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BRILLIANT KNOWLEDGE

LITHIUM'S ADOLESCENCE

Still an early-stage growth story

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EDISON

Lithium's adolescence

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Edison themes

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The short-term cycle in lithium is, and will continue to be, volatile, but the longer-term challenge is to build an industry of fundamentally different scale than its current form that should underpin long-term lithium prices. We estimate that over US$50bn of investment will be needed to boost supply to 4–5x current levels by 2030. We are raising our near-term lithium prices to reflect the current supply/demand cycle and raising our long-run (post 2031) price forecasts (from US$17,000/t to US$22,500/t LCE) to reflect lithium's high demand growth and highly concentrated supply fundamentals.

Strong long-term demand fundamentals

Lithium is a solid long-term structural growth story, reflecting its use in electric vehicle (EV) batteries and other energy storage applications linked to grid decarbonization. We see demand growing at a 20.3% CAGR from 2022 to 2030, which is exceptionally high in commodity and chemical markets. Our estimates point to lithium demand in 2030 of approximately 3Mt, broadly in line with industry and International Energy Agency (IEA) projections and 4–5x current levels. At a typical capital intensity of US$25,000/t (according to our review of public project plans), we estimate that the 2.1Mtpa of additional capacity by 2030 will require US$52.5bn of investment. This is both a financing and a technical challenge in this timeframe. Supply chain security and the decarbonization of critical minerals supply chains mean a wide variety of new entrants will be needed.

Supply constraints to support prices

We (like much of consensus) see a potential acceleration in supply over the next three years as both greenfield and brownfield expansions come online. But delays also need to be factored in (commissioning delays, general disruption and pre-qualification of product). Our cyclical supply/demand forecast indicates a significant supply shortfall based on committed expansions opening up in the late 2020s (0.5Mt in 2027), which is a relatively short runway for uncommitted projects to be funded, approved and built. We include a detailed review of the latest published capex and opex projections for a wide range of potential projects in this review.

Raising our price forecasts

We raise our long-term price lithium carbonate price from US$17,000/t to US$22,500/t to reflect wider industry inflation and our view of persistent deficits. This is well below current spot prices (c US$70,000/t) but we do not see prices falling to this level in the 2020s and only allow for long-term pricing in the 2030s onwards. Even then, we question if conventional long-term price methodology works well in markets that are high growth and highly consolidated, as persistent deficits will leave prices closer to substitution levels for periods of time.

Lithium equities have performed strongly over the past two to three years, mirroring lithium prices. We like both existing producers with cash flows and emerging producers with high-quality projects. Lithium fits two of our current global themes, namely **energy transition** and **critical materials**, and we see continued government support for new entrants along the value chain.

Edison themes

As one of the largest issuer-sponsored research firms, we are known for our bottom-up work on individual stocks. However, our thinking does not stop at the company level. Through our regular dialogue with management teams and investors, we consider the broad themes related to the companies we follow. Edison themes aims to identify the big issues likely to shape company strategy and portfolios in the years ahead.

Companies mentioned in this report

Albemarle
Allkem*
Atlantic Lithium
AVZ
Bacanora
CleanTech Lithium
Core Lithium
EMH
Firefinch
Galan Lithium
Ganfeng Lithium
Ioneer
Keliber (private)
Lake Resources
Leo Lithium
Lepidico*
Liontown Resources
Lithium Americas
Lithium Power International*
Lithium South
Livent
Mineral Resources
Neo Lithium
Piedmont Lithium
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Key conclusions

This report includes a review of both long-run and short-term lithium prices. For long-run prices, we have surveyed available public data on new greenfield and brownfield projects to check timing, capital intensity and potential operating costs and also considered the supply challenge through to the end of the 2020s. Our short-run forecast is constructed on both an unrisked and risked basis, the latter allowing for a range of delays that could affect advertised project ramp-up schedules. The next 12–24 months are particularly uncertain given questions over the timing of supply additions, but the longer-term need for additional greenfield and brownfield expansion capacity is clear.

Our key conclusions include:

- **We raise our long-run prices from US$17,000/t to US$22,500/t** lithium carbonate equivalent (LCE) to reflect the significant need for additional production capacity in the late 2020s. This is well below spot (c US$70,000/t), but we do not expect prices to move towards long-term pricing until post 2030 and also question if traditional long-term pricing methodology works well in high-growth industries. We argue that a significant premium is required to a traditional incentive price because of rapid demand growth (c 20% CAGR 2022–30, which is unusually high and probably unprecedented for a commodity industry). A multiple of traditional incentive prices is also not unprecedented in highly concentrated industries (iron ore has traded at approximately double incentive prices for large incumbent producers for the past decade and copper trades at 3–4x what were thought of as incentive prices as recently as the mid-2000s).
- **Our demand analysis indicates lithium demand growing at a 20% CAGR through to 2030**, boosting demand to 3Mt by 2030, up 4–5x from current levels.
- **We raise our short-term price forecasts to reflect recent price moves, and acknowledge near-term uncertainty.** We project a potential supply/demand surplus on an unrisked basis in 2023, but a more balanced market once potential risks are incorporated (including technical risks, commissioning risks and other general delays). Short-term price momentum may dominate sentiment, but the longer-term need for additional capital spending is the core theme underlying lithium for the 2020s.

Long-term prices driven by underlying demand growth

The conventional approach in commodity market analysis is to construct a long-term price forecast on the basis of incentive prices (ie prices that will return an adequate return on capital at known operating and capital costs). We perform this analysis below, but highlight why this method, which has its origins in slow-growing minerals markets, has its limitations when applied to lithium.

In the longer term, several factors are likely to come into play. At the bottom end of price expectations, incentive prices provide some guide, and we review capital and operating costs of known projects in this note (see section ‘Project economics comparison’ below). In summary, the **cash production costs** for these proposed projects are typically indicated at c US$3,000–4,000/t (LCE basis) for brines (outside China) and the cash cost of production at c US$5,000–7,000/t for the Australian spodumene conversion route.

