Lithium

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Lithium, hydrogen and helium were the three key elements produced in the big bang.

Lithium is the lightest and densest metal, and has huge potential for power generation.

Lithium’s unique properties make it vital for emerging technology such as electric vehicles.

Australia has 17% of the world’s lithium and is the world’s biggest exporter.

Australian lithium exports tripled to be worth $780 million in 2017.

Global electric vehicle sales are expected to increase from 2 million to 50 million by 2030.

Major Australian Lithium deposits

Global uses of Lithium

- 46% Rechargeable batteries
- 26% Ceramics & glass
- 11% Greases & polymers
- 11% Other uses
- 4% Industrial powders
- 2% Air treatments
15.1 Summary

- Lithium has recently begun to draw significant global interest. Demand for lithium has risen sharply, with prices tripling since 2010.
- Global lithium use has risen from around 149,000 tonnes in 2012 to 211,000 tonnes in 2017 (in lithium carbonate equivalent [LCE] terms). Global use is expected to reach almost 1.3 million tonnes by 2027, driven by rising demand for lithium batteries in electric vehicles.
- Australian exports of spodumene ore (the precursor material for lithium) have risen from around $117 million in 2012 to $780 million in 2017, and are expected to rise to around $1.1 billion by 2020. Far greater value could be unlocked should Australia progress in refining these ores into more valuable forms of lithium.

15.2 The forms and uses of lithium

A new market has emerged for a previously marginal commodity

Lithium is the lightest, or least dense, elemental metal, being about half as dense as water. It lacks the strength and durability of steel, but has traditionally found a role in the production of ceramics, glass, greases, steel making, aluminium smelting, as well as air treatment and polymer production, as Figure 15.1 shows.

It has long been known that lithium has very high electrode potential — lithium ion batteries can generate almost 50 per cent more volts per cell than lead-acid batteries. However, it was not until the development of smart-phones and other portable devices that this attribute of lithium was fully harnessed. By 2007, lithium-ion batteries accounted for around 25 per cent of all lithium use. Growth in battery use subsequently slowed for a time, but is now beginning to surge again.

The rise is driven largely by electric vehicles, which are rapidly growing as a proportion of global vehicle sales, becoming a serious alternative to traditional internal combustion engine vehicles (see Figures 15.2 and 15.3).
The rapid take-up of electric vehicles reflects several important advantages. Electric vehicles require no fuel and have fewer moving parts than traditional petrol vehicles, resulting in significantly lower maintenance and running costs over a vehicle lifetime. They do not emit pollution, and can be powered from carbon-free sources. In the future, they are likely to be easier to upgrade and customise. Drawbacks primarily relate to the higher initial purchase cost and battery range. However, significant progress has recently been made on these fronts, with costs falling and range rising rapidly as technology improves.

Electric vehicle sales doubled in 2017 and are set to keep growing strongly, albeit unevenly across countries. Electric vehicles already account for one-third of all vehicle sales in Norway, and have become substantial also in Denmark and in other countries where incentives exist.

Electric vehicle growth is likely to ease slightly in the near-term as China (the largest market) tapers back government support for some light electric vehicles. However, in general terms, the dependence of the technology on government incentives around the world is now starting to recede. Crucial price points are likely to be crossed in the early 2020s, with electric vehicles expected to become fully price competitive with petrol vehicles by around 2023. Electric vehicle production is expected to increase exponentially over the next 10 years, rising from around 2 million vehicle sales in 2017 to more than 40 million sales by 2027.

There are signs of hitches emerging on the supply side. Tesla — the most high profile producer of electric vehicles — is currently failing to meet production timetables as a result of technical issues in its fabrication plants. These issues reflect, in part, the complexity of building a car manufacturing process from scratch: other vehicle makers are currently adapting existing processes relatively smoothly, and the scale of announced plans makes it clear that a massive surge in electric vehicle (and hence lithium) demand is expected in coming years, especially when the crucial price crossover step is reached.

Electric vehicles require large batteries, and rising sales are expected to create huge markets for battery-grade lithium over the next 10 years.

