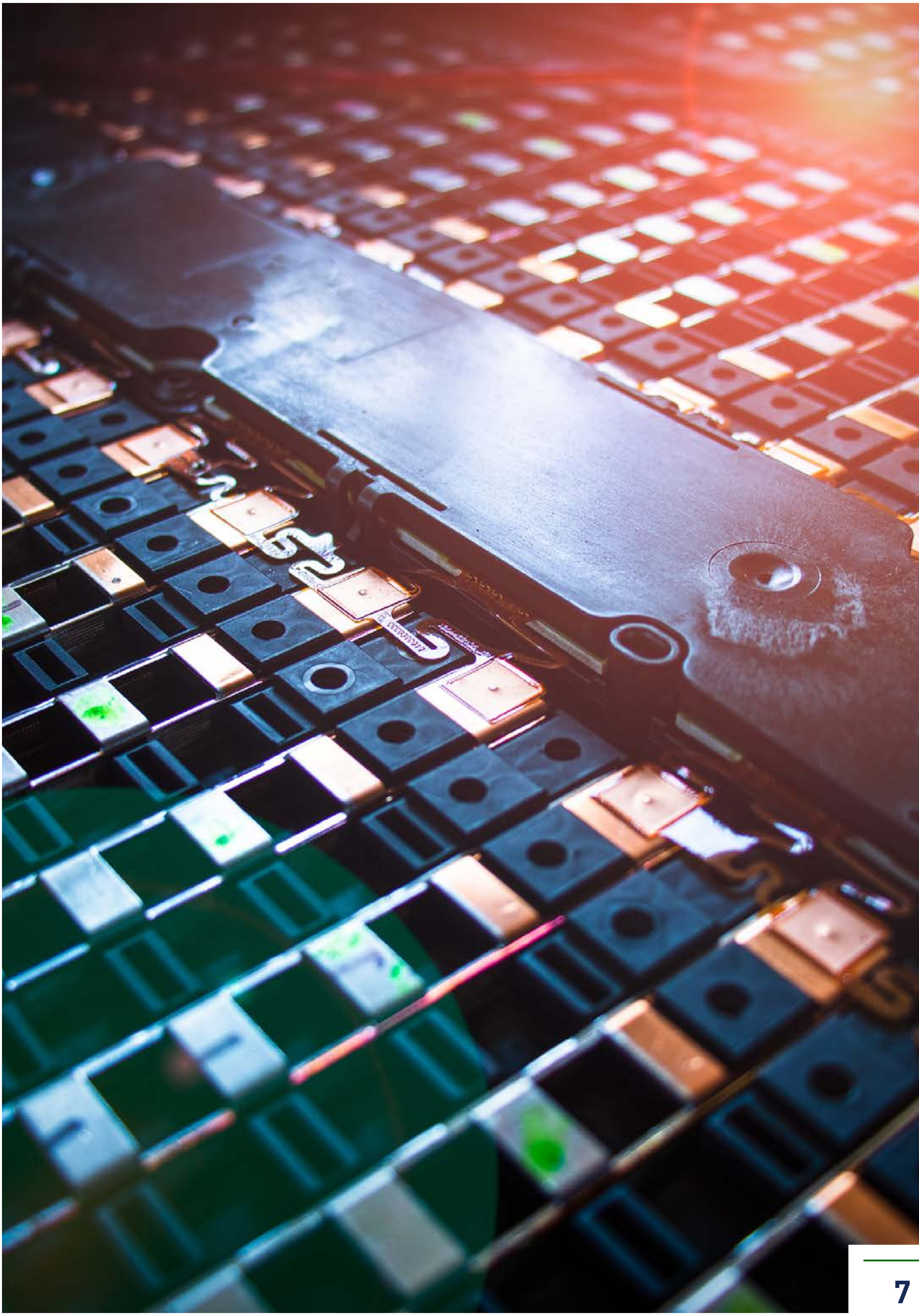
The battery sector is a major economic opportunity for Australia. In recent years, global demand for batteries has soared due to transformations in the energy sector. New renewable energy, transport and industrial technologies are increasingly incorporating batteries into economic networks. As efforts to address climate change gain pace, the global battery market will grow both in size and strategic importance. Australian governments and businesses have identified building the battery sector as a national economic imperative.

However, contemporary battery value chains are neither secure nor sustainable. Several governance problems bedevil the industry. Battery mineral and material production is monopolised by a small number of suppliers, which subject international markets to both political and economic risks to security of supply. Poor institutional frameworks in several supplier countries lead to many adverse social and environmental outcomes, undermining the sustainability credentials of an ostensibly 'green' industry. Existing value chains are not be fit-for-purpose for 21st century battery needs.

Australia has a key role to play in developing a more resilient global battery industry. It has the requisite geological endowments and technical capacity to be a competitive producer of battery minerals and processed materials. Its high-quality governance framework can contribute to social and environmental sustainability; while its strong international relationships make it a politically-trustworthy partner. By taking on a greater role in battery value chain, Australia can contribute to the security and sustainability of this critically important global industry.

To capitalise on these opportunities, Australia will need to upgrade its role in battery value chains. It is already an important up-stream supplier of several battery minerals, particularly lithium, nickel and rare earths. However, its capacity in the mid-stream (geochemical processing) and down-stream (battery product manufacture) stages remains under-developed. As the bulk of value-adding occurs at these later stages, this is a missed opportunity to maximise national economic benefits. Australia should leverage its competitive advantages to 'move along the value chain', by developing mid- and down-stream capabilities in partnership with global industry players.

This report explores how Australia can upgrade its role in the global battery industry. It first reviews the industrial geography of the industry, identifying the role of mineral and materials production in shaping contemporary value chains. It then considers the governance challenges facing battery production, including political and economic risks to supply security alongside social and environmental difficulties in achieving sustainability. It then analyses policy options to upgrade Australia's role in these value chains, with a focus on how Australia can leverage its advantages to contribute to a more secure and sustainable global battery industry. For these efforts to be successful, Australian governments and businesses should develop trade, investment and technology partnerships with international industry players, to prioritise the development of mid-stream local processing capabilities.



Global value chains in the contemporary battery industry

Battery manufacture relies on a set of raw materials with specific technical properties. Different chemistries – whether Nickel-Metal Hydride (NiMH), Lithium-ion (Li-ion), Vanadium Redox Flow (VRFB), or other emerging technologies – each require raw materials inputs with distinct attributes. There are six 'battery minerals' which are frequently identified as being the core raw materials required for the industry.

Figure 1

SIX BATTERY MINERALS

1

Cobalt

Used in cathodes in NiMH and Li-ion batteries

2

Graphite

Used in anodes in Li-ion batteries and future graphene-based technologies

3

Lithium

Used in cathodes in Li-on batteries (either as Li-iron phosphate or lithiated mixed metal oxide)

4

Nickel

Used in electrodes in NiMH batteries, and NMC/NCA cathodes for Li-ion batteries

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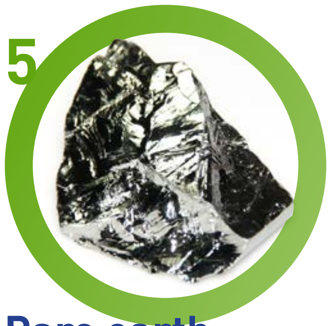
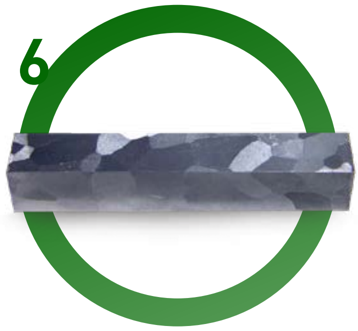


Rare earth minerals

Used in electrodes in several battery chemistries

6



Vanadium

Used in electrolytes in VRFB batteries

The production of battery minerals is a major international industry. With the exception of natural graphite[1], world output of these minerals has grown strongly over the last decade (Table 1), driven both by increasing demand from battery manufacturers as well as alternate technology applications. This has led to a robust international trade in battery minerals, which was valued at $6.5 billion in 2017. They are also geologically abundant, with proven reserves sufficient to meet demand levels for many decades, and in some cases centuries.

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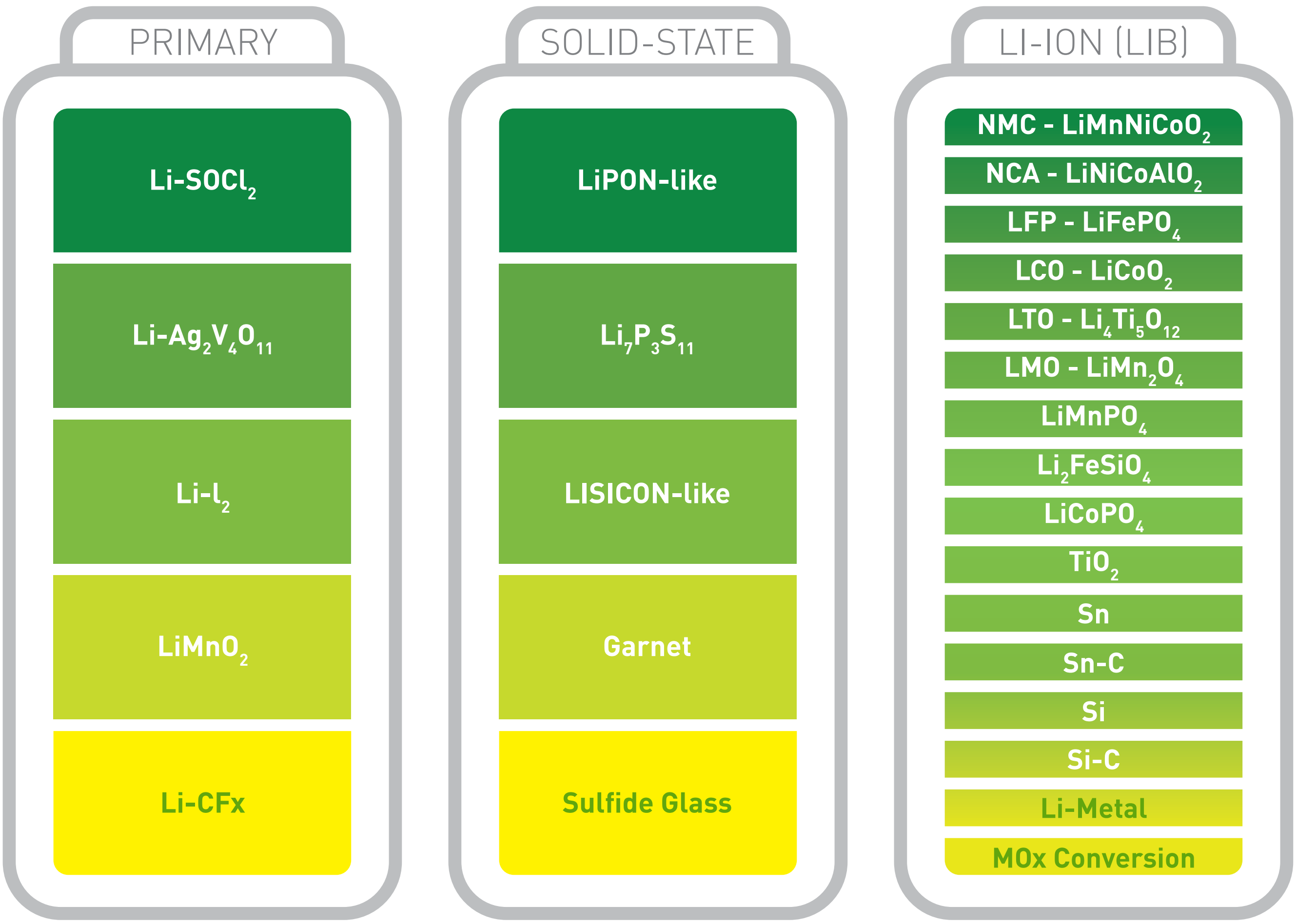
Table 1. Production, trade and reserves of battery minerals, 2017

	World production (thousand tonnes)	Production growth (2007-17)	Life of proven reserves (years)	International trade (USD millions)
Cobalt	120	83.2%	58	552.7
Graphite (natural)	897	-91.9%	335	447.7
Lithium	69	167.4%	203	1741.1
Nickel	2160	30.1%	41	2967.1
Rare Earth Minerals	132	6.5%	909	349.8
Vanadium	71.2	21.7%	281	399.3
Total				**6457.7**

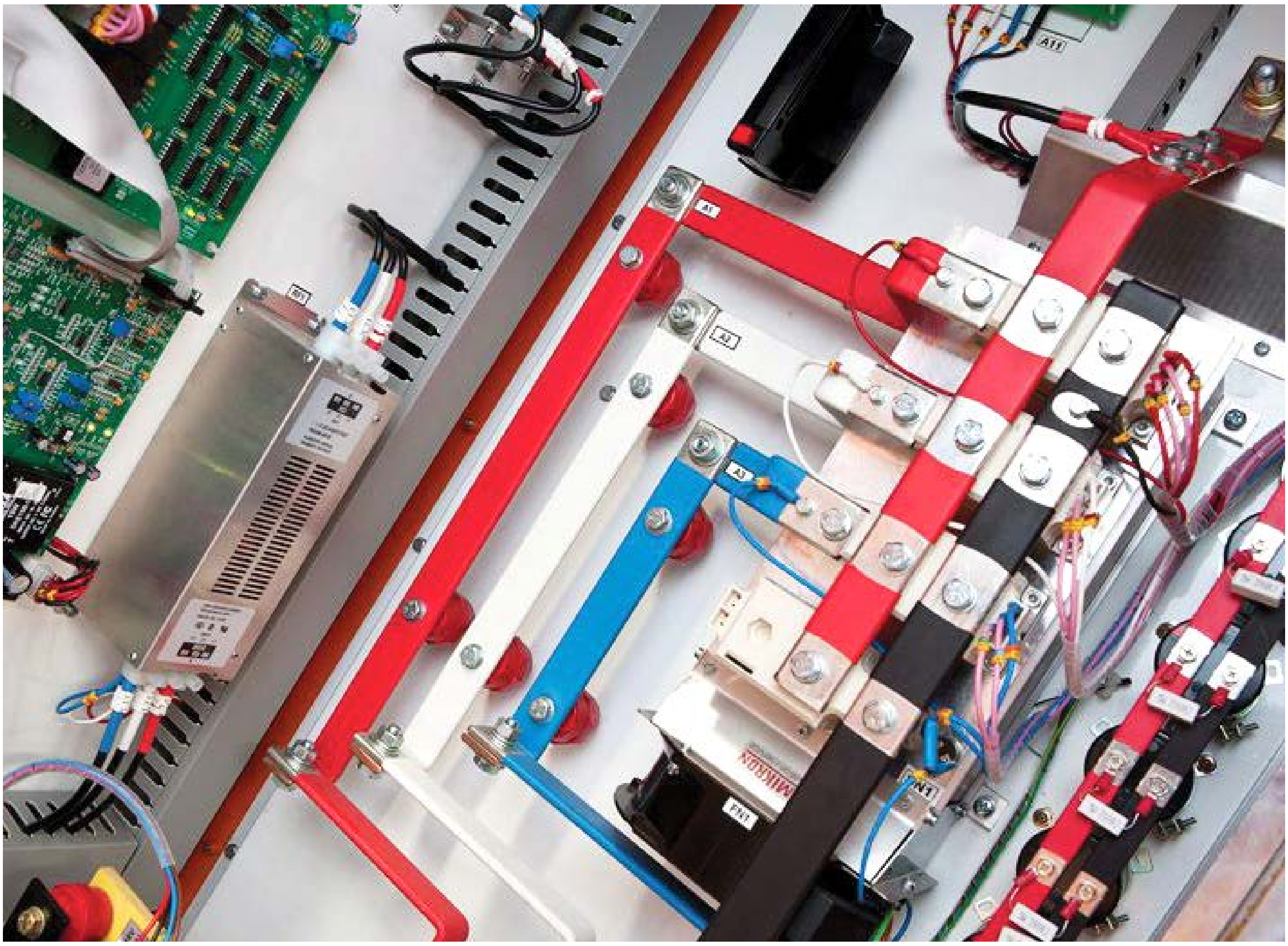
Source: Author's calculations from USGS[2] and UN Comtrade Database[3].
Note: Natural graphite production has declined due to adoption of synthetic graphite technologies.