We emphasize that these operating and capital cost estimates are based on last-published information for the projects we survey and therefore will likely need to be increased over time to allow for both general and mining industry specific inflation. Using the last-published capital and operating cost estimates from the industry a traditional return on capital analysis would reach an incentive price in the region of US$10,000–12,000/t (based on a 15% internal rate of return, IRR (a typical level for project appraisal in mining)). This is a simplification of a traditional approach using likely outdated capital and operating cost inputs.

However, long-run pricing is unlikely to be this low due to several reasons. Firstly, the lithium industry is highly concentrated with large incumbent producers, such as Albemarle and SQM, with high-quality assets. This is similar to iron ore. Iron ore was historically a low-growth industry and this led to large, incumbent producers (Rio Tinto, Vale, BHP and Anglo American) with large-scale assets dominating the industry. These assets can produce at an iron ore cash cost in the region of $15–20/t and delivered costs of US$30–45/t, and incentive prices for marginal growth are in the region of US$50–60/t. Despite this, iron ore prices have averaged US$104/t in real terms over the past 10 years (almost double average incentive prices for the highest quality assets), due in part to cyclical shortages and the incumbent producers choosing not to dominate supply growth. Some major producers have described this as a 'value over volume' strategy; in markets where prices are set by the marginal incremental tonne of production it is normal for incumbent producers to not needlessly accelerate incremental projects. A similar pattern was also seen in the copper industry, where a traditional incentive price methodology indicated long-run prices as low as US$1–1.20/lb as recently as the mid-2000s, while copper has traded largely in a $2–4/lb range since (and currently trades at US$4.20/lb).

Secondly, lithium will remain a high-demand growth industry, so returns on capital are likely to be much higher than historical rates used for incentive price calculations. The demand shock in iron ore took underlying demand growth from c 1% to 4–5% over the past two decades. In lithium, end-use demand growth is accelerating, and we forecast a CAGR of 20% from 2022–30.

In the longer term we see no shortage of greenfield lithium projects globally. We note a number of large-scale spodumene operations in Australia and Africa potentially coming on stream, with processing capacity being added in Australia and China. We also see scope for an inevitable increase in lithium recycling. Given the average EV battery life of c 10 years, with growing EV adoption we will eventually see a gradual increase in battery recycling, which could at some point represent a significant part of supply (similarly to other commodities). But these two factors are likely to come slowly into play and are also likely to be high-margin, high-return industries.

Lithium supply: Potential, but challenges

Our analysis suggests that there is no shortage of lithium projects globally, but there is clearly a limited number of projects that are either in development or at the financial investment decision (FID) stage and could therefore be brought into production in the short term (a typical project development timeline from resource definition to commercial production is up to seven years and could be longer for battery-grade lithium due to the strict quality and testing requirements).

The main reason for the relatively 'slow' supply-side response is the unprecedented speed of the EV market transformation, driven by government policies, and the protracted period of low lithium prices that discouraged investments in new supply. In Exhibit 1 we provide a list of selected advanced lithium projects where some level of detail is public (capital/operating costs, scale and timing). This list excludes potential projects in China, which are more opaque.

Exhibit 1: Currently producing and advanced development assets

Company	Project	Country	Type	Product	Current capacity*, tonnes	Expected capacity*, tonnes	Launch date
Albemarle	Salar de Atacama/La Negra	Chile	Brine	Carbonate	42,000	85,000	2022
	Greenbushes (49%)	Australia	Hard rock	Concentrate	210,000	350,000	2026
	Wodgina (40% Mineral Resources)	Australia	Hard rock	Concentrate	70,000	105,000	2023
	Silver Peak	US	Brine	Carbonate	5,000	10,000	2023
	Kemerton (40% Mineral Resources)	Australia	Conversion	Hydroxide**	-	50,000	2023
	Qinzhou	China	Conversion	Hydroxide**	25,000	25,000	-
	Meishan	China	Conversion	Hydroxide**	-	50,000	2024/25
SQM	Salar de Atacama	Chile	Brine	Carbonate	180,000	210,000	2024
	Salar de Atacama	Chile	Conversion	Hydroxide**	30,000	100,000	2025
	Mt Holland (50% Wesfarmers)	Australia	Hard rock	Hydroxide	-	50,000	H224
	Sichuan	China	Conversion	Hydroxide**	-	30,000	H123
Livent	Fenix/Hombre Muerto	Argentina	Brine	Carbonate	20,000	40,000	2023
Allkem	Olaroz (66.5%)	Argentina	Brine	Carbonate	13,000	42,500	H222
	Mt Cattlin	Australia	Hard rock	Concentrate	25,000	25,000	-
	Sal de Vida – Stage 1	Argentina	Brine	Carbonate	-	15,000	H124
	Naraha (75%)	Japan	Conversion	Hydroxide**		10,000	H222/23
Lithium Americas	Cauchari-Olaroz (51% Ganfeng)	Argentina	Brine	Carbonate	-	40,000	H222
Mineral Resources	Mt Marion (50% Ganfeng)	Australia	Hard rock	Concentrate	60,000	60,000	-
Pilbara Minerals	Pilgangoora	Australia	Hard rock	Concentrate	50,700	77,450	H223
Core Lithium	Finnis	Australia	Hard rock	Concentrate	-	22,500	2023
POSCO	Sal de Oro	Argentina	Brine	Hydroxide	-	25,000	2023/24
Liontown	Kathleen Valley	Australia	Hard rock	Concentrate	-	82,000	mid-24
Sigma Lithium	Grota do Cirilo	Brazil	Hard rock	Concentrate		30,715	2023

Source: Company data, Edison Investment Research. Note: *Both carbonate and hydroxide capacity are presented as reported by the companies (ie hydroxide is not converted into LCE), concentrate capacity is converted into LCE based on the lithium content in concentrate and atomic masses. We also apply a 90% conversion rate from concentrate to hydroxide. To convert hydroxide into LCE, apply a 0.88 factor. **Conversion facility to process carbonate into hydroxide (NB Sichuan will use lithium sulfate as feedstock and is therefore an incremental capacity to SQM's Chile operations).