**Figure 15.3: Planned phase-outs of internal combustion engine (ICE) vehicles**

<table>
<thead>
<tr>
<th>Country</th>
<th>Term</th>
<th>Scope</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>n/a</td>
<td>Ban of ICEs</td>
<td>High</td>
</tr>
<tr>
<td>Denmark</td>
<td>2050</td>
<td>Vehicle CO2 Targets</td>
<td>Medium</td>
</tr>
<tr>
<td>France</td>
<td>2040</td>
<td>Ban of ICEs; Paris by 2030</td>
<td>Medium</td>
</tr>
<tr>
<td>Germany</td>
<td>2030</td>
<td>Ban of ICEs</td>
<td>Medium</td>
</tr>
<tr>
<td>India</td>
<td>2030</td>
<td>Ban of ICEs</td>
<td>Low</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2030</td>
<td>Ban of ICEs</td>
<td>High</td>
</tr>
<tr>
<td>Norway</td>
<td>2025</td>
<td>Ban of ICEs</td>
<td>High</td>
</tr>
<tr>
<td>South Korea</td>
<td>2020</td>
<td>Electric vehicle target - 250,000 (30% market share 2017-2020)</td>
<td>High</td>
</tr>
<tr>
<td>Spain</td>
<td>2020</td>
<td>Ban of ICEs in Madrid centre (car models pre-2000)</td>
<td>High</td>
</tr>
<tr>
<td>Sweden</td>
<td>2030</td>
<td>Ban of ICEs</td>
<td>High</td>
</tr>
<tr>
<td>UK</td>
<td>2040</td>
<td>Ban of ICEs; Scotland by 2032</td>
<td>High</td>
</tr>
<tr>
<td>California</td>
<td>2027-30</td>
<td>Ban of ICEs</td>
<td>High</td>
</tr>
</tbody>
</table>

Global lithium use is expected to grow from around 211,000 tonnes in 2017 (with just under half accounted for by electric vehicles) to 1,265,000 tonnes by 2027 (with almost 90 per cent of use expected to be accounted for by electric vehicles).

**Hard rock deposits have an advantage in the emerging market**

Lithium does not occur naturally in a pure form, and must be refined from other materials. These materials are found in a mix of brine and hard rock deposits. Brine deposits occur when lakes, geothermal waters or petroleum brines are enriched with lithium. These deposits are mainly found in Chile, Argentina and Bolivia, though lower grade brine deposits have also been found in the United States and China (see Figure 15.5).

Lithium also exists in mineral deposits (spodumene or pegmatite). Almost all lithium-rich ore bodies also contain a range of other co-located minerals. Among these, Australia’s Greenbushes mine in Western Australia has the world’s largest developed deposit, though other lithium-rich hard rock deposits also exist in the United States, Mexico, Congo, and Morocco.

Brine deposits produce lithium carbonate — a compound with various industrial and chemical uses (see Figure 15.4) but with a relatively limited use in electric vehicles outside of some cathode material. To create a more suitable material for electric vehicle batteries, lithium carbonate must be refined into lithium hydroxide.

Hard rock deposits such as Australia’s are technically more expensive to extract initially, but have an important advantage in electric vehicle markets: while the initial output is spodumene ore, a relatively simple beneficiation process is applied to transform the ore directly into lithium hydroxide, effectively removing a step from the refining process. This gives Australia — which has large amounts of hard rock deposits — a cost advantage of around 10-15 per cent relative to the largest South American brine producers. This has in turn helped Australia gain an edge in lithium mining (see Figure 15.6).
15.3 Global market conditions

Lithium supply and demand are approaching balance, but prices remain elevated

Rising demand for lithium has placed pressure on every step of the supply chain, with the greatest pressure occurring at the refinement stages. Demand for spodumene ore is rising, but the sheer scale of new output from Australia will likely lead to some degree of oversupply in this market in coming years. It is not expected, however, that oversupply will be severe, and early predictions of sharp falls in spodumene prices have not been borne out. Spodumene prices are instead converging among different markets.

Prices in China — where Australia sells most of its spodumene output — eased to under $US800 per tonne in 2017. However, prices elsewhere in the world continue to rise. As a result, prices are converging towards a global norm. This will likely reduce the bounty of income to Australia to some degree, though any severe decline is likely to be checked as global prices put a floor under Chinese prices.