The battery value chain is often simplified into up- (minerals), mid- (processing) and down-stream (manufacture) stages of production. However, the value chains involved in transforming battery minerals into finished products are extraordinarily complex. Indeed, there are several battery chemistries in use today, differentiated by their suitability for specific industrial or domestic applications. The technological landscape of the sector is further complicated by the fact that several new batteries chemistries, designed to meet emerging needs of new energy and transport system applications, have reached or are soon to reach maturity. Figure 2 illustrates the complex array of established and emerging battery chemistries which are used across the technological ecosystem.

Figure 2. Historic and future battery chemistries



Source: Author's adaptation from Placke et al[4]



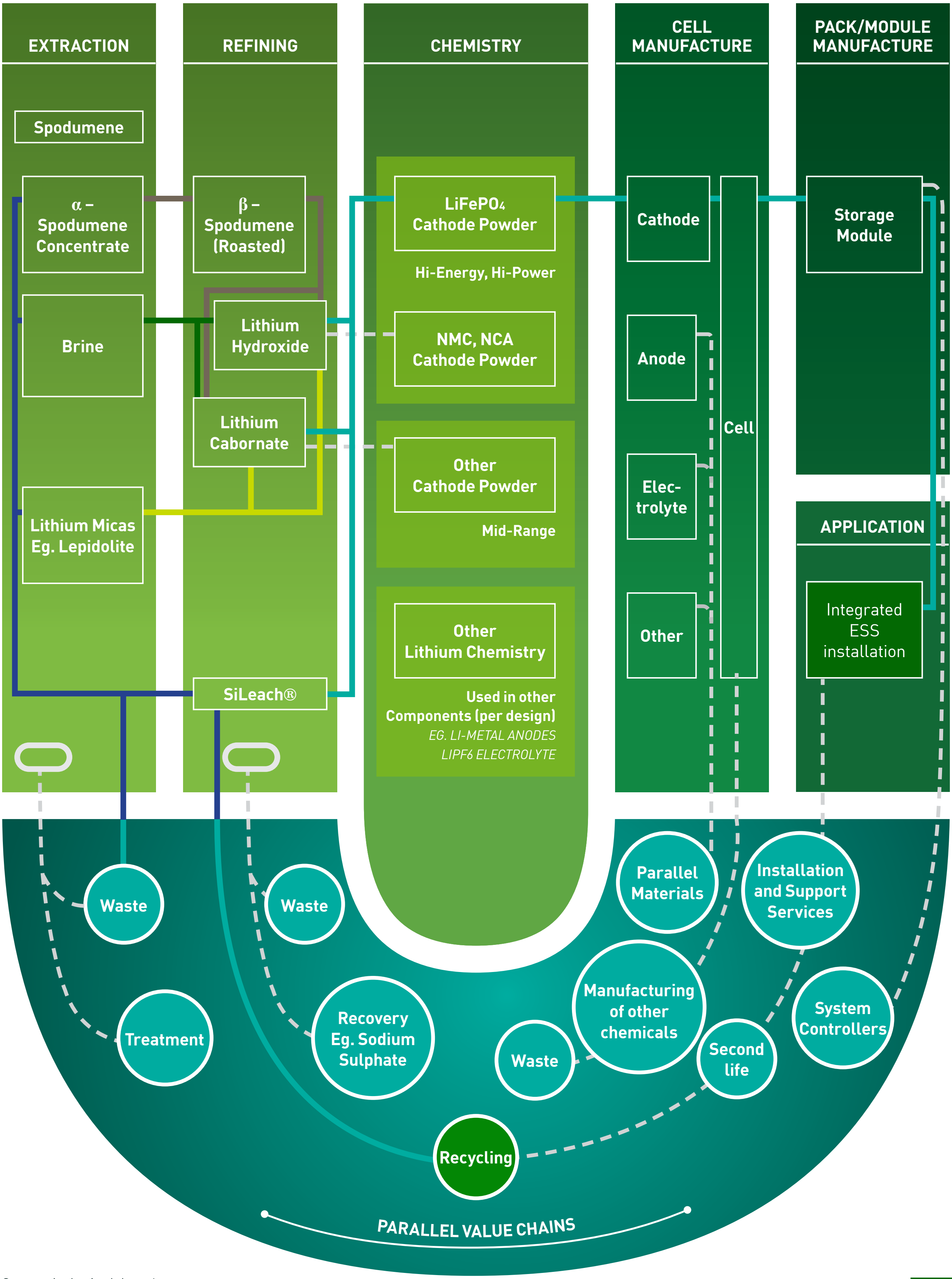
For example, the high energy density of lithium-oxygen batteries offers the required storage capacity for electric vehicles (EVs) and industrial applications, but are too expensive for consumer technologies[5]. Vanadium-redox flow batteries have high energy storage densities, but their size makes them appropriate only for stationary applications such as energy storage systems (ESSs)[6]. Overall, lithium-based chemistries are the most widely-used at present, due to their combination of reasonable energy density, light weight and low cost. They are used across a broad range of technologies, including consumer electronic devices, electric vehicles, energy storage, and aerospace applications.

Mapping the global up-, mid- and down-stream value chains associated with each battery technology type and application is an extremely complex task. However, the value chain for lithium ferrophosphate (LFP)[7] batteries provides an instructive example for understanding contemporary value chains:

- LFP is a relatively cheap and safe technology, as it does not rely on cobalt, susceptible to thermal runaway, and is mined in politically unstable countries[8].
- LFP is important for clean energy sectors due to its suitability for a number of EV (particularly buses and motorbikes) and ESS applications.
- It has low barriers to entry for Australian producers, as the technology relies on battery minerals in which Australia has competitive geological endowments (see Table 4).
- Lithium Australia has improved Australia's capacity to supply the LFP market by innovating on advanced refining processes that turn raw materials, tailings waste, and recycled batteries into LFP[9].

The technical structure of the LFP battery value chain is illustrated in Figure 3, which maps an LFP value chain through to the production of fORTELION units, an ESS designed for domestic application[10]. Figure 3 presents a simplified map of the LFP value chain, which traces how raw materials are transformed through sequential upstream (lithium extraction and refining), mid-stream (production of cathode and anode materials) and downstream activities (cell manufacture and assembly of consumer units). It also identifies the parallel value chains involving waste, recovery, re-use and recycling.

Figure 3. Technical value chain for LFP battery chemistry



Source: Author's elaboration

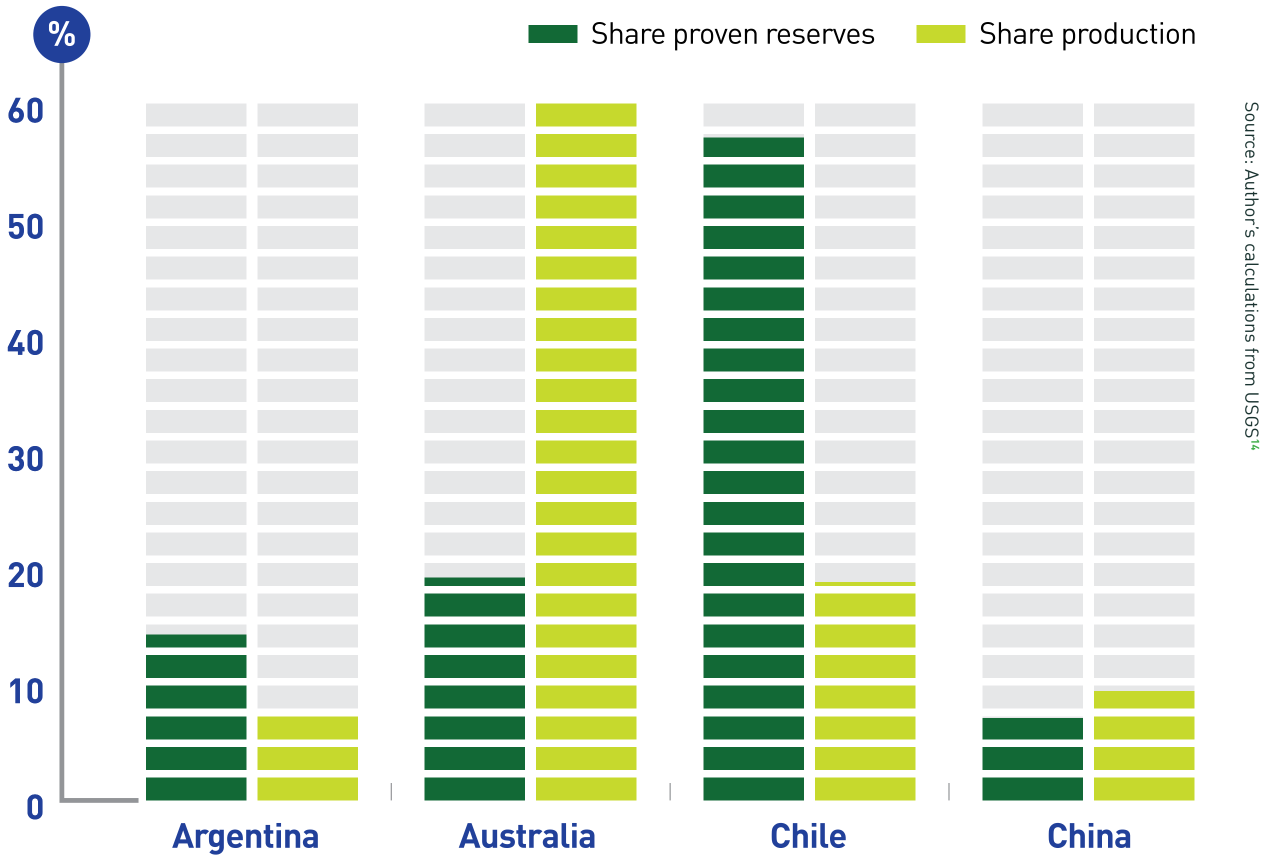
Mineral Extraction: As the principal battery mineral in LFP, lithium is extracted from either saline brines with high lithium content or hard rock spodumene deposits. The lithium concentrate from brine is obtained via evaporation, with the higher price of this process and the removal of contaminants offset by the production of a much higher grade product. The majority of global brine production comes from the 'Lithium Triangle' (located in Argentina, Bolivia and Chile), while Australia accounts for most hard rock production. Spodumene concentrate is cheaper to produce than brines, due to additional costs imposed by royalty arrangements and the use of reagents in brine production. However, as brine producers ship a higher-value product (usually carbonate), the margins for brine-producing firms are higher than for spodumene-based competitors[11].

The defining feature of battery mineral extraction is a high degree of supply concentration.

In all but one of the battery minerals, a single dominant producer accounts for between half and three-quarters of all global supply (Figure 10). For lithium this is Australia (58 percent), and for cobalt the Democratic Republic of Congo (61 percent). More significantly, China is the dominant producer of three of the six battery minerals: graphite (70 percent), rare earths (80 percent) and vanadium (56 percent). Only in nickel is there a diversity of supply options, where seven countries[12] each account for between 5 to 15 percent of global production. This concentration at the extraction stage exposes downstream manufacturers to a heightened degree of supply risk.

Perhaps surprisingly, the geography of battery minerals extraction is only weakly-linked to geological endowments. Possession of sizeable and cost competitive mineral reserves is a necessary but not sufficient condition for a country to occupy a place in the global market. As Figure 4 demonstrates, Australia's primary lithium output (in concentrate) greatly outperforms its geology, accounting for 60 percent of world production from a much smaller 19 percent share of the proven reserve base. In contrast, the market shares of Chile and Argentina underperform relative to their geologic endowments. A similar pattern is observed for rare earths, where China's 80 percent market share is greatly in excess of its 37 percent share of globally proven resources[13]. The weak correlation between geology and production indicates the importance of institutional factors – such as regulatory stability, technical expertise and enterprise competitiveness – in shaping the geography of battery production.

Figure 4. Proven reserves and production of major lithium producers, 2018



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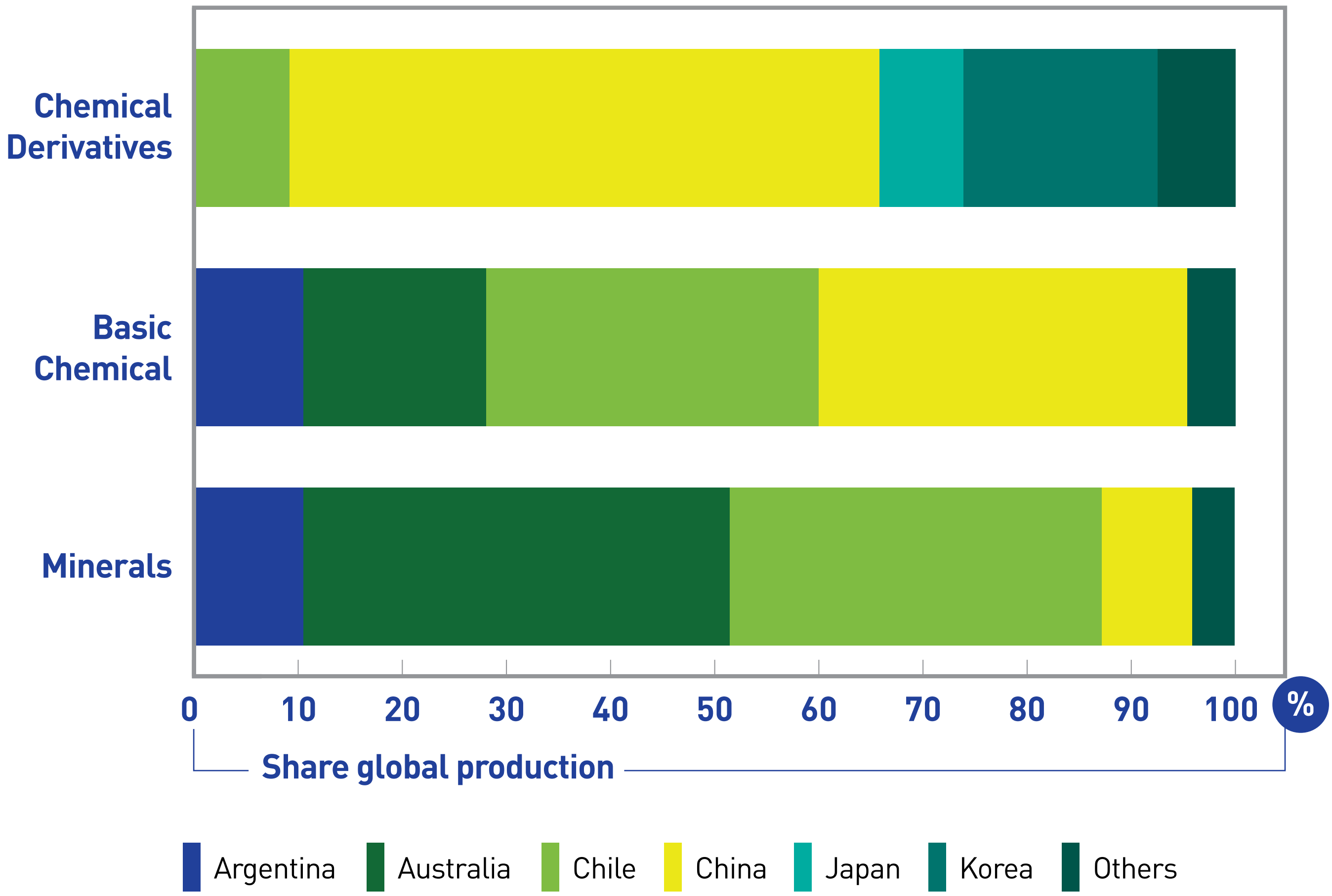
Mineral refining: Supply concentration is even more pronounced at the refining stage. Just over half of world lithium refining (i.e. conversion of primary lithium to carbonates or hydroxide) currently occurs in China, despite the fact it produces only 9 percent of primary lithium[15]. For brine producers in Latin America, lithium salts are usually refined into carbonate locally, before export to chemical processors in Asia. In contrast, hard rock producers in Australia export spodumene concentrate to Chinese conversion plants for the refining of chemical products. While several lithium hydroxide processing projects have recently been launched in Australia (see Box 3), at present (2019) all Australian spodumene is processed in China. This has posed a limit to the expansion of Australian lithium production, as capacity at Chinese facilities has failed to keep pace with growing output of primary lithium.