Firstly, we address an un-risked potential supply. In theory, assuming an unlikely scenario of no project delays, our analysis suggests that approximately 500ktpa of additional lithium capacity (ex-China) could potentially come on stream in the next two to three years, bringing the overall production capacity to c 1Mtpa of carbonate and hydroxide (slightly less in LCE terms if hydroxide capacity is converted into carbonate). This expansion includes greenfield as well as brownfield projects that are either being upgraded or restarted following a period of weak lithium prices (eg Albemarle's Wodgina) in Australia. At present, the biggest supply response in the lithium chemicals space comes from the market leaders Albemarle and SQM, followed by the emerging lithium producers Allkem (ASX: AKE) and Lithium Americas (NYSE: LAC). Similarly, in the lower value add segment of hard rock processing, the main increase in capacity comes from the current producers. Not surprisingly, these companies have stronger balance sheets, better access to capital, industry track records and expertise. Note that we risk all of this potential new supply in our market balance estimates on page 12.

In addition to more advanced projects, we have also screened the lithium universe to identify the projects that could potentially represent further capacity additions over the longer-term horizon. Most of these projects (see Exhibit 2) have been through extensive exploration, and have feasibility studies completed and offtake secured. Some of these projects are expected to move into development (eg Allkem's James Bay) in the near term. On a combined basis, these projects represent c 0.6Mtpa of additional lithium capacity. We note that this selection is dominated by the large-scale hard rock projects aiming to produce either hydroxide or concentrate. Unlike current development projects, which mainly originate in Latin America and Australia, the potential second wave of lithium expansion has more diverse geographical exposure with a number of large-scale potential developments in Europe, Africa and North America.

Exhibit 2: Advanced exploration and early-stage development projects

Company	Project	Country	Type	Product	Stage	Capacity, tonnes
Leo Lithium	Goulamina	Mali	Hard rock	Concentrate	DFS (2021)	96,951
AVZ	Manono	DRC	Hard rock	Concentrate	DFS (2020)	93,047
Lithium Americas	Thacker Pass	US	Clay	Carbonate	PFS (2018)	60,000
Allkem	James Bay	Canada	Hard rock	Concentrate	FS (2021)	42,867
Vulcan	Vulcan	Germany	Brine	Hydroxide	PFS (2021)	40,000
Ganfeng	Sonora Stage 1&2	Mexico	Clay	Carbonate	FS (2019)	35,000
Piedmont Lithium	Carolina	US	Hard rock	Hydroxide	BFS (2021)	30,000
EMH/CEZ	Cinovec	Czech Republic	Hard rock	Hydroxide	PFS (2022)	29,386
Lake Resources	Kachi	Argentina	Brine	Carbonate	PFS (2020)	25,500
Rio Tinto	Rincon	Argentina	Brine	Carbonate	DFS (2018)	25,000
Lithium Americas	Pastos Grandes	Argentina	Brine	Carbonate	FS (2019)	24,000
Ioneer	Rhyolite Ridge	US	Hard rock	Hydroxide	DFS (2020)	22,000
Neo Lithium/Zijin	3Q	Argentina	Brine	Carbonate	FS (2021)	20,000
Lithium Power International	Maricunga	Chile	Brine	Carbonate	DFS (2022)	15,200
Keliber (private)	Keliber	Finland	Hard rock	Hydroxide	BFS (2022)	15,000
Bacanora	Zinnwald	Germany	Hard rock	Fluoride	FS (2020)	7,285
Lepidico	Karibib Phase 1	Namibia/UAE	Hard rock	Hydroxide	FEED/DFS (2022/2020)	4,879

Source: company data, Edison Investment Research

The main lithium producing regions are Latin America, Australia and China. Latin America is the biggest source of lithium produced from brines, while Australia is a major supplier of primary concentrates that are subsequently converted into higher value-add products such as hydroxide or carbonate. Chile has traditionally been one of the largest producers of lithium (coming solely from Salar de Atacama), and although both SQM and Albemarle are significantly expanding capacity, due to its strict permitting regulations as well as the uncertain political environment, the country appears to be gradually losing its position in the greenfield lithium space to Argentina. While we do not expect SQM's and Albemarle's industry leading positions to be challenged any time soon, Argentina has seen a string of greenfield brine projects coming into production (Exhibit 1), with a number of relatively advanced projects potentially slated for future development (Exhibit 2).

Finally, of note is a significant increase in both upstream and midstream lithium processing capacity in Australia. The recently announced restart of Albemarle's Wodgina mine, which was decommissioned in 2019 due to low lithium prices, together with the greenfield Mt Holland project will add further to the currently operating large-scale Pilgangoora, Greenbushes and Mt Marion operations. Combined, these assets could represent more than 400kt LCE capacity. This upstream capacity is expected to be matched by the hydroxide processing capacity that is being built in Australia and Asia/China. Overall, while lithium produced from brines often represents higher-quality and lower-cost 'battery-grade' material and as such the brine lithium projects are likely to be in demand, they are relatively small in scale and at present it appears that the main market balancing supply will come from Australia in the form of spodumene concentrate.

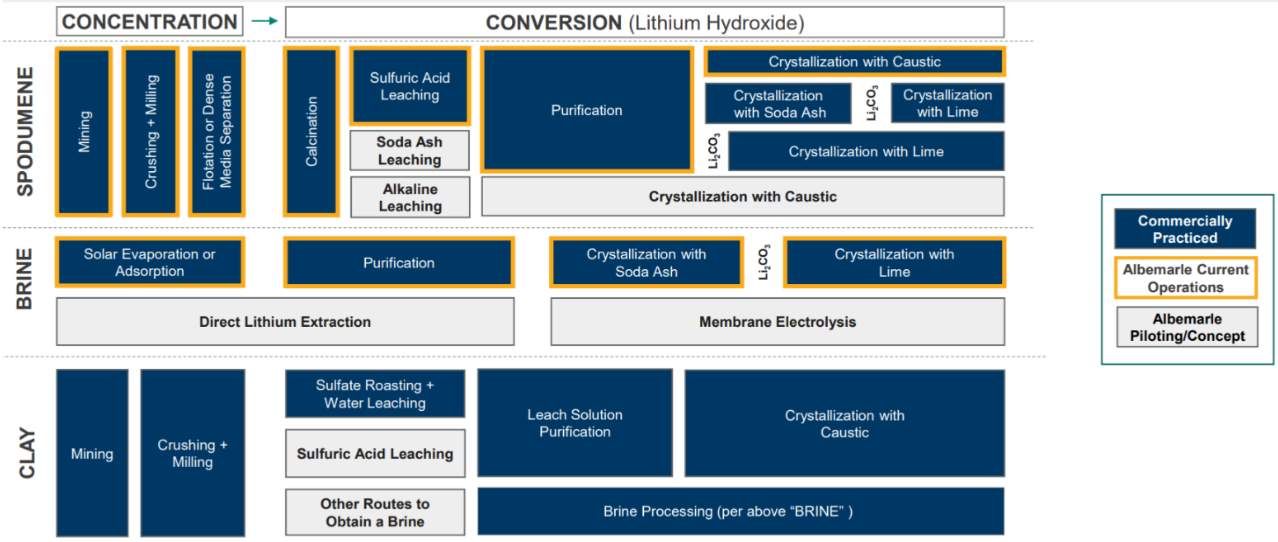
Upstream lithium value chain and project economics