At $17,000 a tonne, the price of more refined lithium hydroxide is historically strong, but slightly lower than its peak in 2017 (see Figure 15.7). While underlying supply and demand factors have played a part in the recent price surge, some of the recent strength derives from concerns over security of supply. These concerns reflect the fact that supply chains feeding the electric vehicle market are highly complex, and many car manufacturers have released very ambitious production schedules. The need for strong and secure supply in a generally opaque and immature market has led to successive rounds of hasty buying, as electric vehicle makers seek to reduce risks to their production schedules.

Electric vehicle production targets are expected to check any sharp drop in lithium prices. To reduce risk, electric vehicle batteries are generally built well in advance of the cars in which they are placed. Matching lithium production against current electric vehicle demand can thus produce a misleading result. When matched against electric vehicle sales twelve months ahead, spodumene and lithium supplies appear more than
sufficient, but a saturated spodumene market is unlikely. It is thus expected that spodumene ore prices will moderate somewhat over the next two years.

Supply of refined lithium faces more mixed prospects. Lithium carbonate faces relatively minimal bottleneck risks, and may in fact be significantly oversupplied in the coming years. Carbonates have a more limited application to the electric vehicle market, and a lot of brine production is expected to come online in 2020 and 2021 in Chile and Argentina.

Some supply bottlenecks may emerge in early stage lithium hydroxide refining, where spodumene ore from hard rock deposits is beneficiated. However, any bottlenecks at this stage will likely not persist for long. The beneficiating process is relatively simple and many countries (including Australia) are well underway with developing the capacity. Concerns about security of supply have elevated prices for lithium hydroxide somewhat: a modest correction to this is expected in the short term, followed by a return to rising prices as electric vehicle demand gathers pace.

The last stage of refining is likely to be where the greatest demand pressure and potential bottlenecks emerge. Refining lithium hydroxide to produce battery material (including high-grade lithium as well as components such as cathodes) is a complex and energy-intensive process. Developing refineries to produce battery grade material can take up to five years when factoring in approval, development, and construction. However, managing potential bottlenecks at this refining stage will be important to keep electric vehicle prices falling.

The final step in the supply chain is the construction of batteries from high-grade battery materials. Plans for the construction of battery facilities are already well advanced in many countries. A 35GWh (gigawatt hours of batteries) Gigafactory is under construction in Nevada. Germany is progressing plans to build a facility known as Terra-E, with a consortium of 17 companies aiming to construct a 34GWh plant by 2028. Northvolt plans to bring 32GWh of battery construction capacity to Sweden, with construction to start in April 2019. Further plants are under construction in China and other parts of Asia.

With demand for lithium certain to grow, and with large investment underway in each stage of its supply chain, it is expected that lithium use will rise by around 600 per cent over the next 10 years (see Figure 15.8). Lithium use in electric vehicle batteries is expected to grow by a factor of ten, even though improvements in chemistry and efficiency will likely reduce the quantity of lithium in individual batteries. Growth is expected to peak in the early to mid-2020s, tapering after 2030 as electric vehicle sales stabilise. The key risk appears to be the possibility that refineries producing high-grade battery material fail to match the speed of other stages in the refining process, creating potential bottlenecks and price volatility at that step.

Lithium prices are expected to remain well above their historical average, but volatility should reduce in time as lithium markets start to operate with more transparency. Lithium, unlike cobalt, cannot be substituted, and remains crucial to electric vehicle batteries. This means steeply rising demand is effectively locked in. The certainty of rising demand is creating strong conditions for new investment.
15.4 Lithium in Australia

Australia is investing heavily in primary supply and early–stage refining. Australia’s dominance of hard rock deposits grants it several key advantages in the emerging lithium market. Lithium produced from hard rock is more easily refined into lithium hydroxide, which makes it more suitable for supplying electric vehicle markets than the carbonate-based output from brine deposits such as those in South America.

This grants Western Australian hard rock producers a 10-15 per cent cost advantage relative to competitors in Chile and Argentina. Hard rock operations in Western Australia also have capacity to increase output faster, as the investment and capital required for initial extraction is lower. Key mines such as Pilangoora are also benefitting from substantial off-take agreements with China and other countries, which lock in certain minimal levels of demand.

