Lithium Demand and Supply

12 May 2021

Mining

Lithium – Demand to Double inside a Decade

Summary

- **71% of current Lithium demand is allocated toward batteries**
- **Forecast global Li Demand to grow 100% over the next decade**
- By 2030, EVs will consume 61% of all Li-ion battery demand
- 2020 BEV sales in EU, US and China totalled 2.31m
- Forecast global 2021 BEV sales at ~3m
- Continued corporate consolidation reinforcing existing producer Oligopoly
- **BUY recommendation large producers such as ORE/GXY & SQM**
- **Speculative BUY recommendation on ETCM, VUL and Cornish Lithium**

After several years of stagnant production and depressed pricing, lithium demand is again growing strongly, its future fundamentally tied to the growth of EVs and hybrids. In deriving our forecast that demand would double inside the next decade, we used the unrealistic (but extremely conservative) assumption that lithium demand will be zero in every other sector other than Li-ion battery growth for EVs.

Predicated on first mover advantage, the ability to quickly increase name plate capacity, and take advantage of improving market conditions, **we recommend ORE/GXY and SQM as strong BUYs**. Resulting from their recent merger, ORE/GXY intend to increase nameplate capacity by 225% to 130ktpa LCE. SQM (the world's second largest producer) is in the midst of increasing its lithium carbonate production by 50%, and its lithium hydroxide output by 40%, inside the next 18 months; whilst committing to a FID to add a 116% (attributable) lithium hydroxide development at its Mt Holland JV.

There are also a number of unconventional suppliers that have captured our imagination. They either have a capex advantage or a dual income model, and are able to deliver a superior investment case than a stand-alone Greenfields explorer. **Speculative Buy recommendations include e3 Metals Corp** (CVE: ETMC): utilising existing O&G holes in Alberta, targeting the Leduc Reservoir hosting lithium enriched brines; **Vulcan Energy** (ASX: VUL): plans to harness geothermal energy in the Upper Rhine Valley, Germany to produce Lithium; and the unlisted **Cornish Lithium**, with some of the most prospective, untapped ground globally, hosting lithium, tin, copper and geothermal (deep and industrial) prospects.

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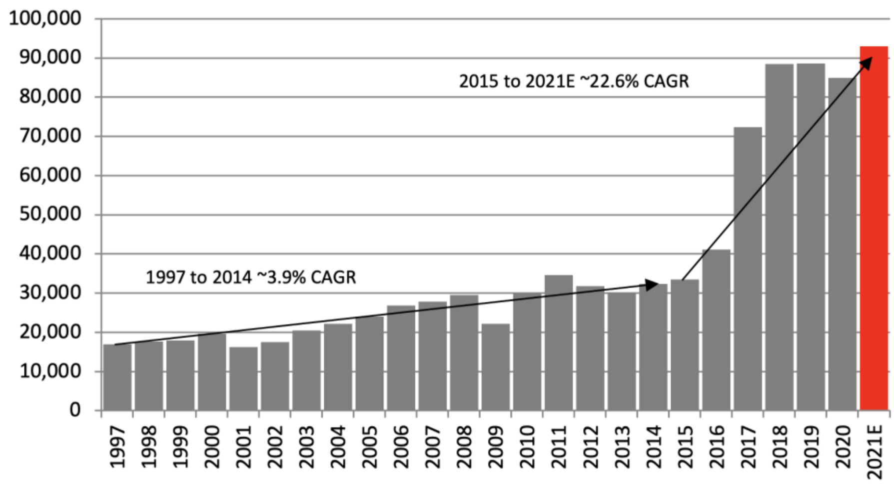
Future Lithium Demand? Let's talk about Batteries!

Originally used as a high-temperature lubricant (still accounts for 4% of total consumption - see Figure 1) in applications such as aircraft engines during WWII, lithium demand soared dramatically as a direct consequence of the Castle Bravo hydrogen bomb test. The resultant yield was 150-200% greater than was thought theoretically possible, it quickly became evident that the discrepancy was the result of both δ^6Li and δ^7Li producing tritium in the midst of a thermonuclear reaction, greatly enhancing the device's output. Lithium oxide is also widely used for processing silica, accelerating the melting of glass, reducing both viscosity and melting point, and decreasing energy requirements; improving melting behaviour of aluminium oxide during the smelting process.

Figure 1: Global Lithium Production (metric tonnes of contained lithium). Capacity increases averaged 2.5 - 4 years from FID (final investment decision) to production, which in developmental terms within the mining industry, is considered rapid.