Lithium production: Brine evaporation versus hard rock mining

By way of background, lithium is typically produced via two main routes: saltwater brines evaporation (the majority of which are the high-altitude dry salt lakes in South America, such as Salar de Atacama in Chile) and hard rock mining. The latter production process is broadly similar to a traditional mineral resource extraction whereby lithium bearing pegmatitic minerals, such as spodumene, petalite or lepidolite, are mined and processed into concentrate (eg SC6, or spodumene concentrate, containing 6% lithium dioxide), which is then converted into lithium carbonate or hydroxide (LiOH). In contrast, the saltwater brine is processed by water evaporation under sunlight. For that purpose, the brine, which contains lithium chloride (LiCl) as well as a variety of salts in the form of sulphites and chlorides of sodium, potassium, magnesium, boron, etc, is pumped into shallow ponds. After 12–18 months the concentration of salts and LiCl in the brine increases, salts are harvested from the ponds, while lithium is further processed into carbonate.

Due to the specific production routes and chemical/mineral composition, lithium from pegmatite is typically processed into hydroxide, while brines produce carbonate. In mineral processing, spodumene concentrate obtained from mining and subsequent beneficiation of ore is calcinated to convert α-spodumene into the beta phase; β-spodumene then reacts with calcium oxide to form lithium aluminate, which following leaching reacts with calcium hydroxide to form lithium hydroxide. In the schematic brine processing, sodium carbonate is added to the concentrated brine solution after the evaporation and salt removal stage, where it reacts with lithium chloride to form lithium carbonate, which can then be filtered out from the solution. Both carbonate and hydroxide are key raw materials used in production of positive electrodes in lithium-ion batteries and can be further processed into metallic lithium.

Exhibit 3: Lithium extraction and processing (based on Albemarle operations)



Source: Albemarle

Project economics comparison: Brine versus hard rock versus integrated

In this section we consider economics for the projects that represent the main lithium production routes: brines, hard rock as well as integrated projects. In general, hard rock mining is more energy and capital intensive and characterised by higher operating costs compared to brine processing, which is however more water intensive. According to Vulcan Energy (ASX: VUL), one tonne of lithium hydroxide produced from brines requires c 470m^3 of water and results in c 5t of CO_2 emissions. This compares to c 170m^3 of water use and 15t of CO_2 emissions for 1t of hydroxide produced via hard rock mining. At the same time, hard rock mining is more scalable (it is not uncommon to see an integrated 40–60kpa LCE spodumene project compared to a 15–25ktpa brine operation) and hard rock operations have also historically produced higher value-added product (hydroxide). However, with the recent increase in the use of lithium iron phosphate (LFP) batteries in China, the carbonate price discount to hydroxide has almost vanished. Overall, our analysis suggests that brine lithium projects are the most competitive with direct opex of about US$3,000–4,000/t of carbonate. This compares to hard rock projects, which have total direct opex of about US$5,500–6,000/t of hydroxide, or c US$6,200–6,800/t of carbonate. Integrated operations achieve direct operating costs somewhere between brine and pure hard rock projects due to their ability to source concentrate at cost.

Brine projects

Exhibit 4 shows a selection of brine projects with recently completed economic studies. These projects aim to produce carbonate and have capacity of about 20–25ktpa. While direct opex estimates vary somewhat depending on the project, they average c US$3,650/t of carbonate. This number is consistent with the currently operational Allkem Olaroz brine project in Argentina, which reported H122 cash production costs of US$3,593/t. The main opex categories for the brine projects are chemical reagents, labour and energy. The projects' capital intensity estimates show more variability as they range from c US$18,000/t to c US$40,000/t, with an average of about US$24,000/t.

Exhibit 4: Selected brine projects

Company	Project	Country	Study	Date	Product	Capacity, tonnes	Opex, US$/t	Cap intensity, US$/t
LPI	Maricunga	Chile	DFS	Jan-22	Carbonate	15,250	3,864	41,075
Neo Lithium	3Q	Argentina	FS	Nov-21	Carbonate	20,000	2,953	18,528
Lithium Americas	Pastos Grandes	Argentina	FS	Jul-19	Carbonate	24,000	3,388	21,417
Lithium Americas	Cauchari Olaroz	Argentina	FS	Sep-20	Carbonate	40,000	3,600	21,300
Lake Resources	Kachi	Argentina	PFS	Apr-20	Carbonate	25,500	4,178	21,333
Lithium South	Hombre Muerto North	Argentina	PEA	Aug-19	Carbonate	5,000	3,122	18,671
Galan Lithium	Hombre Muerto West	Argentina	PEA	Dec-20	Carbonate	20,000	3,518	21,950
Galan Lithium	Candelas	Argentina	PEA	Nov-21	Carbonate	14,000	4,277	29,143
Rio Tinto	Rincon	Argentina	DFS	2018	Carbonate	25,000	4,000	26,000
Average							**3,653**	**23,794**

Source: company data, Edison Investment Research

Hard rock projects

Lithium hard rock projects mine and process lithium containing minerals such as spodumene and petalite to produce concentrates that are subsequently converted into hydroxide or carbonate. Spodumene has a relatively high lithium content and is the most important lithium ore mineral. A typical run of mine ore contains 1–2% lithium oxide (Li_2O). It is upgraded into spodumene concentrate, which in its standard specification contains 6% Li_2O (SC6).