Lithium hydroxide is expected to account for about 25 per cent of all lithium compounds used in batteries by 2021. As electric vehicles increasingly dominate the market, this share is expected to rise to almost 60 per cent over the next ten years. This suggests lithium sourced from Australia has growth potential above even what is suggested by the most optimistic lithium demand projections.

Australian production has traditionally been dominated by the Greenbushes mine — the world’s largest hard rock deposit. However, as Figure 15.9 shows, a succession of new mines and projects is now emerging across Western Australia. This is feeding directly into export value. Earnings for spodumene ore out of Western Australia increased by 166 percent in 2017, to $780 million (see Figure 15.10). The quantity of spodumene produced in Western Australia doubled over the year as a result of output from several large new mines. These include Jiangxi Ganfeng Lithium’s Mount Marion project, and Mineral Resources’ Wodgina project. A third project — Galaxy Resources’ Mt Cattlin mine, which commenced in 2017 — is now approaching its full production capacity.
Spodumene output is forecast to increase sharply again in 2018, as Pilbara Minerals and Altura Mining’s projects at Pilgangoora commence, and Mineral Resources’ Wodgina project ramps up. A further rise in output in 2019 is expected, which would leave Australia accounting for almost 80 per cent of global supply from hard rock deposits.

Substantial investment in new mines is being accompanied by an even larger wave of investment in beneficiation. These plants will create a sizeable body of infrastructure capable of refining huge quantities of raw spodumene into more valuable lithium hydroxide. Five large beneficiating plants are now planned or under construction in Western Australia.

As Figure 15.11 shows, China holds an outsized role in spodumene processing. As a result, many Korean and Japanese firms are supporting Australian beneficiation plants as a means to protect their security of supply and reduce their dependency on Chinese facilities. Such investment holds significant promise for Australia: as Figure 15.12 shows, there are far greater potential earnings in refined lithium than in spodumene ore, and beneficiation plants will start to bring Australia into that market.

A significant beneficiation plant is under construction is at Greenbushes, where Talison Lithium supplies about one-third of the world’s lithium. Talison’s parent company — Tianqi Lithium — is building a new refinery facility in two stages, each with capacity to produce 24,000 tonnes of lithium hydroxide. The plant is on schedule for completion in June quarter 2019, and is expected to offer significant logistical benefits to the company, due to its location near the mine.

Output from this facility and the associated mine could rise in the future, with the firm considering adding two further processing plants, a new crusher, a larger tailings dam and an increased power supply. The total cost for this investment is around $700 million, with $400 million already committed and a subsequent $300 million mooted for the second stage.
Albermarle is building a similar plant at Kemerton in Western Australia, which will have capacity to produce 100,000 tonnes of lithium hydroxide a year by 2025.

Kidman, which owns a site at Kwinana in Western Australia, is also planning to construct a plant, with annual nameplate capacity of 44,000 tonnes of lithium hydroxide. A joint venture between Kidman and Chile’s SQM (called WA Lithium) has contracted to supply Tesla with lithium hydroxide from a Kwinana refinery. Operations are expected to begin in 2021, with the project forecast to create 400 construction jobs and 150 ongoing jobs.

Neometals are also seeking a partner for the proposed plant at Kalgoorlie in Western Australia, which will cost around $200 million and produce 10,000 tonnes of lithium hydroxide annually. The facility is intended to draw on spodumene from the company’s Mount Marion mine.

Finally, Mineral Resources is planning a facility near Port Hedland in Western Australia, which would be capable of producing up to 50,000 tonnes of lithium hydroxide per year.