China is similarly a dominant player in the refining of non-lithium battery minerals. The majority of world refining of rare earths and vanadium is undertaken in China, based on locally-extracted ores. China also plays a major refining role for battery minerals extracted elsewhere. It accounts for 58 percent of the world's refined cobalt (primarily sourced from the Democratic Republic of the Congo) and 29 percent of refined nickel (sourced from several suppliers in Southeast Asia)[16].

Chemical processing: This stage involves the chemical conversion of feedstock lithium (in either carbonate or hydroxide form) into precursor chemicals which can be manufactured into cells. As Figure 5 illustrates, by the chemistry stage the geographic link between mining and manufacturing has largely disappeared. Of the three major primary lithium producers, only Chile maintains a meaningful (if small) presence in the chemical derivatives market[17], while Australia and Argentina are no longer present at all. In their place, the chemistry market is dominated by battery manufacturers in Asia. China produces 56 percent of chemical derivatives, with Japan and Korea accounting for a further quarter of world production.

Figure 5. Lithium battery precursor production, by country and stage of value chain

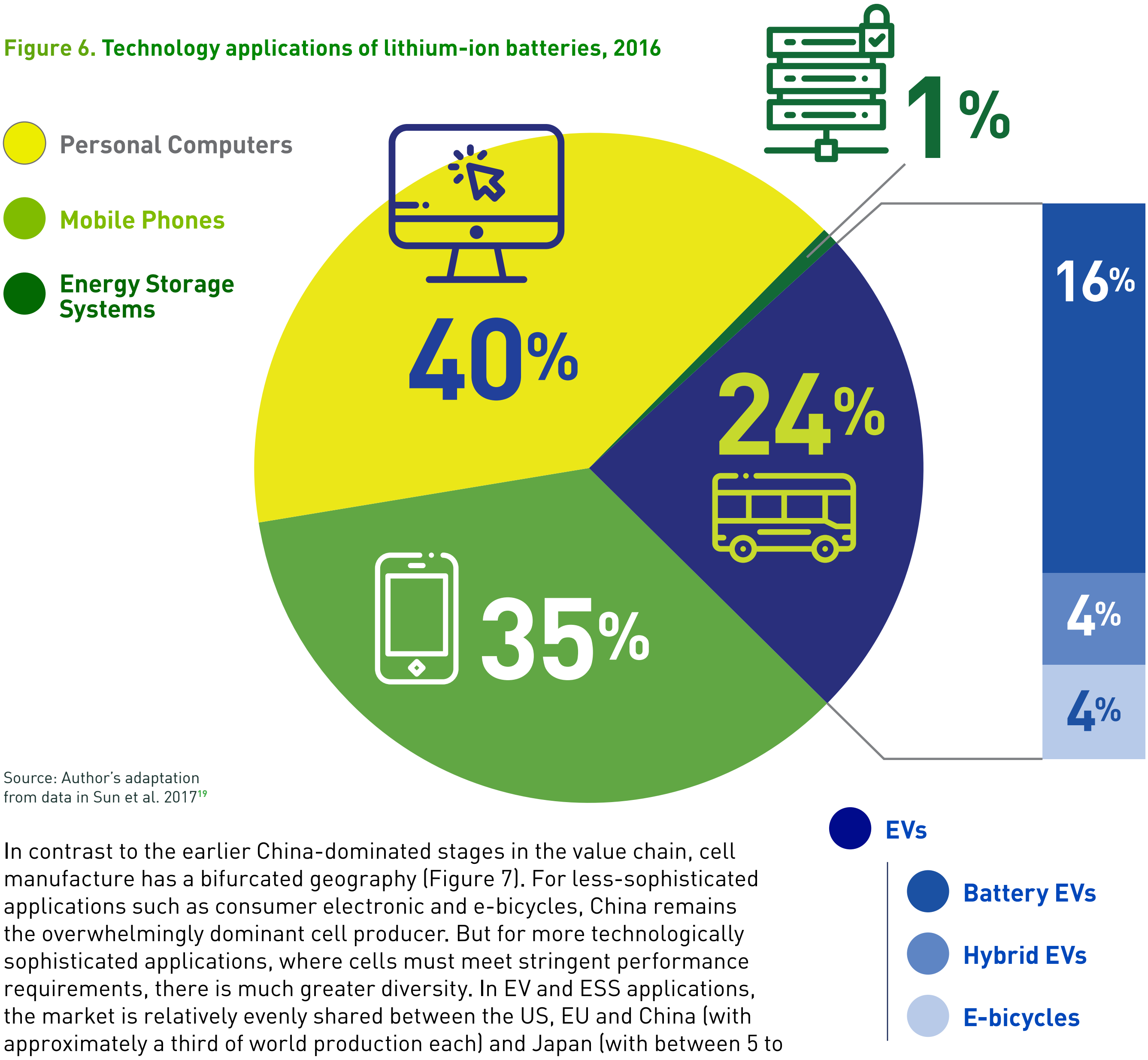


Source: Authors adaption from Sun et al. 2017[18]

China's role as a dominant extractor, refiner and chemical processor make it a major bottleneck in the battery value chain.

Cell manufacture: By the cell manufacturing stage, the battery value chain begins to specialise into different branches aligned to specific applications. For much of its history, the principal end-use of lithium-ion batteries has been in consumer electronics. However, as Figure 6 shows, a more diverse set of uses is beginning to emerge. Consumer electronics remains the dominant application, accounting for 75 percent of lithium-ion battery demand. But the rise of electrified modes of transport – including hybrid EVs, battery-only EVs and electrical bicycles – has now emerged to account for around a quarter of global demand. As EV technologies mature, this share is expected to increase rapidly. By contrast, ESS applications are presently a niche market, accounting for only 1 percent of demand. But like EVs, technological innovation in ESS products will also drive significant demand growth.

Figure 6. Technology applications of lithium-ion batteries, 2016

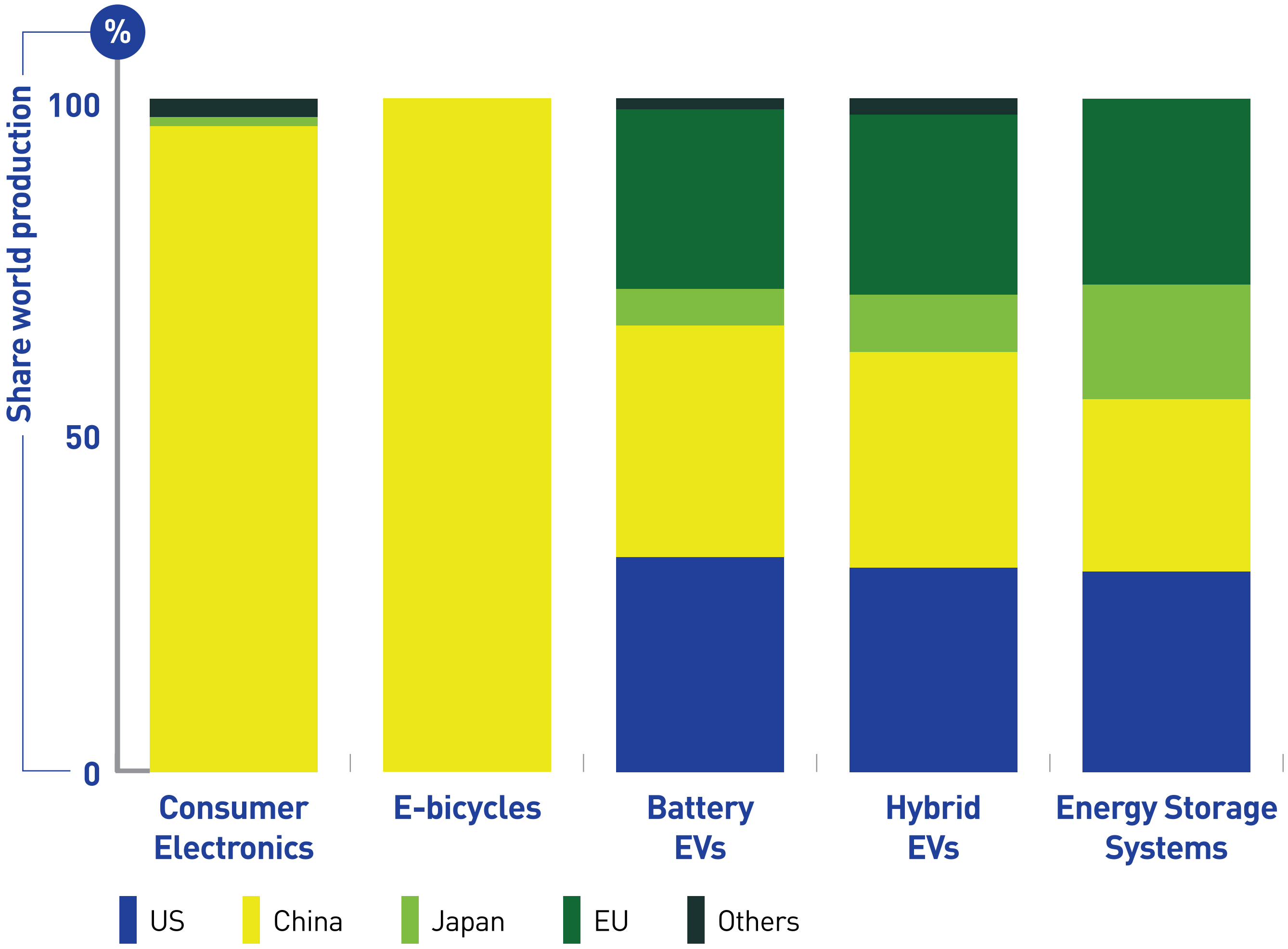


Source: Author's adaptation from data in Sun et al. 2017[19]

In contrast to the earlier China-dominated stages in the value chain, cell manufacture has a bifurcated geography (Figure 7). For less-sophisticated applications such as consumer electronic and e-bicycles, China remains the overwhelmingly dominant cell producer. But for more technologically sophisticated applications, where cells must meet stringent performance requirements, there is much greater diversity. In EV and ESS applications, the market is relatively evenly shared between the US, EU and China (with approximately a third of world production each) and Japan (with between 5 to 15 percent).

At present, China accounts for 83 percent of world cell manufacture overall. However, this is largely due to the fact that the consumer applications in which it is dominant account for 75 percent of all battery demand. Indeed, technological change may dilute China's role. As EV and ESS technologies achieve greater penetration, it will open an opportunity for non-Chinese producers to capture a greater share of the global market. The extent to which this occurs will depend both on the rate of uptake of EV and ESS products, as well as changing patterns of technological leadership in the cell manufacturing stage of the value chain.

Figure 7. Lithium-ion battery production by application and country, 2016



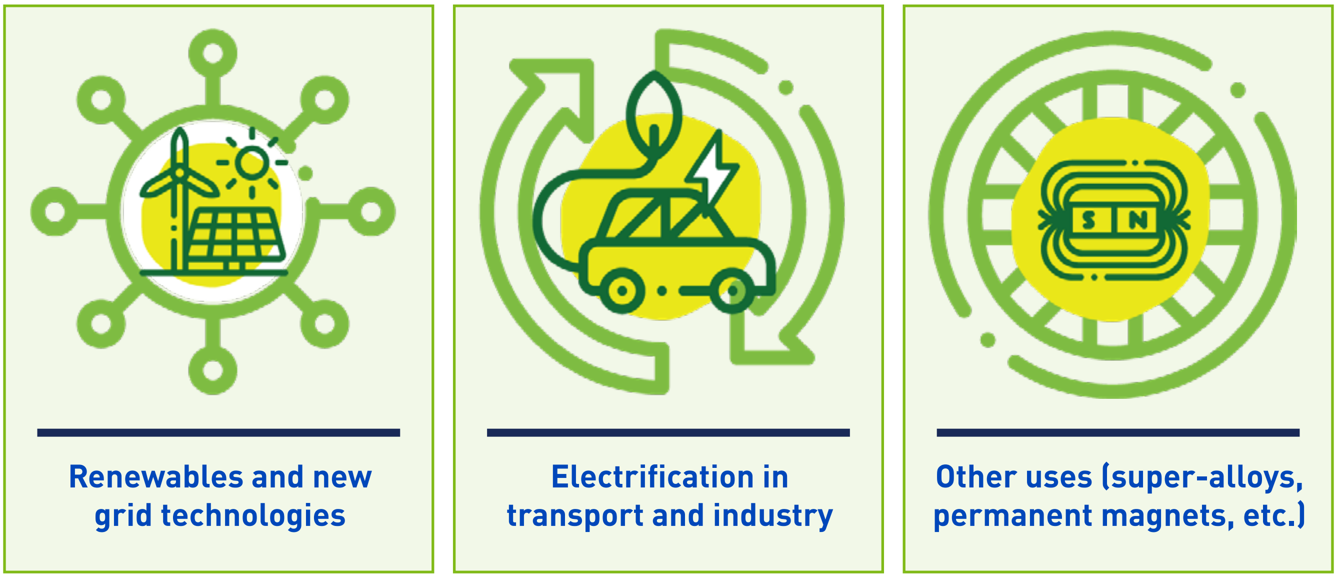
Source: Author's adaptation from data in Sun et al. 2017[20]

Parallel value chains: In addition to the central value chain, there are also parallel value chains involving waste, recovery and recycling. An indicative sample of the parallel material processes involved in LFP battery production are also identified in Figure 3. These include end-of-life disposal, waste recovery from mid-stream processes and recycling. An example of the parallel activities carried out in Australia can be found in the refining technology SiLeach®. This technology can be used as a recovery process for recycled batteries and tailings, as it processes lithium from any raw material to produce lithium carbonate, hydroxide or LFP[21].

Security and sustainability risks in the battery value chain

Batteries are essential for the future of the technology ecosystem. They are already widely used in in industrial and consumer domains, and in coming years they will be an essential requirement for the 'energy transition' towards lower- and carbon neutral energy systems. Batteries are a critical enabling technology for electric vehicles (EVs), whose competitiveness relative to internal-combustion engines hinges on the cost and performance attributes of batteries[22]. They will also play a key role in the deployment of renewable energy generation, where ESS technologies will allow households and network operators to balance intermittent renewables supply with user demand[23]. Battery minerals are also used in other new technologies – such as super-alloys and permanent magnets – which will put further upwards pressure on demand. Estimates suggest that these technological drivers will see global battery demand increased five-fold in the next decade alone[24].

Figure 8. New technology drivers of battery and battery mineral demand



Unfortunately, the value chains that transform battery minerals into finished products are neither secure nor sustainable.

The six battery minerals are members of a group which resource economists label 'critical materials' – a special category of raw materials of outsized importance. This is because critical materials pose unique risks to the security and sustainability of an economy. The commonly used definition of critical materials identifies two distinct features which demarcate the group[25]. First, they have very high *economic importance* for consuming industries, as there are few or no economically- and technically-viable substitutes. Second, they are subject to heightened levels of *supply risk*, which can interrupt physical availability and/or affordability for end-users. Figure 9 illustrates the criticality matrix which is used for identifying critical materials.