We show a selection of lithium hard rock projects in Exhibit 5. Typically, these projects represent small to medium size mining and beneficiation operations with concentrate capacities ranging from c 100kt to up to 800kt of saleable product. The key opex components are energy and labour. Based on a range of publicly available information on project economics, we estimate opex in these studies to range from US$330/t to US$470/t on an FOB basis, with an average of about US$380/t. On an LCE basis this implies an average direct opex to produce spodumene concentrate of about US$3,000/t. Assuming cost of conversion of about US$2,500/t (see below), it suggests a direct cash cost to produce hydroxide of about US$5,500/t. Capital intensities in the group of projects included below average about US$561/t of concentrate or US$4,400/t LCE.

Exhibit 5: Selected lithium hard rock projects

Company	Project	Country	Study	Date	Product	Capacity, ktpa	LCE eq., ktpa (rounded)	Opex (FOB), US$/t	Capital intensity, US$/t
Core Lithium	Finnis	Australia	DFS	Jul-21	Concentrate	175,000	23,000	400	363
Allkem	James Bay	Canada	FS	Dec-21	Concentrate	321,000	40,000	333	890
Leo Lithium	Goulamina Stage 1&2	Mali	DFS/PFS	Dec-21	Concentrate	726,000	97,000	358	448
AVZ	Manono	DRC	DFS	Apr-20	Concentrate	700,000	73,000	371	524
Liontown	Kathleen Valley	Australia	DFS	Nov-21	Concentrate	613,000	82,000	425	895
Sayona	Authier	Canada	DFS	Nov-19	Concentrate	114,116	15,000	469	835
Atlantic Lithium	Ewoyaa	Ghana	Scoping	Dec-21	Concentrate	255,000	34,000	278	490
Sigma Lithium	Grota do Cirilo	Brazil	PFS	Apr-22	Concentrate	230,000	31,000	357	535
Average								**382**	**561**

Source: company data, Edison Investment Research

Integrated hard rock projects

Finally, we consider a number of integrated projects that are looking to produce hydroxide or carbonate from concentrates. Exhibit 6 presents a selection of hard rock and clay projects that follow a similar production route whereby ore is mined and beneficiated into concentrate, which is then processed into either hydroxide (typical for spodumene) or carbonate (typical for clay). These projects are less homogeneous with cash cost estimates as they are significantly distorted by the inclusion of by-product credits. Of note are the lower opex estimates for the clay projects such as Sonora and Thacker Pass (although these projects had their economic studies completed in 2018). The cost of conversion also varies significantly, ranging from c US$1,700/t to US$5,000/t, with an average of c US$3,000/t.

In terms of capital required, the average capital intensity of integrated non-brine products (US$26,036/t – see Exhibit 6) in our survey below is higher than, but similar in scale to, the capital intensity of integrated brine projects (US$23,794/t – see Exhibit 4). It is reasonable to assume a typical capital intensity of US$25,000/t from this data. Given that production will need to grow from 0.9Mtpa to 3Mtpa if this demand growth is to be met, this implies 2.1Mtpa of new capacity needs to be built. At US$25,000/t capital intensity per unit of annual production, this implies capital in the order of US$52.5bn is required to meet this demand growth.

Exhibit 6: Selected integrated lithium projects

Company	Project	Country	Study	Date	Product	Capacity, ktpa	Opex before by-products, US$/t	Opex net of credits, US$/t	Conversion opex, US$/t	Capital intensity, US$/t
Piedmont Lithium	Carolina	US	BFS	Dec-21	Hydroxide	30,000	4,634	3,657	1,774	32,933
EMH	Cinovec	Czech Rep	PFS	Jan-22	Hydroxide	29,386	6,727	5,567	3,103	21,908
Ioneer	Rhyolite Ridge	US	DFS	Apr-20	Hydroxide	22,000	6,227	599	N/A	40,182
Lepidico	Karibib Phase 1	Namibia/UAE	DFS	May-20	Hydroxide	4,879	10,237	1,656	5,018	29,617
Liontown	Kathleen Valley	Australia	Scoping	Nov-21	Hydroxide	87,000	6,182	5,864	3,303	17,092
Lithium Americas	Thacker Pass Phase 1 & 2	US	PFS	Aug-18	Carbonate	60,000	4,088	2,570	1,649	17,661
Ganfeng	Sonora Stage 1 & 2	Mexico	FS	Jan-18	Carbonate	35,000	3,910	3,418	N/A	22,857
Average							**6,001**	**3,333**	**2,969**	**26,036**

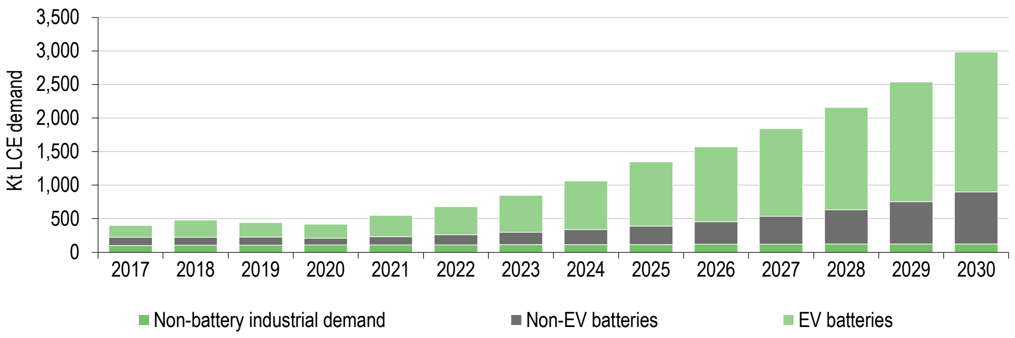
Source: company data, Edison Investment Research

Lithium demand: Explosive growth

The lithium market is undergoing a significant transformation due to the rapid increase in the use of batteries in EVs and electronics. Overall, our forecast is for global LCE demand of 1.3Mt in 2025 and 3Mt in 2030, which is broadly in line with the demand projections of major producers and the IEA.