<table>
<thead>
<tr>
<th>Owner</th>
<th>Lithium hydroxide output (tonnes)</th>
<th>Commencing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albermarle</td>
<td>100,000</td>
<td>After 2022</td>
</tr>
<tr>
<td>Mineral Resources</td>
<td>50,000</td>
<td>After 2022</td>
</tr>
<tr>
<td>Talison Lithium</td>
<td>48,000</td>
<td>After 2019</td>
</tr>
<tr>
<td>Kidman</td>
<td>44,000</td>
<td>2021</td>
</tr>
<tr>
<td>Neometals</td>
<td>10,000</td>
<td>After 2022</td>
</tr>
</tbody>
</table>

This investment pipeline will ensure that Australia shifts rapidly beyond the first stage of primary production, becoming a refiner of significant scale by the early 2020s. More than $3 billion is committed to the development of facilities that will supply lithium hydroxide to the electric vehicle market, and the number of full-time workers on lithium projects in Western Australia has increased from 399 in December 2014 to more than 2600, with thousands more to come.

Lithium royalties are also rising sharply. Royalties for non-iron ore commodities in Western Australia are set to rise to $834 million in 2017-18. Lithium is expected to earn around $131 million of this, with lithium royalties set to rise by $41 million over the year. This will see lithium surge past nickel, copper and alumina to become the third biggest royalty earner (behind iron ore and gold) for Western Australia in 2018-19.

**Australia has potential to move further up the value chain**

Although Australia is currently gaining considerable income from the production of spodumene, over the long term it is likely that this form of output will account for only 0.7% of the potential value of the lithium supply chain. Australia is already moving beyond this, however, due to its substantial investments in facilities to produce lithium hydroxide.

While Australia has clear advantages in early-stage refining (due to the scale of its spodumene supply and the desire of many international firms to reduce their dependence on Chinese refineries), later-stage refining is likely to be better distributed globally. The opportunities around high-level refining (transformation of lithium hydroxide into high-grade precursor chemicals and battery parts such as cathodes) are likely to be particularly significant, and Australia holds several significant advantages in entering this market.

Australia holds a distinct geological benefit when compared to potential alternatives. Electric vehicle batteries and other large-scale energy storage devices require around 35 raw materials, and all are readily available in Western Australia. Refineries in Western Australia would have access to world class port facilities, with a new port opening soon in Kwinana. Kwinana also has pre-existing facilities for chemical production and supply, which would simplify the supply chain for advanced refining processes. Western Australia also has relatively low energy costs and reliable gas supplies.
While high-grade refining facilities will be expensive and slow to construct, it is likely that they will generate considerable value over time. Supply bottlenecks (and potential opportunities for filling niche markets) are likely to create particularly lucrative opportunities for high-level refineries in an era of rapid technological change.

However, some issues need to be addressed in order to improve the prospects for large investments. Lithium markets are evolving rapidly, and long-term investment may depend, in part, on the ability to quickly obtain skilled workers when and where they are needed.

Important research is currently underway among firms in Western Australia in areas such as cathode development, which may prove highly beneficial to long-term efforts to build a high-end refining industry in Australia. Australia also faces relatively high construction costs relative to places like Sichuan, where Chinese competition is likely to emerge. While other advantages in logistics and raw material supply may offset this, expedited approvals (or pre-approvals for specified sites in existing industrial hubs) may provide an important competitive edge for lithium refining in Australia.

A relatively small number of firms hold patents over the pivotal technologies, and such firms would need to be approached to ascertain what incentives might draw them to Western Australia.

Although high-grade refining would present many opportunities to Australia, a further opportunity also exists. As noted previously, a number of countries are already constructing facilities which will transform high grade material into batteries. Australia’s prospects for entry into this market are mixed. Australia would likely need to be strongly established at all previous stages of the supply chain in order to position itself for battery production.

This is partly for logistical reasons: if high-grade battery materials were not produced here, they would have to be imported, with the batteries subsequently exported to offshore electric vehicle producers. This would add considerably to logistical costs, given batteries are large, heavy, and relatively fragile. Electric vehicle firms are already demonstrating a preference for building battery facilities directly connected (or sited very close) to electric vehicle assembly plants.

Battery production would thus depend heavily on the existence of high-grade refineries in Australia. The presence of an electric vehicle assembly plant in Australia would also boost the chances for a connected battery facility, though such a development would likely be contingent on a successful expansion of electric vehicles onto Australia’s roads.