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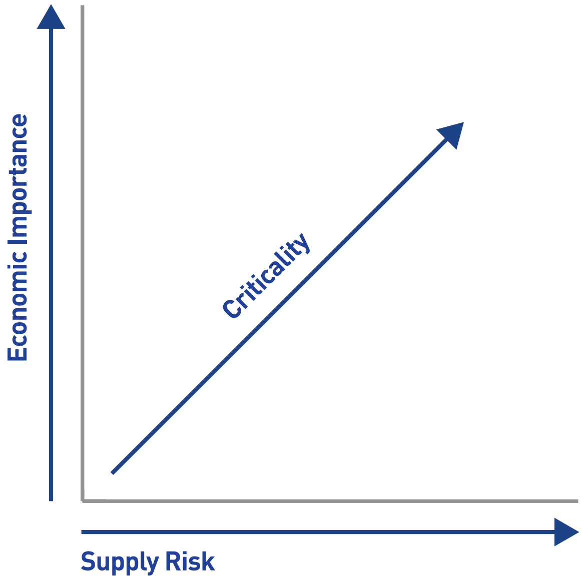
There is no universally-agreed list of critical materials. As each economy has its own distinctive industrial structure and geological endowments, whether a particular material should be classified as critical or not depends on the economy in question. However, many governments have undertaken 'criticality studies', which apply the matrix (Figure 9) to determine which materials are critical for their specific context. Five governments – the EU, US, Japan, India and Australia – have conducted such studies in recent years[26]. While they produce minor differences, a union of their findings produces a set of thirty materials which are typically deemed critical[27]. Importantly, all six battery minerals have been classified as critical materials[28].

Figure 9. Criticality matrix for defining critical materials



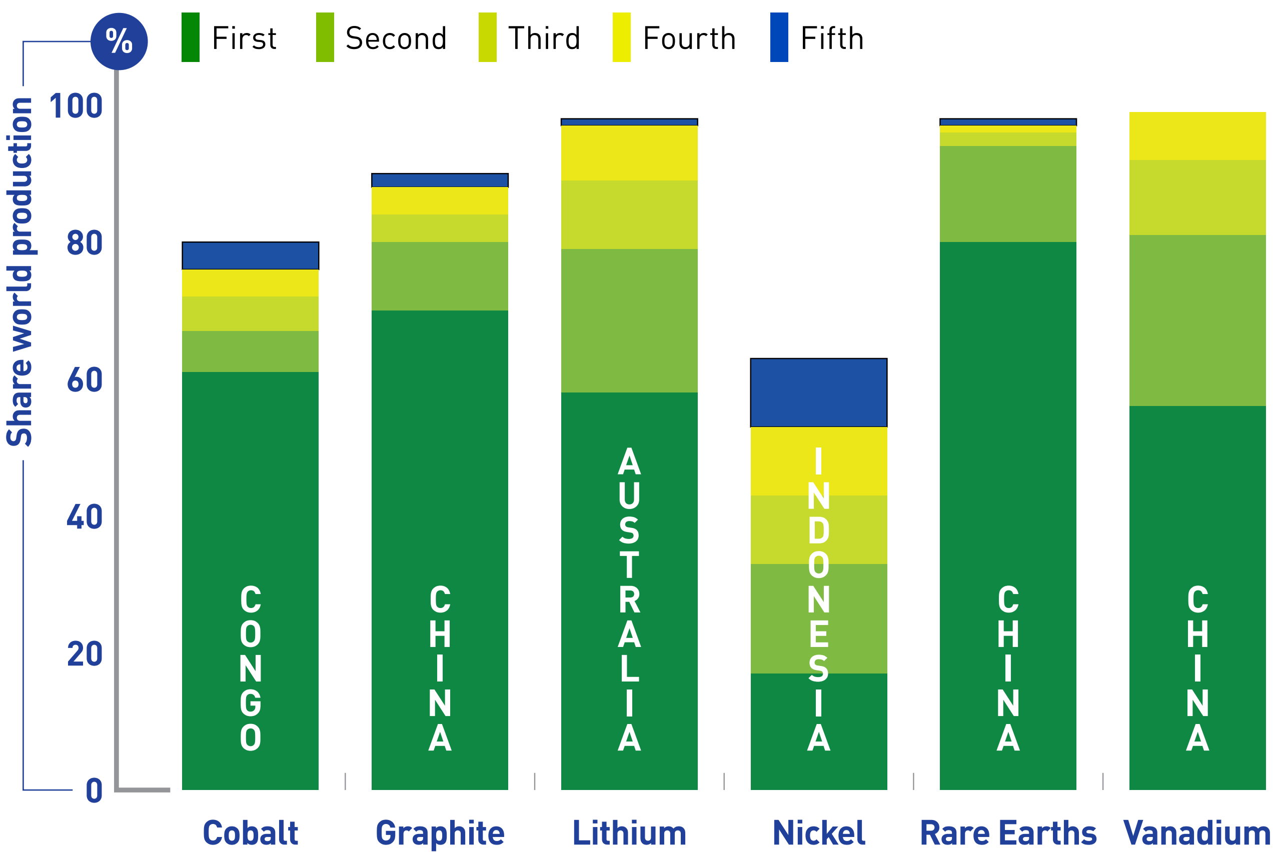
The use of critical materials means battery value chains face a distinct set of security and sustainability challenges relative to industries based on other (non-critical) bulk commodities.

Security risks in the battery value chain

Security risks are one of the most prominent challenges, and arise from the small size of markets. While essential for the production of battery-based technologies, only small quantities of these minerals are required per unit. Global markets are therefore of a much smaller scale than that for other mineral commodities. International trade in battery minerals and materials was worth $6.5 billion in 2017 (Table 1), though over half is accounted for by nickel (which is predominantly used in the production of stainless steel). These markets are a fraction of the size of the $16 billion trade in bauxite/alumina, $55 billion in copper and $90 billion in iron ore[29]. This is partially due the fact that the majority of value-adding lies in the downstream and technology-intensive steps, with upstream minerals extraction the least valuable (and lowest priced) stage[30].

Battery mineral markets are also characterised by a high degree of monopoly at both the up-stream (mineral) and mid-stream (material) stages. As Figure 10 shows, with the exception of nickel all feature a single dominant supplier, which accounts for between 50 to 80 percent of global production. In three of the battery minerals, that dominant supplier is China. A similar degree of concentration occurs at the mid-stream materials stage of the value chain, with China again playing a prominent role. China currently produces 56 percent of all lithium-based chemical precursors (Figure 4), 58 percent of refined cobalt[31], and effectively all separated rare earth oxides[32]. It is only at the downstream cell manufacturing stage where there is a diversity of suppliers.

Figure 10. Producer concentration in battery minerals, 2017



Source: Author's calculations, from USGS[33]

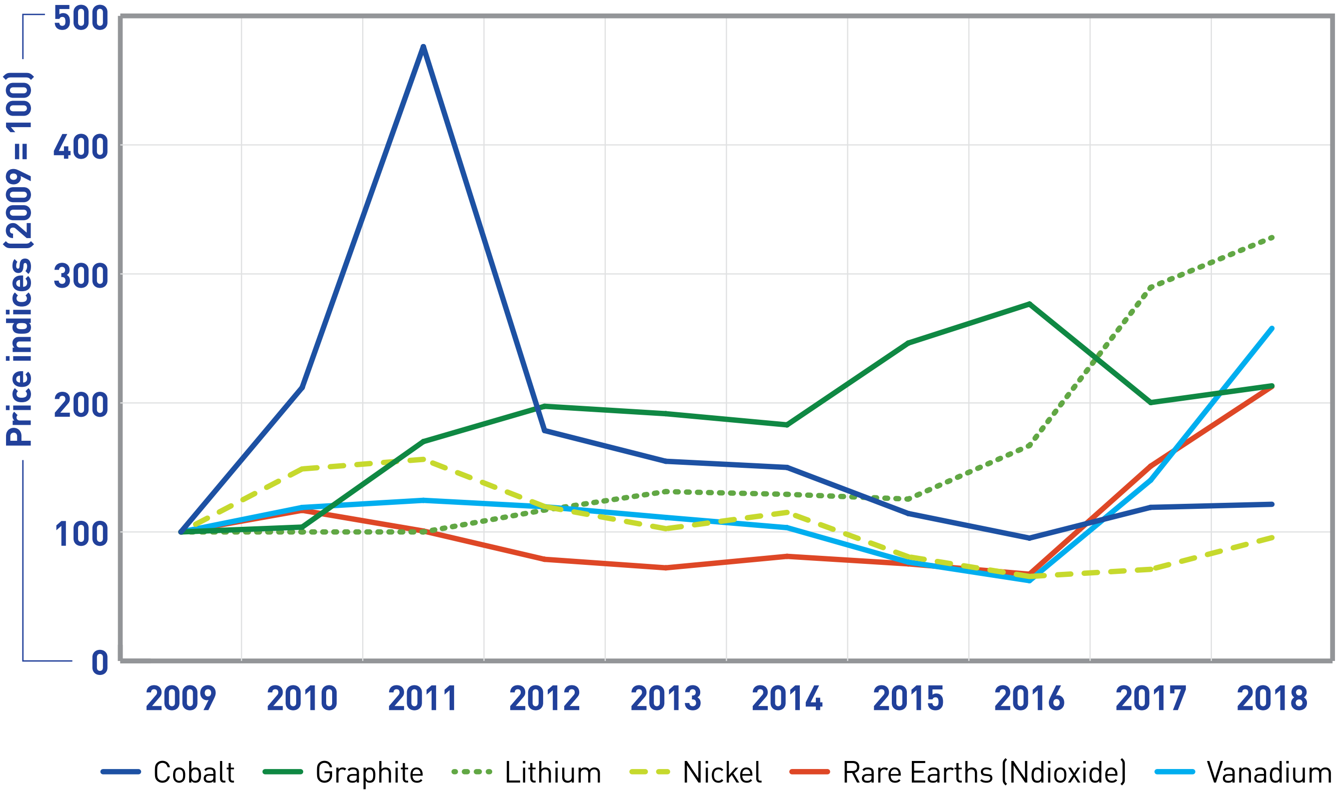
Monopoly means that battery minerals markets are subject to very high levels of supply risk. With a small number of countries accounting for the bulk of world production, adverse events can more easily lead to interruptions in international trade. These may occur for a variety of reasons, including social problems such as unrest or civil war, environmental factors such as extreme weather events or disasters at mining/processing locations, and political conflicts where producing states withhold supply in order to extract concessions from consumers.

Few other commodity markets are subject to such extreme levels of concentration.

By corollary, battery mineral markets are highly volatile. With a single player accounting for the majority of output, adverse events can quickly throw supply and demand out of balance. The most prominent example occurred for rare earths in 2010, where an interruption in Chinese rare earth supply to Japan saw with world prices increase almost four-fold as consumers scrambled to secure supplies (Figure 11). Similar – albeit less pronounced – levels of volatility are also seen in other battery minerals, where surging demand from downstream users has been prices more than double in recent years. With few suppliers in the market, there is less capacity for supply to adjust to demand shocks emerging from the adoption of new energy technologies.

Volatile price cycles make it difficult to plan the long-term investments required for vertically-integrated battery value chains.

Figure 11. Price volatility in battery minerals, 2009-2018



Source: Author's calculations, from USGS[34]

Given the narrow, monopolised and volatile nature of these markets, battery minerals have considerable value as political assets. This grants the dominant supplier power to dictate the terms for trade and investment, and determine which customers have access to supply, on what terms, and at what price. It also 'politicises' the operation of international markets, as trade and investment flows are influenced by political negotiations between governments rather than market dynamics.

The manipulation of markets by supplier governments is a common problem. In the battery minerals value chain, the majority of value-adding occurs in the mid- and down-stream stages of production. This creates an incentive for host governments to impose distortive policies, which attempt to capture a greater share of economic rents by mandating local processing. These distortive policies can take a variety of forms, including export prohibitions, taxes, and other licensing and performance requirements. They are extremely common. As Table 2 shows, exporting governments maintain 198 distinct trade restrictions on battery minerals and materials, with export taxes and licensing requirements the most common. These policies undermine cross-border value chains by distorting the operation of market mechanisms, and deterring investment into the sector.

Table 2. Global trade restrictions on battery components, 2017

	Export prohibitions	Export taxes	Licensing requirements	Other export measures	**Total**
Cobalt	7	29	35	18	**89**
Graphite	0	2	2	2	**6**
Lithium	0	0	5	0	**5**
Nickel	11	19	38	18	**86**
Rare earths	0	4	5	1	**10**
Vanadium	0	1	1	0	**2**
Total	**18**	**55**	**86**	**39**	**198**

Source: Author's calculations, from OECD[35]. Note: Includes both battery minerals and products derived principally thereof.

A more dramatic security risk arises from the use of the so-called 'resource weapon'. This is a form of economic sanction, where a government withholds (or threatens to withhold) supply of a critical material to extract some kind of concession from a target. The resource weapon can be an effective tool for diplomatic sanctions in situations where a consumer is dependent on a particular supplier. There is also a long track record of its use in international diplomacy. Famous examples including the OAPEC oil embargo of 1973 (targeting countries which supported Israel during the Yom Kippur War)[36], and Russian threats to supply gas to Eastern European neighbours on at least fifteen occasions during the last decade[37]. As battery markets are highly monopolised, with few viable sources of alternate supply in the short-term, they make an ideal instrument for diplomatic sanctioning.

Indeed, the resource weapon has been recently deployed in the battery minerals sector.

In late 2010, rare earth minerals were the subject of a trade conflict between China and Japan, which had originally begun over the disputed Senkaku/Diaoyu Islands[38]. While Chinese supply to Japan was suspended for only fifty-nine days, the dispute had a dramatic effect on global markets. Prices for rare earth oxides immediately spiked four-fold, before taking over a year to return to pre-dispute levels (Figure 11). In the more recent US-China trade dispute, Chinese authorities have made similar threats that the 'rare earths weapon' will be deployed if a negotiated settlement cannot be reached[39]. While this threat has yet to be executed, its effects on global markets would be of a similar magnitude to the Japan-China dispute of 2010. China's monopoly position in the vanadium and graphite markets could potentially enable similar of these minerals uses during diplomatic disputes.