The ongoing EV revolution, with traditional internal combustion engines being gradually replaced by EVs, has caused a profound change in the lithium consumption pattern. Historically, the vast majority of lithium was used in industrial applications such as speciality glass and lubricants, with (rechargeable) batteries representing only a small proportion of the overall consumption. However, driven by expanding energy storage needs (both e-mobility and grid related), lithium battery demand has experienced explosive growth in recent years, with EV batteries representing c 58% of total global lithium demand in 2021, according to our estimates. Due to the favourable long-term EV demand fundamentals driven by decarbonisation and ambitious climate targets, this trend should continue in the foreseeable future and we expect EV batteries to account for c 70% of global demand by 2030.

Exhibit 7: Lithium demand forecast by major end-use



Source: Edison Investment Research estimates

The chart above summarises our demand projections. We have based our EV demand forecasts on EV penetration rates across all types according to IEA projections based on the announced pledges of host governments. This includes projected sales of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) of 20m in 2025 and 44m in 2030, up from 6.6m in 2021. The short-term path of EV adoption can be volatile (constrained by vehicle availability, charging infrastructure and consumer preferences), but this projection is broadly a 40–50% adoption rate globally by 2030. Given many developed markets and developed market automakers are signalling the phasing out of internal combustion engine (ICE) drivetrains around the end of this decade, this forecast could have upside. Overall, we project demand in EV applications of 2.1Mt in 2030, up from approximately 420kt in 2022, a fivefold increase.

In addition, we have modelled demand for batteries from other sectors and expect other end-uses to experience similar growth (from 150kt of LCE demand in 2022 to 780kt of LCE demand in 2030, also a fivefold increase). This includes a large array of energy storage applications in other forms or in transport and e-mobility, and also strong growth in energy storage applications linked to the decarbonization of the electricity grid. The growth in renewable sources for power (for energy decarbonization, but also energy diversity) will go hand in hand with grid power storage to boost flexibility as renewable sources such as wind and solar often do not generate power that coincides with peaks in daily demand. For a fuller discussion of trends in battery energy storage systems see our report Battery energy storage – Key role in ensuring energy system flexibility.

Longer-term demand forecasting in a high-growth market is uncertain. Our forecast is for global LCE demand of 1.3Mt in 2025 and 3Mt in 2030, which is broadly in line with the demand projections of major producers and the IEA:

- In its capital markets day presentation on 24 January 2023, **Albemarle** issued another upward revision to its expectation of global lithium demand. It raised its expectations to **1.8Mtpa in 2025** (up from its March 2022 projections of 1.5Mt) and **3.7Mtpa in 2030**, up 15% from its March 2022 estimate of 3.2Mtpa. The latest 2030 projection of 3.7Mt is a 48% increase from its September 2021 projection for 2030 of 2.5Mt, underlining the continued upward revisions of market growth expectations over the past two to three years.
- In its September 2022 investor day presentation, **SQM** indicated a total demand of approximately 750kt in 2022, growing at 20–23% in 2023 and reaching **1.2–1.6Mt of LCE in 2025** and **2.3–3.3Mt of LCE in 2030**, with an EV penetration rate of 47%.
- In its 2022 global EV outlook (May 2022), the **IEA** expected global EV stock across all transport modes to expand from almost 18m vehicles in 2021 to over 200m in 2030 (CAGR of over 30%) under the Stated Policies Scenario (SPS; reflects current policies and measures). This suggests annual EV sales reaching 18m in 2025 and exceeding 30m in 2030. In a more ambitious Announced Pledges Scenario (APS; assumes the announced ambitions and targets are met in full

and on time), the IEA sees global EV stock exceeding 85m vehicles in 2025 and rising to 270m in 2030. In terms of battery demand, this translates into 2.2TWh under SPS and 3.5TWh under APS in 2030 compared to just 0.34TWh in 2011. According to the IEA, to achieve these production levels requires building an additional 52 gigafactories with annual production capacity of 35GWh under SPS and 95 gigafactories under APS. Assuming that an average battery uses c 0.8kg/kWh of LCE (consumption varies slightly based on the cathode chemistry and type of electrolyte, but we understand that NCM811 and LFP batteries use roughly the same amount of lithium), the IEA's current forecasts imply lithium consumption of c 1.8Mt of LCE for SPS and c 2.8mt of LCE for APS in 2030. This demand assessment is in line with the IEA's own estimates that suggest lithium consumption of 330kt (1.8Mt LCE) under STS and **500kt (2.7Mt LCE) under APS in 2030.** These forecasts do not include non-EV energy storage solutions that use batteries.

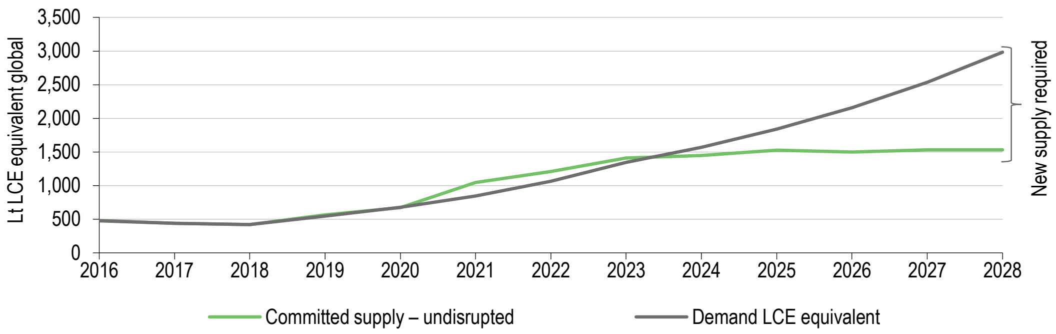
Supply/demand balance and short-term price changes

We see the potential for significant supply growth in the next two years, although we also question whether this will be delivered on time due to a range of ramp-up delays and other supply risks. We show our workings on an unrisked and risked basis below. In the longer term, we see the need for significant additional investment.