Policy will play an important role in the immediate future

Australia has strong potential to move to the centre of the global lithium supply chain given its geological advantages, its experience in rolling out mining investment, and the skills of its workforce. It is unlikely, however, that Australia will move into battery assembly straight away. The core question at this moment is whether Australia can become a destination for high-grade lithium refining.

Various factors will need to be considered, such as site pre-approvals, research and development, and access to skilled workers. Given the pace of change and efforts now underway to solidify the supply chain, it is likely that key decisions around the future of lithium in Australia will need to be made within the next few months. Countries which capitalise on the opportunities of the emerging global lithium market could earn hundreds of billions of dollars in coming decades, and could play a pivotal role in fostering a new wave of clean energy technology around the world.
### Table 15.1: Lithium outlook

<table>
<thead>
<tr>
<th>World</th>
<th>Unit</th>
<th>2017</th>
<th>2018(^f)</th>
<th>2019(^f)</th>
<th>2020(^f)</th>
<th>Annual percentage change</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lithium production</strong> (^a)</td>
<td>kt</td>
<td>366</td>
<td>384</td>
<td>403</td>
<td>411</td>
<td></td>
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<tr>
<td><strong>Consumption</strong></td>
<td>kt</td>
<td>211</td>
<td>234</td>
<td>264</td>
<td>305</td>
<td></td>
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<tr>
<td><strong>Stocks</strong></td>
<td>kt</td>
<td>383</td>
<td>533</td>
<td>672</td>
<td>778</td>
<td></td>
</tr>
<tr>
<td>– weeks of consumption</td>
<td></td>
<td>94.4</td>
<td>118.6</td>
<td>132.2</td>
<td>132.6</td>
<td>25.7</td>
</tr>
</tbody>
</table>

#### Spodumene price

- nominal
  - US$/t
    - 2017: 739
    - 2018: 850
    - 2019: 824
    - 2020: 735
    - 2018\(^f\): 15.0
    - 2019\(^f\): -3.1
    - 2020\(^f\): -10.8

- real \(^b\)
  - US$/t
    - 2017: 756
    - 2018: 850
    - 2019: 807
    - 2020: 707
    - 2018\(^f\): 12.5
    - 2019\(^f\): -5.0
    - 2020\(^f\): -12.5

#### Lithium hydroxide price

- nominal
  - US$/t
    - 2017: 17,540
    - 2018: 16,500
    - 2019: 16,000
    - 2020: 12,000
    - 2018\(^f\): -5.9
    - 2019\(^f\): -3.0
    - 2020\(^f\): -25.0

- real \(^b\)
  - US$/t
    - 2017: 17,934
    - 2018: 16,500
    - 2019: 15,679
    - 2020: 11,540
    - 2018\(^f\): -8.0
    - 2019\(^f\): -5.0
    - 2020\(^f\): -26.4

#### Australia

<table>
<thead>
<tr>
<th>Unit</th>
<th>2017</th>
<th>2018(^f)</th>
<th>2019(^f)</th>
<th>2020(^f)</th>
<th>Annual percentage change</th>
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<tbody>
<tr>
<td><strong>Mine production</strong> (^a)</td>
<td>kt</td>
<td>211</td>
<td>247</td>
<td>295</td>
<td>301</td>
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<tr>
<td><strong>Export volume</strong> (^c)</td>
<td>kt</td>
<td>1037</td>
<td>1212</td>
<td>1448</td>
<td>1477</td>
</tr>
<tr>
<td>– nominal value (^a)</td>
<td>A$m</td>
<td>780</td>
<td>1030</td>
<td>1193</td>
<td>1086</td>
</tr>
<tr>
<td>– real value (^bs)</td>
<td>A$m</td>
<td>798</td>
<td>1030</td>
<td>1169</td>
<td>1044</td>
</tr>
</tbody>
</table>

Notes: \(^a\) Lithium Carbonate Equivalent. This is a measure of the quantity of refined product produced from spodumene ore. \(^b\) In 2018 calendar year US dollars; \(^c\) Spodumene concentrates; \(^s\) Estimate; \(^f\) Forecast.

Sources: Department of Industry, Innovation and Science (2018); Company reports; Roskill (2018); Government of Western Australia Department of Mines, Industry Regulation and Safety (2018)