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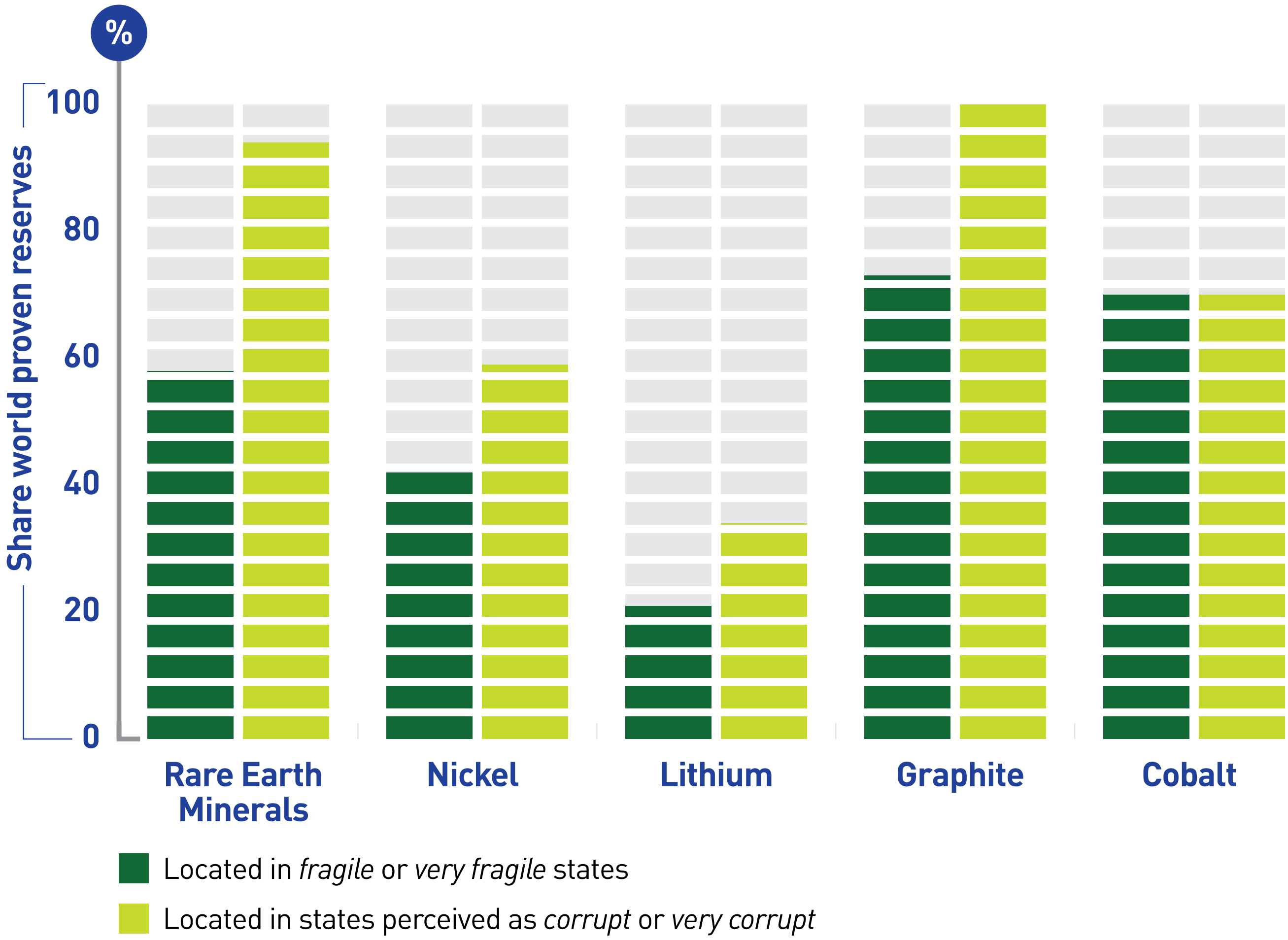
Sustainability risks in the battery value chain

Sustainability risks are an equally important – if sometimes underappreciated – value chain problem. The mining governance regimes of battery-mineral rich countries often fall short of international best practice for managing sustainability issues. Many of the countries which are endowed with battery minerals have poorly developed political and regulatory institutions. As research by the International Institute for Sustainable Development reveals, a significant share of proven global reserves are found in states that suffer from high political instability and levels of corruption (Figure 12). Weak political institutions often lead to under-developed regulatory and governance regimes, which can produce adverse social and environmental impacts from mining activities. Three sustainability challenges – relating to social conflicts, environmental management and labour standards – commonly affect battery mineral production.

Figure 12. Political instability in battery mineral-rich countries



Source: Author's adaptation from data in Church and Crawford 2018[40]

In some countries, social conflicts are catalysed by the exploitation of battery minerals. As resource extraction generates economic rents while simultaneously imposing social costs (such as environmental degradation and land use challenges), they can often become a source of political tension.

Box 1 outlines a number of social conflicts which have arisen in part due to disputes over battery minerals extraction. As the cases illustrate, conflicts often arise due to under-developed institutional frameworks, which lead to disputes over land rights, environmental management and the sharing of economic benefits. These conflicts are also politically complex, drawing in mining companies, local communities and host states.

Box 1. Social conflicts in battery mineral suppliers

COBALT IN THE DEMOCRATIC REPUBLIC OF THE CONGO: The mining sector is the DRC's largest source of export income, and the country is a major global producer of cobalt, copper, tantalum, tin and gold. However, the sector is rife with corruption, which contributes to the cycles of fragility, conflict and violence for many decades. There are minimal institutional provisions governing the country's mining sector, resulting in many cobalt mines falling under the control of illegal armed groups in the past. These mines have continued to be connected to child labour, environmental degradation, unsafe working conditions and other human rights abuses.

NICKEL IN GUATEMALA: Despite its resource-rich economy, Guatemala does not have a comprehensive set of regulations to govern mineral exploitation. Nickel mining first emerged in Guatemala during the civil war in the 1960s, and has been concentrated in rural areas which are home to the indigenous Maya people. This has resulted in high numbers of Maya being displaced from their homes. One of the largest nickel mines in Guatemala, the Fenix Mining project in El Estor, has been accused of forcing villagers from their lands, committing acts of sexual violence, and murder.

THE LITHIUM TRIANGLE: The region where Argentina, Chile and Bolivia share borders is known as the 'Lithium Triangle'. This region holds 59% of known world lithium reserves, with conflicts arising primarily due to the ecological impacts of mining practices. Some brine production techniques are damaging to the surrounding environment, threatening fragile salt flat ecosystems. There is minimal government oversight and regulation surrounding the ecological impacts of lithium mining. As a result, there have been protests and conflicts surrounding this issue and companies have come under fire for allegedly encroaching on indigenous land and restricting water access.

Source: Adapted from case studies in Church and Crawford[41]

In extreme cases, social conflicts can contribute to so-called 'resource wars'.

Resource wars are armed conflicts whose political origins are at least partially connected to disputes over natural resources[42]. Some occur due to resource scarcity, as governments use military means to capture control of valuable assets from adversaries[43]. Civil wars are another type, which are fought for control of, and/or financed by revenues from, natural resource industries[44]. The most prominent example is the series of civil wars and insurgencies that have raged in the Democratic Republic of Congo (DRC) since the mid-1990s, where armed militias and government forces have repeatedly clashed for control of lucrative critical materials mines. The International Rescue Committee estimates the Second Congo War (officially 1998-2003) caused 5.4 million deaths, making it the deadliest global conflict since the Second World War[45].

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Water management is a key environmental challenge. This is particularly pronounced for the extraction of lithium from salt brines, which requires large amounts of water. This process has threatened the fragile salt flat ecosystems found within the region including Bolivia's *Salar de Uyuni*, the largest salt flat in the world[46]. The water-intensive method of extraction has resulted in diversion of water to mines from communities across the Lithium Triangle, with operations in Chile's *Salar de Atacama* consuming 65% of the region's water. With the Salar being one of the driest places on the planet, farms have been significantly affected and rural livelihoods are threatened by the redirection of water to mining operations[47].

Waste management also poses public health problems. The amount of battery minerals used in final goods is only a tiny fraction of the total raw materials that are extracted. For example, 2000 tonnes of waste are produced for every tonne of rare earth oxides, with some of this waste radioactive due to the co-occurrence of uranium and thorium[48].The world's largest rare earths mine – Bayan Obo in Inner Mongolia, China – has accumulated a massive tailings dam known informally as the "Baotou toxic lake". Only ten kilometres from the upper waters of the Yellow River, and containing over 150 million tonnes of highly toxic and radioactive tailings, it has become an international *cause célèbre* for the social and environmental costs of critical materials mining[49].

Labour practices are also a widespread concern. In the DRC's 150,000 artisanal mines, labourers work for as little as 65 cents a day with only hand tools, a lack of safety equipment, and minimal oversight[50]. The risks associated with artisanal mining extend to the general population, with doctors from the city of Lubumbashi discovering lead, cadmium and cobalt levels in urinary concentrations to be five, four, and forty-three times higher than the general population[51]. Child labour is unfortunately common, with 40,000 children estimated to be working in artisanal mines in the DRC alone[52]. Campaigns to eradicate child labour have floundered due to the limited regulatory capacity of state agencies[53].

Sustainability challenges pose a direct threat to the social license to operate of the battery industry.

Social license to operate refers to the *informal* 'license' granted to a company by the stakeholders which are affected by its operations, which extends beyond the *formal* license of legal regulations[54]. While social license is a key requirement for all resource-based sectors, it is especially significant for companies in the battery industry. New products incorporating batteries – whether EVs, renewable energy technologies, or advanced manufacturing – are frequently promoted as 'green' solutions to pressing environmental problems. The sustainability credentials of battery-based technologies are greatly undermined if they rely on mineral inputs which are produced in a socially- or environmentally-unsustainable manner. If these challenges are not addressed, the adoption of battery technologies may simply shift environmental costs 'up the value chain' from end-users to raw materials producers. Social license will only be achieved when sustainability is secured across the battery value chain.

Sustainability issues also expose technology companies to legal liability for conditions within their supply chains. In December 2019, a group of Congolese families launched a ground-breaking legal case against a group of companies in the battery value chain, which alleges that child labourers were killed and injured while unsafely mining for cobalt[55]. Lodged in Washington DC by International Rights Advocates, the case names two mining companies (Glencore and Zheijiang Huayou Cobalt), and several technology companies which they supply (Apple, Google, Dell, Microsoft and Tesla) as defendants. The case argues that these technology companies, though not directly responsible for mining conditions, nonetheless gained significant financial benefits from including within their supply chains illegal cobalt produced by the mining companies. While the outcome of the case remains to be determined, it indicates that social license risks will not only affect battery mineral companies but also the downstream users which rely on these products.

International strategies for improving battery value chain governance

The battery value chain faces serious security and sustainability challenges. Monopolised production and political conflict undermines the security of supply chains; while weak governance frameworks have led to adverse social and environmental outcomes. Indeed, these challenges will become even more pressing in future years. If battery value chains are insecure today, they will certainly not be fit-for-purpose to support the energy system transitions required in the 21st century. As a result, many involved players – including governments, businesses and civil society groups – have launched efforts to reform value chain governance.

Private sector governance initiatives have principally focused on sustainability challenges.

A major sustainability challenge is that the technology sector has little reliable information on whether their value chains incorporate environmentally and/or socially problematic suppliers. In the absence of this information, or recognised standards for how to implement responsible sourcing, companies have limited capacity to respond to social license imperatives. As a result, several private sector initiatives – which typically combine both companies and civil society groups, in some cases without governmental assistance – have sought to address these informational gaps. Box 2 outlines six of the most prominent private sector-led initiatives for the battery sector, though many more exist. These combine information sharing, the development of agreed best practices, and in some cases independent certification schemes.

Box 2. Private sector-led governance initiatives in the battery value chain

EXTRACTIVE INDUSTRIES TRANSPARENCY INITIATIVE (2003):

A set of transparency standards that requires governments to publish timely and comprehensive information about their resource governance regime, validated by an independent and stakeholder-driven assessment process. The standard has been adopted by fifty-one countries.

RESPONSIBLE MINERALS INITIATIVE (2008):

A private-sector initiative which shares information, develops resources and provide third-party audits to ensure responsible sourcing of mineral products. Over 380 companies are members. A particular strength is the RMI's focus on providing resources to mid-stream companies in the processing and refining sector.

OECD DUE DILIGENCE GUIDANCE FOR RESPONSIBLE SUPPLY CHAINS OF MINERALS FROM CONFLICT-AFFECTED AND HIGH-RISK AREAS (2011):

A set of best-practice guidelines designed to assist companies to undertake risk assessment and implement responsible sourcing principles for conflict minerals. While the Guidance is voluntary, it provides companies a suite of internationally-recognised responsibility standards which companies can incorporate into their own corporate planning activities.

RESPONSIBLE COBALT INITIATIVE (2016):

Launched by the Chinese Chamber of Commerce for Metals, Minerals & Chemicals, the RCI is a set of voluntary standards that support downstream cobalt users to implement the 2011 OECD Guidance. Many global electronic and automotive companies, including Volvo, Daimler, Apple and Sony, have joined the initiative.

WEF GLOBAL BATTERY ALLIANCE (2017):

A public-private coalition, sponsored by the World Economic Forum, to promote sustainability within battery value chains. The Alliance's work targets responsible sourcing (with a focus on cobalt and lithium), development of a circular economy for battery materials, and pro-development innovations in value chains governance.

IRMA STANDARD FOR RESPONSIBLE MINING (2018):

A set of corporate standards and certification scheme to ensure business integrity and social and environmental responsibility in mining projects. It is the only mining responsibility standards which includes both self-assessed and independent certification, allowing companies to credibly assure stakeholders of compliance.

Source: See note[56].

These private sector-focused initiatives are of critical importance for companies in the battery value chain. In recent years, many global corporations – including Google[57], Toyota[58], Intel[59], Du Pont[60], Volkswagen[61], GE[62], Samsung[63], IBM[64], Apple[65], and GM[66], amongst many others – have incorporated supply chain reform into their corporate social responsibility (CSR) frameworks. However, without transparency on social and environmental conditions, downstream companies have no practical way to implement these CSR commitments. By helping to close the information gap, these initiatives greatly increase the ability of companies to take action on sustainability concerns. Several of these private sector initiatives have also collaboratively developed voluntary standards that outline best practices for managing these supply chain issues. These standards function as an international reference point which can help corporate managers design, implement and audit their supply responsibility efforts.

An ongoing challenge facing these private sector-led initiatives is that none have yet emerged as an industry standard. Without central coordination, there has been a proliferation of different initiatives, with some adopted by only a small group of companies, and/or focused on one particular battery mineral. This has resulted in a fragmented governance landscape that lacks a consensus approach which multiple companies can adopt. Many also set standards but do not include certification schemes, increasing compliance and information costs. By way of comparison, in the diamond industry a single set of sustainability standards – the Kimberley Process[67] – functions as a single global standard agreed by all companies, industry bodies and civil society groups. It also includes a certification scheme that enables companies to trace provenance across the value chain. An integrated Kimberley Process-like approach would significantly improve the coherence and quality of sustainability governance in the battery value chain.

By contrast, government-led initiatives have instead focused on addressing security risks.

Recognising that security risks pose a major threat to the competitiveness of battery technologies, many governments have launched initiatives to provide more security for their battery materials supply. While these generally focus on the broader group of commodities which the government has identified as the critical material for its economy, the six battery minerals feature prominently in these policies.

The leading governmental initiatives include:

- **The European Union's** *Raw Materials Initiative*[68]. Launched in 2008, this was the first government policy to recognise the need to develop new and more secure critical materials value chains to meet industry needs. It comprised three strategies, including improving supply sustainability, better developing mining and processing industries within Europe, and promoting efficiency and recycling within value chains. These efforts were then directed towards the battery value chain with a *Strategic Action Plan on Batteries in 2018*[69], and a $3.5 billion 'Important Project of Common European Interest' for research into battery technologies in 2019[70].
- **Japan's** *Strategy for Ensuring Stable Supplies of Rare Metals*[71]. To reduce the risks of over-dependence on single producers, the strategy aimed to diversify import sources, promote recycling and the use of substitutes, and build international partnerships with new suppliers. Initially launched in 2009, efforts under the strategy accelerated rapidly following the 2010 rare earths dispute between Japan and China.
- In 2010, the **US Department of Energy** launched a *Critical Materials Strategy*[72] focused on minerals required for the energy sector. This emphasised R&D and international partnership efforts. In 2019, it was complemented by the US **Department of Commerce's** *Federal Strategy to Ensure Secure and Reliable Supplies of Critical Minerals*[73] that added efforts to develop both up- and mid-stream domestic capabilities, as well as international cooperation with new suppliers.
- **India** issued the *Critical Non-Fuel Mineral Resources for India's Manufacturing Sector: A Vision for 2030*[74] in 2016. Recognising that secure critical materials supply would be important for national efforts to develop the manufacturing sector, the policy sought to upgrade India's domestic technological capabilities and engage in international partnerships.

These governmental strategies seeks to promote the security of critical materials supply chains through a variety of policy interventions. Table 3 provides a comparative analysis of the content of these policies. All the governments have undertaken **criticality studies** (designed to identify and measure supply risks), as well as **R&D efforts** to improve technical capacity across the various stages of the value chain. They have also all committed to undertaking **diplomatic engagement** with partners to promote new suppliers entering the market. However, the more complex and/or costly policy interventions only feature in some of the strategies:

- Only the US and Japanese governments maintain **emergency stockpiles** of critical materials. These are government-held stocks that can be released to industrial users in situations where foreign supply is interrupted for political or economic reasons. They provide an economy measure of protection against the 'resource weapon', particularly for users in the defence sector. However, as the cost of maintaining these stockpiles is high, few governments have elected to undertake this policy.
- Only the Japanese government has undertaken **investment promotion** efforts. This aims to directly support the emergence of new suppliers, through sponsorship packages that include investment and/or offtake contracts. It has the advantage of addressing the root cause of supply insecurity – monopolised markets – by fostering a more diverse range of supply options. However, it also exposes a government to commercial risks by directly supporting enterprises.
- Only the EU has systematically incorporated **sustainability instruments** into its policy efforts. These establish methodologies for measuring sustainability (developed in consultation with private sector partners), enable standardised reporting and assessment of impacts. They have the advantage of applying sustainability metrics across the entire value chain, not solely at the upstream site of battery minerals extraction. An example is the *Product Environmental Footprint* methodology, which has been developed by the European Commission and recently customised for application to mobile rechargeable batteries[75].