To test the potential short-term supply/demand balance, we have constructed a supply projection based on corporate reports and nationally reported lithium production historically and compared this with a bottom-up model of lithium demand constructed by Edison and based on growth projections of key end-use sectors. In line with USGS conversion factors, we have expressed an overall balance in terms of LCE units but acknowledge that not all lithium units are produced or consumed in this manner. We therefore highlight that our supply/demand balance is indicative, and supply may not be in the form demanded by consumers (and hence the market may be tighter than our analysis indicates). Our uncorrected supply estimates are based largely on projected mine output, while our 'risked' projections allows for both project delays and interruptions as well as processing bottlenecks in reaching the specification of products demanded by consumers.

We have included all committed and funded expansion plus some expansions by the major producers that are not yet committed but look likely to be approved. In addition, we have allowed for the emergence of some battery recycling (based on a 10–15 year battery life), although the rates of recycling and recovery in this nascent industry are highly uncertain (a topic we plan to return to). Our projection for demand and supply (on an unrisked basis) as described above is shown in the chart below. In the short term, we see potential for supply exceeding demand in 2023 and 2024, and then (based on committed supply additions) a structural deficit opening up post 2025.

Exhibit 8: Unrisked supply/demand – a potential surge, but long-term supply gap



Source: Edison Investment Research estimates

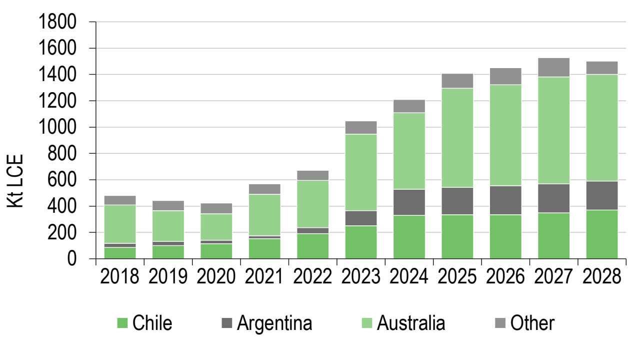
We highlight that our unrisked supply estimate shows the potential for 56% growth in 2023, but this is overly simplistic. Several factors complicate a simple calculation.

- **Mining and processing plants in minerals extraction often have delays.** We are not aware of any natural resources industry that has delivered this level of supply growth in a single year smoothly, and plant commissioning delays are to be expected. In the lithium industry, parts specific to processing (for example crystalisers) are likely to be in high demand and these supply industries will need to adapt to the acceleration in demand as well. Based on our discussions with project developers, many of these constraints are real and are not reflected in advertised timelines for project commissioning.
- **The industry is tightly controlled.** Approximately 25–30% of our unrisked supply projection is from SQM, Albemarle and Allkem, some of the largest existing incumbent producers. The history of commodity markets is that large producers tend not to oversupply their markets.
- **Producing to specification can be difficult.** Our analysis is based on LCE units, but producing battery-grade material and having this product accepted by consumers can take time.
- **Lithium has no terminal market.** Unlike metals such as copper, zinc and lead, lithium has no deliverable physical contract on exchanges. As such, any surpluses will need to be stored and financed by either the mining or trading community, and there is no history of surpluses of this scale being managed.
- **Geopolitical risks.** The trend in commodity markets is to increase the security of supply chains. Lithium (like many other critical minerals) has a processing and production chain that is complex, with significant links to China.

We believe a combination of the above factors will lead to supply growth being closer to demand growth – we have factored in a delay to expected ramp-ups in the order of 50% of headline incremental growth, and spread these increases over the subsequent two years. While we have not formally adopted a delay calculation in line with 'McNulty curves', which represent empirically driven ramp-up delays to mineral processing (and would argue that lithium's challenge is possibly unprecedented), our delays to ramp-up are broadly in line with type-3 development curves in this classification (which are the third most delayed, out of four possibilities).

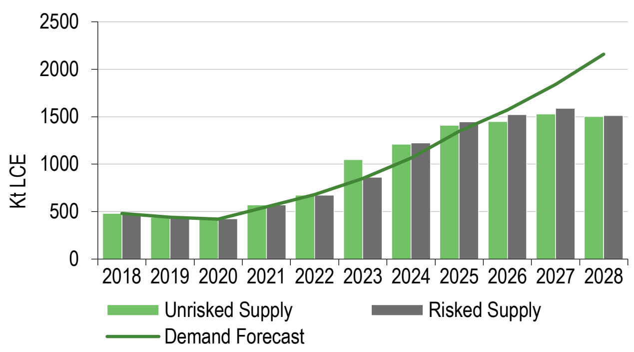
This results in supply and demand being more closely matched in 2023 (see Exhibit 10 below), but we acknowledge that the fundamentals in 2023 are likely to be uncertain.

Exhibit 9: Lithium supply by national source



Source: Edison Investment Research estimates

Exhibit 10: Risked supply close to demand in 2023



Source: Edison Investment Research estimates

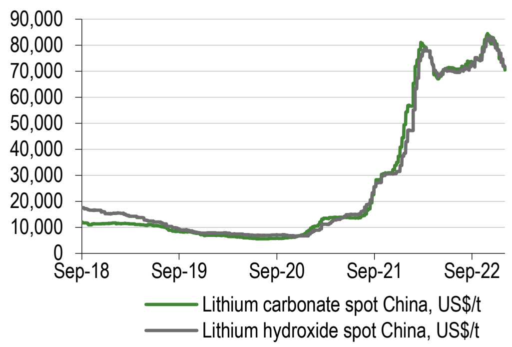
Further out, a deficit emerges in 2026, even allowing for the delayed ramp-up in known projects. Given typical approval, funding and construction times, this deficit will require the approval of high-quality projects in the next year.

Lithium prices: Short-term volatility, long-term strength

Lithium prices have been volatile over the past year, spiking to a peak of just over US$80,000/t (LCE spot basis) and averaging US$62,000/t in 2022. At the time of going to press, spot prices for carbonate had eased slightly to approximately US$70,000/t (Exhibit 12). This compares to the average carbonate spot price in China of only c US$6,200/t in 2020. Lithium was the best performing commodity in 2022, outperforming all other industrial metals by a wide margin.