Table 3. Comparison of national critical materials strategies

Policy	Action	European Union	United States	Japan	India
Criticality studies	Economy-wide surveys to identify industrial uses and supply risks for critical materials	●	●	●	●
Research & development	Improvement of technical capabilities in value chains, including process efficiency, recycling and substitutes	●	●	●	●
Emergency stockpiling	Maintain emergency stocks of critical materials for release to market during supply interruptions		●	●	
Investment promotion	Support new producers to enter the market, through packages combining investment and offtake contracts			●	
Diplomatic engagement	Diplomatic activities to improve value chain security, including cooperation with new suppliers	●	●	●	●
Sustainability instruments	Develop standards and metrics by which sustainability across the entire value chain can be measured and reported	●			

These reform initiatives are an important first step in addressing the security and sustainability challenges afflicting the battery value chain.

They reveal an increasing awareness of challenges facing battery value chains, and the need for new governance strategies to ensure these are fit for purpose in the 21st century. Importantly, as both private sector- and government-led strategies are underway, they are evidence of a strong international consensus behind the need to reform industry governance. However, the persistence of security and sustainability challenges also indicates that more could be done to increase their effectiveness and impact. Several notable gaps include:

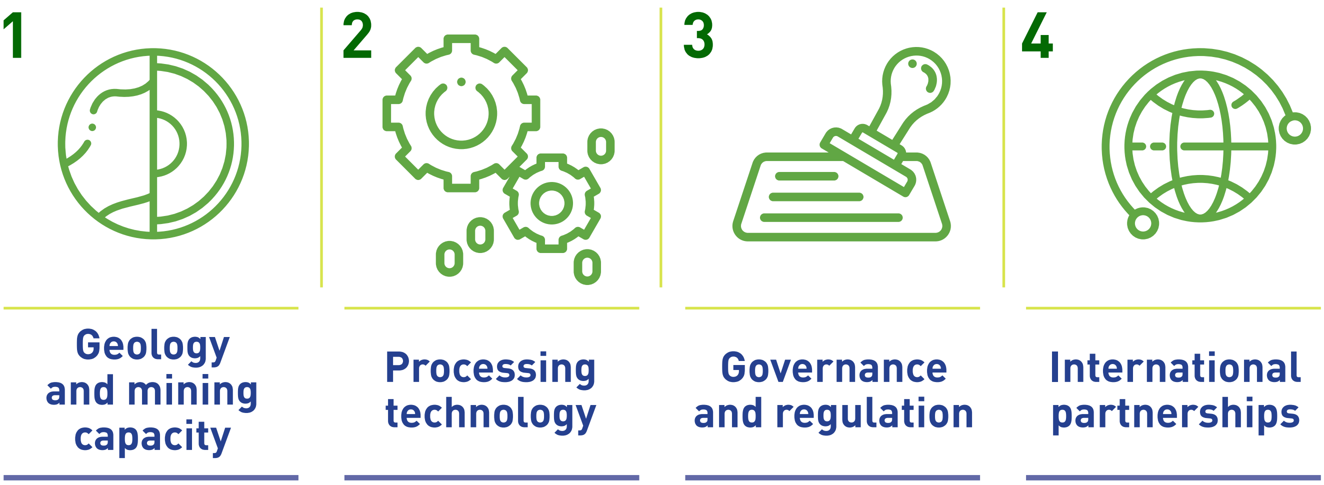
- **A need to consolidate private sector sustainability initiatives.** The emergence private sector-led efforts is an important first step in addressing sustainability, but the proliferation of different initiatives and standards fragments the governance regime. Developing globally-agreed standards – which are shared by businesses, industry associations and civil society groups – is needed to ensure coherent sustainability governance. The Kimberley Process in diamonds provides an instructive example that the battery industry might attempt to replicate.
- **Weak linkage between government and private sector efforts.** There is a clear division of labour in these reforms, with governments focusing on supply security while the private sector prioritises sustainability. Yet the two dimensions are clearly inter-linked. Governments alone cannot improve the diversity of battery value chains, as this requires investment from private businesses. Nor can the private sector alone solve sustainability issues, which often arise from the under-developed regulatory frameworks provided by governments. Better results would be delivered if these challenges were approached as an integrated problem, with governments and the private sector equally contributing to both sides of governance reform.
- **A focus on minerals production rather than whole-of-value-chain approaches.** Sustainability efforts have largely targeted problems arising at the mining stage; while security efforts have similarly focused on ensuring diverse supply of battery minerals. But given the complexity of international battery production, these issues are equally pertinent at the mid- and down-stream stages of the value chain. For reform strategies to be successful, they will need to adopt a whole-of-value-chain perspective that locates difficulties at one stage of production in the larger networked web in which they are enmeshed.
- **The development of new producers and partners.** Despite these initiatives being underway for many years, the level of concentration in battery mineral and material industries remains stubbornly high (see Figure 5 and Figure 10). Only the nickel market has sufficient diversity to insulate value chains against political and economic shocks. This indicates there is a pressing need to redouble efforts to bring new players into the battery value chain. Key will be finding new partners which are able to meet both security and sustainability requirements.

Policy options for integrating Australia into battery value chains

Australia has the potential to make a major contribution to the development of more secure and sustainable battery value chains. Its geological endowments, technological capability and reliable institutional framework mean it is ideally placed to support the expansion of the global battery industry. Indeed, Australia already plays a key role, as an important supplier of several battery minerals in raw or semi-processed form. Both governments and businesses have identified 'moving along the value chain' – leveraging geological endowments to establish mid- and down-stream processing capabilities – as a key economic opportunity for Australia. But to achieve this goal, Australia needs to design policies and business strategies that will maximise the prospects for successful integration with new and existing battery value chains.

There are four requirements for successful participation in battery value chains.

Figure 13. Requirements for participation in battery value chains



1.

Geology and mining capacity is arguably Australia's strongest asset. The unique geology of the Australian continent means it is well-endowed with many high-quality and easily-exploited battery mineral resources (Table 4). It is already the world's top producer of primary lithium, the only commercial-scale producer of rare earths outside China, and occupies an important position in the cobalt and nickel markets. While there is currently no commercial production of graphite and vanadium, strong endowments indicate the scope for developing these as well. A recent assessment by Geoscience Australia has identified that all six battery minerals have either the 'highest' or 'significant' potential for future commercial development. Possessing commercial potential in all six battery minerals is a significant advantage for Australian efforts to grow its role in battery value chains.

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Table 4. Australia's battery mineral potential, 2017

Mineral	Development potential*	Share world resources^	Resource rank^	Share world production^	Production rank^	Other major producers#
Cobalt	**Highest**	17%	2nd	5%	3rd	DRC 61%, Russia 5%, Cuba 5%
Graphite	**Significant**	3%	7th	None		China 70%, Brazil 10%, Canada 4%
Lithium	**Significant**	18%	3rd	47%	1st	Chile 21%, China 10%, Argentina 8%
Nickel	**Highest**	26%	1st	9%	6th	Philippines 17%, Indonesia 16%, Russia 10%
Rare earths	**Highest**	3%	6th	13%	2nd	China 80%, Russia 2%, India 1%
Vanadium	**Significant**	18%	3rd	None		China 56%, Russia 25%, South Africa 11%

Source: ^Geoscience Australia[76]; #Author's calculations from United States Geological Survey[77];
*Development potential classifications from Geosciences Australia[78].

2.

In comparison, Australia's mid-stream processing capabilities are at an early stage of development. At present, Australia principal role is as an exporter of raw or minimally-processed (i.e. concentrated) battery minerals. This industrial pattern reflects Australia's established role as a cost-competitive and reliable mineral supplier to Asian economies, particularly the iron ore and metallurgical coal required for steelmaking. However, this role is beginning to change, as a number of new investments have made in battery materials processing in recent years:

- **Lithium hydroxide:** Albermarle[79], Covalent Lithium and Tianqi Lithium[80] are constructing lithium hydroxide refineries at the Kemerton and Kwinana strategic industrial areas just south of metropolitan Perth. These will create the first hydroxide processing capacity available to the burgeoning spodumene industry in Western Australia.
- **Nickel suplhate:** BHP's Nickel West division is presently reorienting its processing facilities from a focus on nickel metal (used by steelmakers) to battery grade nickel sulphate (a battery precursor)[81]. A new nickel sulphate refinery is currently being commissioned in Kwinana.
- **Separated rare earth oxides:** Lynas Corporation operates an integrated value chain that connects mining facilities at Mt Weld in Western Australia, which produces a monazite rich concentrate through flotation, with an Nd-Pr focussed light rare earths processing plant in Malaysia. Northern Minerals has established a pilot processing plant at its Brown Range project that has demonstrated the technical feasibility of separating dysprosium from mixed carbonates[82] from a xenotime-rich resource. Alkane Resources operate a pilot plant at ANSTO Minerals to extract rare earths, niobium, tantalum and zirconium from eudialyte.

These committed investments in processing capacity indicate that the first Australian steps along the battery value chain are already underway. But they all sit towards the upstream end of the value chain, and no projects targeting more sophisticated components – such as cathodes, other precursors, or cell production – have yet reached the final investment decision stage. As the bulk of value-adding occurs in the mid- and down-stream stages, this means Australia captures only a very small share of value. According to a recent study by Austrade, only 0.53 percent of the value realised in global battery production ($1.13 billion) is presently realised by Australia[83].

While Australia is an established battery minerals producer, it has only just begun the transition to a materials processor role.

3.

Australia is very well-positioned in terms of governance and regulatory quality. Australia is a consolidated democracy, with effective rule of law and well-developed regulatory frameworks. This means is does not suffer the problems of political fragility, corruption and low transparency to the extent that many other jurisdictions are affected. In terms of resource governance specifically, its established regulatory framework is internationally recognised as one of the best investment environments for mining investment globally. As Table 5 demonstrates, Australia has the highest rank of any battery mineral producer in industry surveys on investment attractiveness, policy perceptions and mining practices. Indeed, there is a significant gap between three highly-regarded jurisdictions (Australia, Canada and Chile), and the very poor risk rankings of dominant suppliers such as China, Russia, Indonesia, the Philippines and the DRC.

Table 5. Jurisdictional risk in major battery mineral and material producers, 2018

	Investment attractiveness	Policy perceptions	Best-practices mineral potential
Argentina^	37th	38th	43rd
Australia#	2nd	5th	2nd
Brazil	58th	57th	56th
Canada*	20th	30th	20th
Chile	6th	23rd	9th
China	78th	74th	73rd
DRC	67th	82nd	24th
Indonesia	47th	70th	25th
Philippines	65th	79th	37th
Russia	27th	57th	15th

Sources: Fraser Institute[84]. Note: Rank out of 83 surveyed jurisdictions, higher is better. ^Catamarca province; #Western Australia; *Ontario province.

4.

Established international partnerships are also a key strength. Australia has an extensive network of free trade agreements (FTAs) with all key players in the battery mineral sector, including China, Korea, Japan, the US, Indonesia, Malaysia and ASEAN. Negotiations are also currently underway with the EU[85]. All of Australia's FTAs contain provisions that facilitate cross-border trade and investment in the battery sector, such as tariff reduction and investment protections. Australia's bilateral FTA with Japan also includes a path-breaking resource cooperation chapter, which facilitates inter-governmental dialogue on joint resource development initiatives[86]. The strength of these international economic relationships is reflected in the fact that many partners – including the US, China, Japan and Korea – have made investments in the Australian battery materials sector in recent years (Box 3).

In the current global political context, the value of Australia's reliability as an economic partner cannot be understated.

The last decade has seen a number of fissures emerge in the architecture of global economic governance, with worrying consequences for cross-border value chains. These include the ongoing US-China trade war[87], the suspension of the World Trade Organisation's Appellate Body function[88], the withdrawal of major power from key trade blocs (the US from the Trans-Pacific Partnership[89] and India from the Regional Comprehensive Economic Partnership[90]), and geopolitical anxieties over China Belt and Road Initiative[91]. If the rules-based global economic system continues to fracture, the resilience of value chains – which inherently require robust economic rules – will be increasingly in doubt. In this context, Australia's commitment to rules-based international relationships, and its trusted ties with all key players in the battery sector, becomes a unique advantage. Companies and civil society groups can be confident that trade and investment connections to Australia will not be subject to the conflict and politicisation seen between many other major economic powers today.

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Box 3. International investments in the Australian battery materials sector

JAPAN – LYNAS CORPORATION: An Australian producer of semi-processed rare earth oxides, with a focus on Neodymium-Praseodymium (Nd-Pr). Nd-Pr is used in permanent magnets, including those needed in electric motors. Lynas is the only commercial-scale rare earths manufacturer outside of China, with mining facilities at Mt Weld in Western Australia and an advanced processing plant in Kuantan, Malaysia. Lynas has been supported by investment and offtakes from its Japanese partners – Sojitz and JOGMEC – but services a diverse export market which includes China, South Korea and Vietnam.

KOREA – PILBARA MINERALS: Supported by investment from POSCO, Pilbara Minerals is a West Australian based lithium-tantalum manufacturer. The company has positioned itself to be a primary supplier to the electric vehicle industry, via offtake partnerships with POSCO, Great Wall Motor Company, Ganfeng Lithium and General Lithium. Pilbara Minerals' Pilgangoora project is one of the most significant hard rock lithium projects in the world, and began export of concentrate in August 2018.

UNITED STATES – ALBEMARLE: A US specialty chemicals company, Albemarle is constructing a new lithium processing plant near Bunbury, Western Australia. At completion, the Kemerton project will have the capacity to process one million tonnes of spodumene ore into 100,000 tonnes of lithium hydroxide annually. This lithium hydroxide is an essential element in the production of cathodes within lithium-ion batteries, and Albemarle's investment in the plant is valued at over AUD 1 billion.

CHINA – TIANQI LITHIUM: A global battery powerhouse, Tianqi Lithium's first overseas project will be based in Western Australia. Its lithium processing plant in Kwinana will convert spodumene to lithium hydroxide, and is valued at AUD 700 million. It will source the spodumene from the Greenbushes mine, a joint venture between Albemarle and Tianqi. This project acts as a node in Tianqi's broader network of lithium producers in the Sichuan, Chongqing and Jiangsu provinces of China. Tianqi also holds a 24% stake in the Chilean mining company Sociedad Química y Minera (SQM), which in turn is in a joint venture with Wesfarmers in the Australian company Covalent Lithium Ltd.

AUSTRALIA – NICKEL WEST: BHP's Nickel West division is currently transitioning from a focus on the steel industry to participation in the battery value chain. For many years an established supplier of nickel metal to the steel industry, Nickel West has progressively reoriented its operations to the battery industry, which currently account for 75 percent of sales. To support this transition into the battery value chain, it is currently constructing a refinery at Kwinana which specialises in the nickel sulphate product required by battery manufacturers.

This analysis shows that Australia is currently well-positioned in terms of three of the four requirements for successful integration in battery value chains: geology, governance and international partnerships. However, it is the refining sphere that Australia presently lacks capability. While several refining projects have recently been launched, there remains much to be done to augment the breadth of the technology ecosystem in these areas. There is also a need to take further steps downstream, beyond the refining of chemical precursors (lithium hydroxide, nickel sulphate and separated rare earth oxides) to the manufacture of battery components (cathodes, anodes and cells) themselves. This move from minerals to materials will ensure Australia captures a greater share of value generated in the battery industry as it expands in coming decades.

Australian policy interventions should now focus on building the mid- and down-stream processing capabilities of the battery sector.

To support this agenda, Australian governments have launched several new battery policy initiatives. Recognising the role for government in catalysing transformative industrial change, these policies have a focus on developing the mid- and down-stream capabilities which are presently under-developed. The most prominent initiatives include the following:

- Geoscience Australia first identified critical materials as a major economic opportunity in 2013 with *Critical commodities for a high-tech world: Australia's potential to supply global demand*[92]. This study undertook the first national criticality assessment, and mapped areas where Australian endowments were matched to international demand.
- Specific battery-related opportunities were first identified in Austrade's 2018 study *The Lithium-ion battery value chain: New economic opportunities for Australia*[93]. This report specifically identified the need to leverage Australia's minerals endowment to develop an expanded processing and manufacturing role in the battery value chain.
- A *Critical Minerals Strategy*[94] issued in 2019 by Austrade and the Department of Industry, Innovation and Science outlined the first integrated national policy to capitalise on these identified opportunities. Its goals included the attraction investment into critical materials sectors, R&D activities to improve national technological capacity, and the provision of infrastructure to improve competitiveness of new projects.
- In 2019, Commonwealth funding was extended to create the Future Battery Industry Cooperative Research Centre (FBI-CRC)[95]. A government-academia-industry partnership, the FBI-CRC aims to identify gaps in Australian battery value chains and support technical advances to increase sustainability and competitiveness.
- These national efforts were complemented by the State of Western Australia's *Future Battery Industry Strategy*[96] issued in 2019. This strategy aims to foster the development of a local battery industry by promoting battery precursor and cell-manufacturing activities.

However, these headline initiatives are only the most prominent of a wide range of government policies targeting the battery industry. At present, Australian governments – including both the Commonwealth, and all the states and territories – collectively maintain fifty-nine distinct policy initiatives which in some way support the industry's development. A comprehensive inventory of these policies is included in the Appendix of this report (Table 6). Some are specifically targeted at the battery value chain, whereas others take a broader industry focus that includes batteries with other sectors. Nonetheless, the large number of initiatives, and the fact that these have been launched by all Australian jurisdictions, is indicative of the attention the battery industry is attracting amongst economic policymakers.

This suite of policies will make a significant contribution to the growth of the national battery industry. Around half constitute 'facilitation' initiatives – commitments by government to promote the industry to potential investors, and configure regulatory frameworks in a manner appropriate to its specific needs. That several of these efforts are intra-federal partnerships also recognises the intersection between state (mining, land use, infrastructure and industrial regulation) and federal (trade, investment, taxation and infrastructure) responsibilities. These facilitation measures are complemented by grant and R&D initiatives, which are important in developing the technical capabilities required for cost-competitiveness. The Commonwealth also offers a number of financial support programs – primarily through Export Finance Australia (EFA) – which can assist companies to secure project finance.

Table 6. Australian policies for battery industry development, by jurisdiction and type

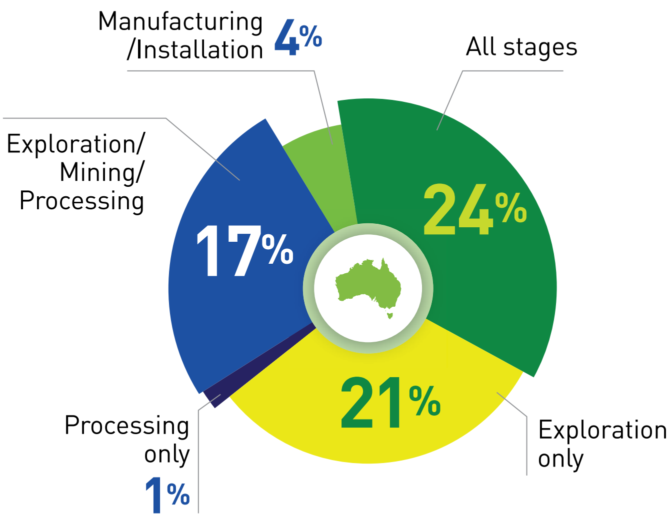
	Facilitation	Finance	Grant	R&D	Tax reform	Total
Commonwealth	6	8	4	7		25
Intra-federal	3			1		4
NSW	2		1	1		4
NT	5		1	1		7
QLD	6		1	1		8
SA	2		1	1		4
Tas	1		1	1		3
VIC	5		1			6
WA	1		2	2	1	6
Total	**31**	**8**	**12**	**15**	**1**	**67**

Source: Summary from Appendix

However, there are also several gaps in the Australian policy suite.

One of the most notable gaps concerns the stage of the value chain targeted by policy. Twenty-four policies focus on exploration only, and a further fourteen bundle together exploration, mining and processing activities (Figure 14). These upstream activities are areas in which Australian commercial and technical capacity is already well-established. By contrast, only four policies target the down-stream stage; all of which are long-standing renewable energy policies that do not directly contribute to the creation of an Australian battery industry. Tellingly, there is only one policy amongst the fifty-nine – a Western Australian lithium royalty reform of 2019 – which is dedicated specifically to addressing the mid-stream stage! Given the major technical and commercial differences between mining and processing, there is a clear risk that mid-stream projects will not receive appropriately-configured forms of governmental support. This is a particularly significant omission, given that mid-stream is the area in which Australian capabilities are in greatest need of development.

Figure 14. Australian policies for battery industry development, by stage of value chain



Source: Author's calculations from Appendix.

There is a lack of battery-specific initiatives in the policy mix. Only four – the FBI-CRC, the Western Australian lithium royalty reform, and high-level battery strategies from Austrade and the Western Australian government – are directly focused on opportunities in the battery value chain. The overwhelming majority are policies targeted at the entire mining and/or manufacturing sectors. This lack of battery industry-specific policies poses two risks. The first is that policy frameworks designed for application across many industries may not 'fit' the unique and specific needs of projects in the battery value chain. The second is that battery-related projects will need to compete with a wider pool of applicants, and may be crowded-out by other mining or manufacturing projects which will be competing from a more established industrial base.

Governments need to make battery-related projects a priority within broader industry programs.

Challenges facing provenancing and sustainability standards also need to be addressed. While Australia's strong regulatory environment is a major source of competitive advantage, it will need to demonstrate its sustainability credentials in a transparent and verifiable manner. At present, the lack of widely-agreed industry standards or certificate schemes prevents verifiable *"Made sustainably in Australia"* marketing of battery-related products. There already exists a number of new blockchain-based provenancing platforms for diamonds, which have originated from the Kimberley Process, whose models might be fruitfully applied to battery minerals[97]. Given the major focus of European firms on sourcing ethical and environmentally-sustainable material inputs, developing agreed and transparent provenancing solutions will be essential for Australian producers to engage with European battery value chains.

The environmental performance of Australia's resource sector will also need to be improved. At present, the majority of Australian mining operations depend primarily on carbon-intensive hydrocarbons for the energy supply, and processing facilities depend on fossil-fuel based electricity. This means Australian mineral resources are comparatively 'dirty', in carbon footprint terms, vis-a-vis supplies from other countries whose resources sectors make greater use of renewables. As social license in the battery value chain will significantly depend on establishing green credentials, de-carbonising the Australian resource sector will be critical for successful participation in value chains.

There are also opportunities to link battery industry initiatives with broader reform of Australia's energy systems. As renewables penetration increases, governments have begun to work with generators and network operators to develop 'energy transformation' plans. These aim to transition energy systems from traditional (centralised generation, transmission and distribution) systems to newer architectures that better integrate intermittent and decentralised renewables. At present, all Australian states and territories have such energy transformation plans in place[98]. Battery technologies will be essential for success, particularly for Distributed Energy Resource (DER) systems[99] which incorporate storage to manage supply intermittency (see Box 4). However, at present there are few formal links – let alone cases of project-level alignment – between the energy transformation plans and battery industry initiatives. As energy transformation will be a major source of demand for battery products, they could fruitfully be leveraged for the growth of downstream battery manufacturing capability.

Box 4. Illustrative Distributed Energy Resource projects in Australia

REGIONAL: Horizon Power's *Carnarvon DER trials*

In Western Australia, rural energy utility Horizon Power is trialling a set of DER projects aimed at regional energy grids. Its Carnarvon DER project is a three-year trial of feed-in management systems, which is testing various 'behind-the-meter' innovations. This includes equitably limiting the quantity of solar exported back into the grid during peak generation, and more efficient utilisation of batteries in PV installations to store and distribute loads. Analysis from these trials will inform long-term energy generation and storage systems implementation.

METROPOLITAN: Jemena Electricity Networks and AusNet Services' *Dynamic Grid-Side Technologies*

In Victoria, a partnership between electricity companies is testing battery storage technologies to sustainability increase solar PV penetration in traditional distribution networks. Supported by funding from the Australian Renewable Energy Agency (ARENA), the *Demonstration of Three Dynamic Grid-Side Technologies* project is testing new systems on two suburb sites with high rooftop PV penetration. The tests include conducting phase switching of customer loads on traditional low-voltage feeders, managing load balances at the source distribution transformer, and utilising battery storage to sustainably absorb higher DER penetration.

Source: See note[100].

Finally, fostering international partnerships will also require greater attention. As Section 4 of this report demonstrates, the Australian battery industry is not being created *de novo*. Rather, it will need to position itself within an existing network of global value chains, and move from an up- to mid-stream supplier role. This agenda will inherently require international partnership with industry incumbents, who can provide trade, investment and technology links that will accelerate the development of local capabilities. It is instructive that all the major battery-related projects launched in recent years (see Box 3) are international partnerships with existing players in the global sector. Some policy initiatives – such as those from Austrade and EFA – explicitly recognise the importance of international partnerships for the industry's growth. It will be important for the others to do the same, and incorporate mechanisms to support international partnerships within their implementation frameworks.

Key findings and next steps

Australia is well-positioned to capitalise on new opportunities in the battery industry. As the transition towards cleaner sources of energy progresses, the global market for batteries will increase dramatically. Australia possesses the attributes required for success: world-class geological endowments, reliable regulatory institutions, established international partnerships, and emerging processing capabilities. All levels of Australian government have now identified the economic opportunity on offer, and have launched policy initiatives to support the industry's development. Major investments from international companies have already begun to flow into the sector.

A major value proposition for Australia are its credentials as a secure and sustainable supplier. Existing battery value chains will not be fit-for-purpose for 21st century needs. Risks associated with monopolised markets undermine the security of supply networks. Economic and social sustainability challenges in many suppliers also threatens social license, a critical asset for a technology dependent on its 'green' credentials. Australia is unique as one of the few suppliers with strong regulatory frameworks at the domestic level, and trusted political relationships internationally. It therefore offers a more secure and sustainable partner for the growth of the global battery industry.

To capture these opportunities, Australia will need to upgrade its role in the value chain. The Australian battery industry is integrated within cross-border value chains that connect up-, mid- and down-stream producers across many different countries. Australia already plays a major role in these value chains as a battery minerals supplier. Future opportunities exist in 'moving along the value chain', by leveraging resource-endowments as a foundation for subsequent processing and manufacturing activities. As the majority of the value-add in battery value chains comes at the mid- and down-stream, these stages will offer the best returns for the Australian economy.

Domestically, efforts should initially target the development of capabilities at the mid-stream processing stage. While Australia has an established battery minerals industry, its processing capabilities are comparatively less developed. Mid-stream processing is also a natural 'next step' that can be built upon existing minerals capability. It is therefore the area in which policy efforts will generate the greatest return on investment. Recent investments in lithium hydroxide, nickel sulphate and rare earths separation projects indicate the commercial appetite and potential for success. Additionally, Australia will need to take significant steps to decarbonise its operations to be labelled as a producer of "clean" battery materials.

Internationally, government and business should also actively pursue international partnerships with key industry players. Success in global value chains will not be achieved by working alone. Australia will need to integrate itself within existing networks, and ensure its projects are calibrated to the technical and economic requirements of partners. Developing trade, investment and technology links with leading companies in the value chain will be essential to link Australian projects to downstream consumers across the global battery industry.

Appendix

Table 7. Australian policies supporting battery industry development

	Jurisdiction	Title	Agency	Summary	Industry focus/ function	Support type	Battery material coverage	Targeted stage of value chain
1	Cwealth	Future Battery Industry CRC	FBI-CRC	FBI-CRC will provide industry-led research capability to help advance Australia's role in the global battery industries value chain	Battery Industry	R&D	All	All
2	Cwealth	Advanced Manufacturing Early Stage Research Fund	Advanced Manufacturing Growth Centre Ltd	Grant Program to support SMEs in early stages of small-scale development of new technologies and products	Advanced Manufacturing	Grant	All	All
3	Cwealth	Advancing Renewables Program	Australian Renewable Energy Agency	Grant Program to support renewable energy projects	Renewable/Clean Energy	Grant	All	Assembly; Installation
4	Cwealth	CEFC Direct Investments	Clean Energy Finance Corporation	Direct equity & investments for individual projects, both large and small scale	Renewable/Clean Energy	Finance	All	Assembly; Installation
5	Cwealth	CEFC Debt Markets	Clean Energy Finance Corporation	Investment in Australia's green bonds market, accessible for project developers	Renewable/Clean Energy	Finance	All	Assembly; Installation
6	Cwealth	CEFC Innovation Fund	Clean Energy Finance Corporation (CEFC) & Australian Renewable Energy Agency (ARENA)	Specialist finance for early stage clean energy businesses and technologies	Renewable/Clean Energy	Finance	All	Assembly; Installation
7	Cwealth	Linkage Projects Grant	Australian Research Council	Grants for mature research plans in STEM research areas, to coordinate research partnerships	Research Partnerships	Grant	All	All
8	Cwealth	Loans - EFA	Export Finance Australia	Loans from EFA that can be drawn for export-related transactions or setting up overseas	Trade Support	Loan	All	All
	Cwealth	Bonds - EFA	Export Finance Australia	EFA Support in securing bank-issued bond or provision of bond to buyer	Trade Support	Finance	All	All

	Jurisdiction	Title	Agency	Summary	Industry focus/ function	Support type	Battery material coverage	Targeted stage of value chain
10	Cwealth	Guarantees - EFA	Export Finance Australia	Guarantee from EFA to enable further bank finance for export-related transactions or overseas business expansion	Trade Support	Finance	All	All
11	Cwealth	Project & Corporate Finance - EFA	Export Finance Australia	Finance to larger exporters, particularly for engagement in emerging and frontier markets	Trade Support	Finance	All	All
12	Cwealth	Export Market Development Grants (EMDG)	Austrade	Grants to reimburse export promotion expenses	Trade Support	Grant	All	All
13	Cwealth	Major Projects Facilitation	Major Projects Facilitation Agency	Assists strategically significant projects at all stages to provide information on federal approvals	Government Interaction	Facilitation	All	All
14	Cwealth	NAIF Finance	Northern Australia Infrastructure Facility	Provision of fixed interest rate loans for economic infrastructure projects in northern Australia	Infrastructure	Loan	All	All
15	Cwealth	Australia's Critical Minerals Strategy	Department of Industry, Innovation and Science and Department of Foreign Affairs and Trade	Commonwealth strategy to establish Australia as "a world leader in the exploration, extraction, production and processing of critical minerals"	Minerals and Resources	Facilitation	All	Exploration/ Mining; Processing;
16	Cwealth	Critical Minerals Trade and Investment Roadshows	Austrade	International roadshows promoting Australia's critical minerals capacity	Critical Minerals	Facilitation	All	All
17	Cwealth	Australian Critical Minerals Prospectus	Austrade	Prospectus on Australia's geological endowment of critical minerals	Critical Minerals	R&D	All	Exploration/ Mining/ Processing
18	Cwealth	CRC Optimising Resource Extraction (CRC ORE)	CRC ORE	CRC ORE is engaged in research to develop technology to allow lower-grade ores to be economically and efficiently mined	Research Partnerships	R&D	All	Exploration/ Mining/ Processing
19	Cwealth	National Resources Statement	Department of Industry, Innovation and Science	Statement on the Commonwealth Government's key goals for the resource sector	Minerals and Resources	Facilitation	All	Exploration/ Mining/ Processing