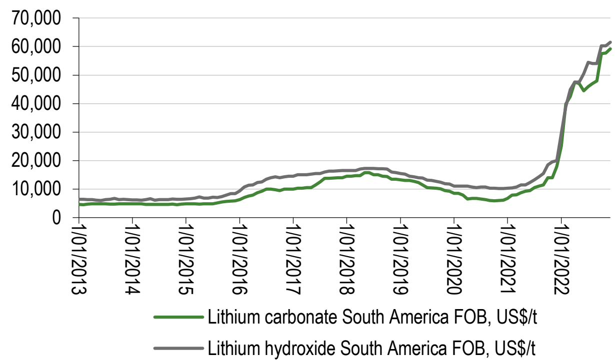
Forecasting average prices for 2023 is particularly uncertain given that prices are relatively high and the supply/demand outlook is particularly dependent on the ramp-up in projects. We raise our 2023 price forecast from US$24,000/t to US$55,000/t and acknowledge, given the uncertainty in fundamentals in 2023, that this may require further adjustment as the year progresses.

Exhibit 11: Lithium prices, China spot



Source: Refinitiv

Exhibit 12: Lithium prices, South America FOB



Source: Refinitiv

Contract prices should generally follow the spot but with a certain lag. Based on the current market fundamentals, we conservatively model the average contract hydroxide price at US$55,000/t in 2023–24.

A cyclical forecast should only apply to a period where a reasonable visibility of likely project commissioning is possible. We would place this as four to five years at present, around which time either demand destruction or the acceleration of marginal supply could come into play. We acknowledge the late 2020s are particularly uncertain and, as such, apply long-run pricing only beyond 2031. It is possible that continued demand growth continues to place upward pressure on these equilibrium prices. We do not believe that lithium equities discount an extrapolation of current spot prices.

Exhibit 13: Edison contract lithium price expectations, US$/tonne

	2022a	2023	2024	2025	2026	2027	Long term
Lithium hydroxide	63,500	56,000	56,000	51,000	46,000	40,000	23,500
Lithium carbonate	62,000	55,000	55,000	50,000	45,000	39,000	22,500

Source: Edison Investment Research

We assume a US$1,000/t price difference between carbonate and hydroxide, which is lower than the historical levels (driven by the traditional value chain for industrial applications), but could also be conservative given high carbonate demand in China due to the growing use of LFP batteries. We understand that the spot carbonate price is on par, if not at a premium, to hydroxide.

Listed lithium companies – varying entry points

Investors have a wide variety of options in listed equites to gain exposure to the lithium market. These exposures include existing large-scale lithium-focused producers with direct exposure to the current lithium price (such as SQM, Allkem and Livent) and a growing list of companies in the project development stage, which we include in our project analysis section of this report and summarise below in terms of equity market listing. In addition, there is a growing list of emerging lithium exploration and very early-stage development plays, which we have not included in this report for brevity, which will be needed to help fill the expected demand growth over the next decade.

Exhibit 14: Listed lithium companies ranked by market cap

Company	Market cap (US$m)	Ticker	Listing	Asset/project*	Country	Type
Albemarle	33,155	ALB	NYSE	Salar de Atacama	Chile	Brine
				Greenbushes (49%)	Australia	Hard rock
				Wodgina (40% Mineral Resources)	Australia	Hard rock
				Silver Peak	US	Brine
				Kemerton	Australia	Conversion
				Qinzhou	China	Conversion
				Meishan	China	Conversion
SQM	25,617	SQM	NYSE	Salar de Atacama	Chile	Brine
				Mt Holland (50%)	Australia	Hard rock
				Sichuan	China	Conversion
Ganfeng	23,024	002460	SHE	Sonora Stage 1&2	Mexico	Clay
				Salar del Carmen	Chile	Brine
				Mt Holland (50% Wesfarmers)	Australia	Mineral
Mineral Resources	12,120	MIN	ASX	Mt Marion (50% Ganfeng)	Australia	Hard rock
Pilbara Minerals	10,119	PLS	ASX	Pilgangoora	Australia	Hard rock
Allkem	5,922	AKE	ASX	Olaroz	Argentina	Brine
				Mt Cattlin	Australia	Hard rock
				Sal de Vida	Argentina	Brine
				Naraha	Japan	Conversion
Livent	4,633	LTHM	NYSE	Fenix/Hombre Muerto	Argentina	Brine
Lithium Americas	3,245	LAC	NYSE	Pastos Grandes	Argentina	Brine
Sigma Lithium	3,186	SGML	TSX	Grota do Cirilo	Brazil	Hard rock
Liontown	2,386	LTR	ASX	Kathleen Valley	Australia	Hard rock
Sayona	1,566	SYA	ASX	Authier	Canada	Hard rock
Core Lithium	1,477	CXO	ASX	Finnis	Australia	Hard rock
Piedmont Lithium	1,192	PLL	NASDAQ	Carolina	US	Hard rock
Lake Resources	797	LKE	ASX	Kachi	Argentina	Brine
Vulcan Energy	723	VUL	ASX	Vulcan	Germany	Brine
Ioneer	640	INR	ASX	Rhyolite Ridge	US	Brine
Leo Lithium	508	LLL	ASX	Goulamina	Mali	Hard rock
Atlantic Lithium	307	ALL	LON	Ewoyaa	Ghana	Hard rock
Galan Lithium	253	GLN	ASX	Hombre Muerto West	Argentina	Brine
Lithium Power Int.	196	LPI	ASX	Maricunga	Chile	Brine
Lepidico	86	LPD	ASX	Karibib Phase 1	Namibia/UAE	Hard rock
CleanTech Lithium	73	CTI	LON	Laguna Verde	Chile	Brine
EMH	68	EMH	LON	Cinovec	Czech Rep.	Hard rock
Lithium South	43	LIS	TSX	Hombre Muerto North	Argentina	Brine

Source: Refinitiv. *Note: Only selected projects are shown in this table that are included in our supply analysis.

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