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	Jurisdiction	Title	Agency	Summary	Industry focus/ function	Support type	Battery material coverage	Targeted stage of value chain
20	Cwealth	Exploring for the Future Initiative	Geoscience Australia	Investment to further explore parts of Australia for minerals, energy and groundwater (minerals across the whole of Northern Australia)	Exploration Support	Facilitation	All	Exploration
21	Cwealth	MinEx CRC	MinEx CRC	Promoting government-business-academic research collaborations in minerals exploration	Research Partnerships	R&D	All	Exploration
22	Cwealth	The Lithium-Ion Battery Value Chain	Austrade	Identifies Australia's potential to participate in the lithium and battery value chain	Battery Industry	R&D	All	All
23	Cwealth	Mineral Resources	Commonwealth Science and Industrial Research Organisation (CSIRO)	CSIRO Mineral Resources partners with companies to provide solutions for mineral discovery and processing	Minerals and Resources	R&D	All	Exploration/ Mining/ Processing
24	Cwealth	R&D Tax Incentive	Innovation and Science Australia; Australian Tax Office	Tax offset for some of a company's cost of doing eligible R&D activities	Research and Development	R&D	All	All
25	Cwealth	Critical Minerals in Australia: A Review of Opportunities and Research Needs	Geoscience Australia	Review of critical minerals opportunities and research needs	Critical Minerals	Facilitation	All	Exploration/ Mining/ Processing
26	Cth-State	National Mineral Exploration Strategy	Australia Minerals	Coordinated Cth-State Strategy to drive mineral exploration across the country	Exploration Support	Facilitation	All	Exploration
27	Cth-State	Australia Minerals	Australia Minerals	Collaboration among Cth and State geoscience agencies and Chief Geologists to increase exploration	Exploration Support	R&D	All	Exploration
28	Cth-State	Critical Minerals Work Program	COAG Energy Council	To be developed - Outcome of the inaugural Resources Meeting @ COAG	Critical Minerals	Facilitation	TBD	All
29	Cth-State	Strategic Resources Advisory Group	COAG Energy Council	To be developed - Outcome of the inaugural Resources Meeting @ COAG	Critical Minerals	Facilitation	TBD	All
30	NSW	Competing Globally: NSW Trade and Investment Action Plan 2017-18	Department of Premier and Cabinet; Department of Industry	NSW trade expansion policy statement, including minerals and resources sector	Trade Support	Facilitation	Cobalt, Lithium, Nickel, Rare Earths	All

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	Jurisdiction	Title	Agency	Summary	Industry focus/ function	Support type	Battery material coverage	Targeted stage of value chain
31	NSW	NSW Minerals Strategy	Department of Industry, Innovation and Science	Strategy focused on advancing NSW minining industry, includes prospects for developing processing industries	Minerals and Resources; Critical Minerals	Facilitation	Cobalt, Lithium, Nickel, Rare Earths	Exploration/ Mining/ Processing
32	NSW	Geophysical Surveys and State Mapping	Geological Survey of New South Wales (GSNSW)	Enhanced Geological Survey activity to map NSW	Exploration Support	R&D	All	Exploration
33	NSW	New Frontiers Cooperative Drilling Program	Geological Survey of New South Wales (GSNSW)	Grants to fund 50%, 75% or 100% of drilling for individual projects	Exploration Support	Grant	Cobalt, Lithium, Nickel, Rare Earths	Exploration
34	NT	The Territory critical minerals plan	Department of Trade, Business and Innovation	Three-point plan to accelerate exploration, support projects and grow refining and processing activity of CM in the Territory	Critical Minerals	Facilitation	Cobalt, Lithium, Rare Earths, Vanadium	Exploration/ Mining/ Processing
35	NT	Resourcing the Territory Initiative	Department of Primary Industry and Resources	Four-year strategy including a range of initiatives to support the NT's resources sector	Minerals and Resources	Facilitation	All	Exploration/ Mining/ Processing
36	NT	Geophysical Surveys and Territory Mapping	Northern Territory Geological Survey (NTGS)	NT's Premier geoscience agency	Minerals and Resources	R&D	All	Exploration
37	NT	Geophysics and Drilling Collaborations	Department of Primary Industry and Resources	Co-funding for select new exploration, especially unexplored areas and/or through use of innovative exploration tools	Exploration Support	Grant	All	Exploration
38	NT	International Minerals and Energy Investment Attraction Program	Department of Primary Industry and Resources	Assists NT explorers to secure investment from overseas; including bilingual publication of prospectus' summaries	Minerals and Resources	Facilitation	All	Exploration
39	NT	Major Project Status	Department of Trade, Business and Innovation	For certified major projects, coordinated support is provided to engage both the NT and Cth Government	Government Interaction	Facilitation	All	All
40	NT	International engagement, trade and investment strategic plan 2018 to 2021	Department of Trade, Business and Innovation	NT trade expansion policy statement, including minerals and resources sector	Trade Support	Facilitation	All	All

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	Jurisdiction	Title	Agency	Summary	Industry focus/ function	Support type	Battery material coverage	Targeted stage of value chain
41	QLD	Collaborative Exploration Initiative	Department of Natural Resources, Mines and Energy	Supports mineral exploration in under-explored areas	Exploration Support	Grant	All	Exploration
42	QLD	Department of Natural Resources, Mines and Energy Strategic Plan 2019-2023	Department of Natural Resources, Mines and Energy	Overarching strategic plan to sustainably maximise the use of QLD's resources	Minerals and Resources	Facilitation	All	Exploration/ Mining/ Processing
43	QLD	A Strategic Blueprint for Queensland's North West Minerals Province	North West Minerals Province Taskforce	Overarching strategy and actions to further development of QLD's North West Minerals Province, including a focus on rare earths	Minerals and Resources	Facilitation	All	Exploration/ Mining/ Processing
44	QLD	Geophysical Surveys and State Mapping	Geological Survey of Queensland	Enhanced Geological Survey activity to map the NWM Province	Exploration Support	R&D	All	Exploration
45	QLD	Strategic Resources Exploration Program	Department of Natural Resources, Mines and Energy; Geological Survey of Queensland	Programs to boost exploration and support for resource development projects	Exploration Support	Facilitation	All	Exploration
46	QLD	North West Queensland Economic Diversification Strategy	Department of State Development, Manufacturing, Infrastructure and Planning;	NW Economic Plan - Including 'develop a technology minerals industry supporting secondary prospectivity'	Minerals and Resources; Other Industry	Facilitation	All	Exploration/ Mining/ Processing
47	QLD	Industry Case Managers	Department of State Development, Manufacturing, Infrastructure and Planning	One-stop-shop to streamline approvals and regulatory processes on major projects	Government Interaction	Facilitation	All	All
48	QLD	Queensland Trade and Investment Strategy 2017-2022	Trade and Invest Queensland	Trade and Investment strategy, with a focus on resources sector	Trade Support	Facilitation	All	All
49	SA	Accelerated Discovery Fund	Department of Energy and Mining	Co-funding for greenfield exploration activity	Exploration Support	Grant	Cobalt, Graphite, Nickel, Rare Earths	Exploration
50	SA	Case Management of major mineral projects	Department of Energy and Mining	Coordinated support through regulatory approvals process	Government Interaction	Facilitation	Cobalt, Graphite, Nickel, Rare Earths	Exploration/ Mining/ Processing

	Jurisdiction	Title	Agency	Summary	Industry focus/ function	Support type	Battery material coverage	Targeted stage of value chain
51	SA	Geophysical Surveys and State Mapping	Geological Survey of South Australia	SA's geoscience agency	Minerals and Resources	R&D	Cobalt, Graphite, Nickel, Rare Earths	Exploration
52	SA	New Horizons: South Australia's Investment and Trade Statement 2018	Department of Premier and Cabinet; Department of Trade, Tourism and Investment	SA trade expansion policy statement, including minerals and resources sector	Trade Support	Facilitation	Cobalt, Graphite, Nickel, Rare Earths	All
53	Tas	Tasmanian Trade Strategy 2019-2025	Department of State Growth	Tasmanian trade and investment strategy, including minerals and resources trade	Trade Support	Facilitation	All	All
54	Tas	Exploration Drilling Grant Initiative	Mineral Resources Tasmania	Co-funded grants for exploration drilling projects, particularly for greenfield projects	Exploration Support	Grant	All	Exploration
55	Tas	Geophysical Surveys and State Mapping	Mineral Resources Tasmania	Geological Survey activity to map Tasmania	Exploration Support	R&D	All	Exploration
56	WA	Future Battery Industry Strategy	Department of Jobs, Tourism, Science and Innovation	WA Strategy to grow the state's production and export of battery quality materials, & enhance the state's processing assets	Battery Industry	Facilitation	All	All
57	WA	Exploration Incentive Scheme (EIS)	Geological Survey of Western Australia	EIS supports a range of programs to encourage exploration in WA, including the Co-funded Innovative Drilling Program & targeted drilling programs	Exploration Support	Grant	All	Exploration
58	WA	Co-funded Innovative Drilling Program	Geological Survey of Western Australia	Grants for a 50% refund for innovative exploration drilling projects	Exploration Support	Grant	All	Exploration
59	WA	Geophysical Surveys and State Mapping	Geological Survey of Western Australia	Free provision of sophisticated mapping of the State of WA	Minerals and Resources	R&D	All	Exploration
60	WA	Minerals Research Institute of Western Australia (MRIWA) Grants	Minerals Research Institute of Western Australia (MRIWA)	MRIWA primary function is to provide and administer grants to carry out minerals research	Minerals and Resources	R&D	All	Exploration/ Mining/ Processing

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	Jurisdiction	Title	Agency	Summary	Industry focus/ function	Support type	Battery material coverage	Targeted stage of value chain
61	WA	Lithium feedstock royalty amendment	Department of Mines, Industry Regulation and Safety	5% lithium royalty to apply to "first product sold" (spodumene concentrate, carbonate or hydroxide), to provide taxation clarity for lithium processing investors.	Battery Industry	Tax reform	Lithium	Processing
62	VIC	State Of Discovery: Mineral Resources Strategy 2018-2023	Department of Jobs, Precincts and Regions	Department of Jobs, Precincts and Regions	Minerals and Resources	Facilitation	All	All
63	VIC	Extractive Resources Strategy	Department of Jobs, Precincts and Regions	Department of Jobs, Precincts and Regions	Minerals and Resources	Facilitation	All	Exploration/ Mining/ Processing
64	VIC	Geophysical Surveys and State Mapping	Geological Survey of Victoria	Department of Jobs, Precincts and Regions	Exploration Support	Facilitation	All	Exploration
65	VIC	Base Metals Victoria: An Emerging Base Metal Province	Department of Jobs, Precincts and Regions	Department of Jobs, Precincts and Regions	Minerals and Resources	Facilitation	All	Exploration/ Mining/ Processing
66	VIC	Metallic Minerals in Victoria: Tantalum, Niobium and Lithium	Department of Jobs, Precincts and Regions	Department of Jobs, Precincts and Regions	Minerals and Resources	Facilitation	Lithium	Exploration/ Mining/ Processing
67	VIC	TARGET	Department of Jobs, Precincts and Regions	Department of Jobs, Precincts and Regions	Exploration Support	Grant	All	Exploration

Source: Author's compilation, from Australian government agency websites, as of December 2019. TDB indicates specific policy details to be determined.

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About the Future Battery Industries Cooperative Research Centre

FBICRC is an independent centre where industry, government and researchers can come together to create the tools, technologies and skills to grow the role of battery storage in Australia's electricity grids, and make Australia a larger player in global battery value chains. Australian minerals are critical to the global battery technology revolution. Our resources, thinking, innovation and expertise will enable us to seize this once in a generation, national opportunity to develop the next wave of battery industries.

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Endnotes

1 Production of natural graphite has declined in recent years as synthetic graphite manufacturing has increased to commercial scale. However, overall graphite demand remains strong.

2 United States Geological Survey (various years), *Mineral Commodity Summaries*, https://www.usgs.gov/centers/nmic/mineral-commodity-summaries

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8 Marcelo Azevedo et al. (2018), 'Lithium and Cobalt: A Tale of Two Commodities', McKinsey & Company Metals and Mining, https://www.mckinsey.com/industries/metals-and-mining/our-insights/lithium-and-cobalt-a-tale-of-two-commodities

9 The West Australian (2017), 'Lithium Australia produces 99.8% Li20 from uneconomic ore', 12 May.

10 Advanced Rechargeable & Lithium Batteries Association (2018), *The Batteries Report* 2018, https://rechargebatteries.org/

11 S&P Global Market Intelligence (2019), *Essential Insights: Lithium Costs & Margins*, https://pages.marketintelligence.spglobal.com/Lithium-brine-vs-hard-rock-demo-confirmation-MJ-ad.html

12 The seven major nickel suppliers are Indonesia, the Philippines, New Caledonia, Russia, Australia, Canada and China.

13 Author's calculations from United States Geological Survey (various years), *Mineral Commodity Summaries*.

14 United States Geological Survey (various years), *Mineral Commodity Summaries*.

15 Xin Sun et al. (2017), 'Tracing global lithium flow: a trade-linked material flow analysis', *Resources, Conservation and Recycling*, 124: 50-61.

16 Author's calculations, from British Geological Survey (2019), *World Mineral Production 2013-17*, Keyworth: British Geological Survey.

17 Chilean lithium hydroxide production is largely from SQM's Salar de Carmen plant.

18 Xin Sun et al. (2017), 'Tracing global lithium flow: a trade-linked material flow analysis', *Resources, Conservation and Recycling*, 124: 50-61, Figure 5.

19 *Supra* note 18.

20 *Supra* note 18.

21 Adrian Griffin (2019), *Closing the Loop on the Energy Metal Life Cycle*, https://lithium-au.com/wp-content/uploads/2016/11/15052019-Lithium-Australia-121-Singapore-conference-presentation.pdf.

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25 See US National Academies of Science (2009), *Minerals, Critical Materials and the US Economy*, Washington, D.C.: The National Academies Press.

26 Criticality studies for specific countries are as follows: European Commission (2017), 'List of Critical Raw Materials for the EU', No. COM(2017)/490, https://ec.europa.eu/transparency/regdoc/rep/1/2017/EN/COM-2017-490-F1-EN-MAIN-PART-1.PDF; Department of Energy (US) (2011), *Critical Materials Strategy 2011*, https://www.energy.gov/sites/prod/files/DOE_CMS2011_FINAL_Full.pdf; Geosciences Australia (2013), *Critical commodities for a high-tech world: Australia's potential to supply global demand*, Canberra: Geosciences Australia; Hiroki Hatayama and Kiyotaka Tahara (2015), 'Criticality Assessment of Metals for Japan's Resource Strategy', *Materials Transactions*, 56(2): 229-235; Department of Science and Technology (India) & Council on Energy Water and Environment (India), C*ritical Non-Fuel Mineral Resources for India's Manufacturing Sector: A Vision for 2030, New Delhi: CEEW*

27 The union list of the thirty commodities identified in the policies listed at note 26 is: Antimony, Baryte, Beryllium, Bismuth, Chromium, Cobalt, Fluorspar, Gallium, Germanium, Helium, Indium, Lithium, Magnesium, Manganese, Molybdenum, Natural Graphite, Nickel, Niobium, Phosphate Rock, Platinum Group Metals, Rare Earth Minerals, Selenium, Silicon Metal, Tantalum, Tin, Titanium, Tungsten, Vanadium, Zinc, Zirconium.

28 The Australia, Japanese and Indian governments have officially identified all six battery minerals as critical materials in their respective criticality assessments. However, the US government omits cobalt and nickel, and the EU lithium and nickel. See note 26.

29 Author's calculations, from United Nations Statistics Division, *UN Comtrade Database*, https://comtrade.un.org/

30 Australian Trade and Investment Commission (2018), *The Lithium-ion Battery Value Chain: New Economy Opportunities for Australia*, p. 30.

31 *Supra* note 16.

32 At present, only one non-Chinese company – Australia's Lynas Corporation – supplies a separated rare earth oxide (Nd-Pr) product at commercial scale. However, as Nd-Pr is used for permanent magnets in EV motors, it is not strictly a part of the battery value chain. All other rare earth producers supply mixed oxide products, which require further separation by Chinese refineries.

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