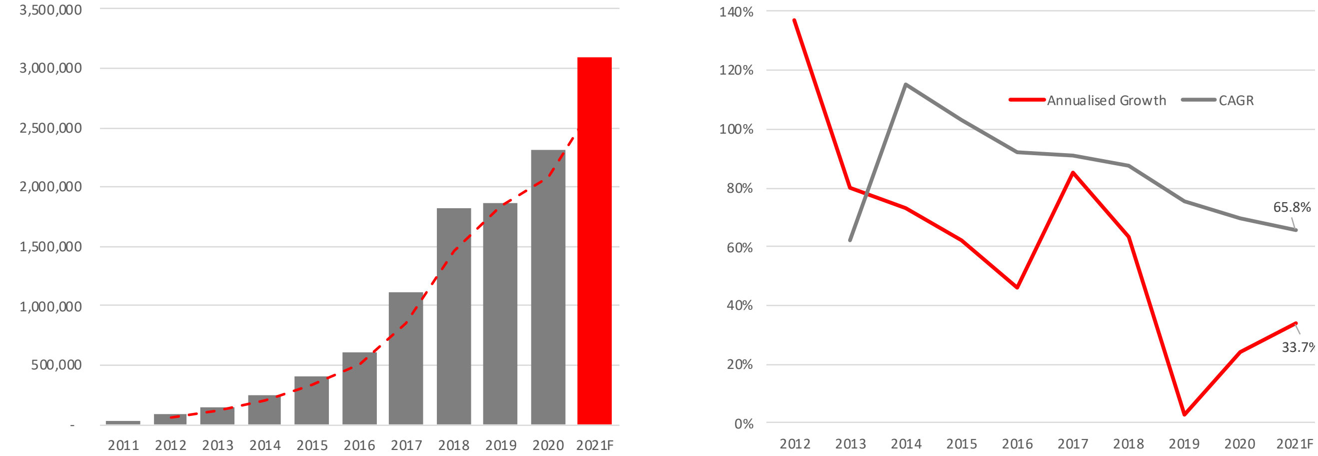
Source: Ministry of External Affairs (2019), USGS (2021), Roskill (2021), FD

Prices were suppressed for a decade following 1995 after excess lithium stocks were (~41kt LiOH) disposed onto the open market from the US nuclear weapons' programme. Primary demand began to grow from 2007 onwards as the manufacture of lithium-ion batteries required a supply response; initially, Li battery usage was dominated by disposables with voltages of between 1.5 and 3.7V. By 2010, Li-ion growth was dominated by increasing demand for rechargeable batteries, essential for smartphones, tablets, laptops, power tools, and other consumer devices.

By 2015, a fundamental change began to occur, global lithium battery demand was primarily driven by large, dense Li-ion batteries catering to a burgeoning EV/Hybrid market, measuring a 22.6% CAGR (see Figure 1). A single Tesla S model 90kWh battery uses 63kg LCE, an equivalent content of ~13k cell phones; underlying why Li market analysis is increasingly about future EV and Hybrid demand.

We estimate the actual number of EVs sold in 2020 in the major markets of the US, EU and China to be ~2.31m (~4.6%) units out of ~50.7m vehicles sold collectively in those jurisdictions. The relative slack in uptake over the past decade has been blamed, in some quarters, on low oil prices resulting from US shale developments. On that point, it is worth noting that oil still forms the basis of our global transport economy, providing more than 97% of the fuel that powers the world's cars, trains, shipping and flight. Moreover, it is at a level little different than that of four decades ago

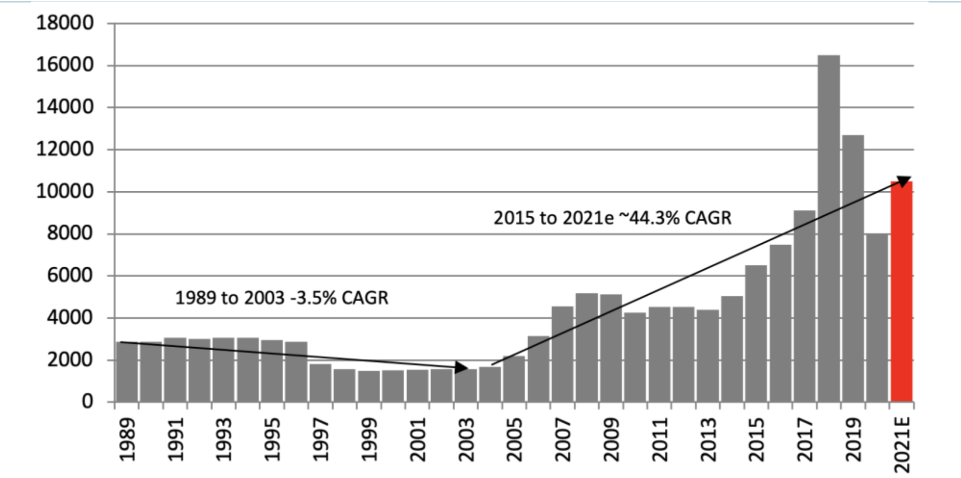
Figures 2 & 3: Number of newly registered EVs collectively from the US, EU and China (left); and comparing annualised versus CAGR growth rates over the same period (right). Collation of data from Figures 18 to 23.



Source: FD

According to Chemetall, the cost of lithium is relatively immaterial to the production costs of Li-ion batteries, only equating to ~1% of the total battery cost, implying that demand is relatively inelastic to price. A doubling in price, therefore, would have a negligible effect on underlying production costs, or even on final demand. The accuracy in forecasting Li demand has become perilous, being inextricably linked to idealistic proclamations, which in hindsight, more often than not, have little basis in regards to facts on the ground. Resulting in a number of high-profile projections being inaccurate by an order of magnitude.

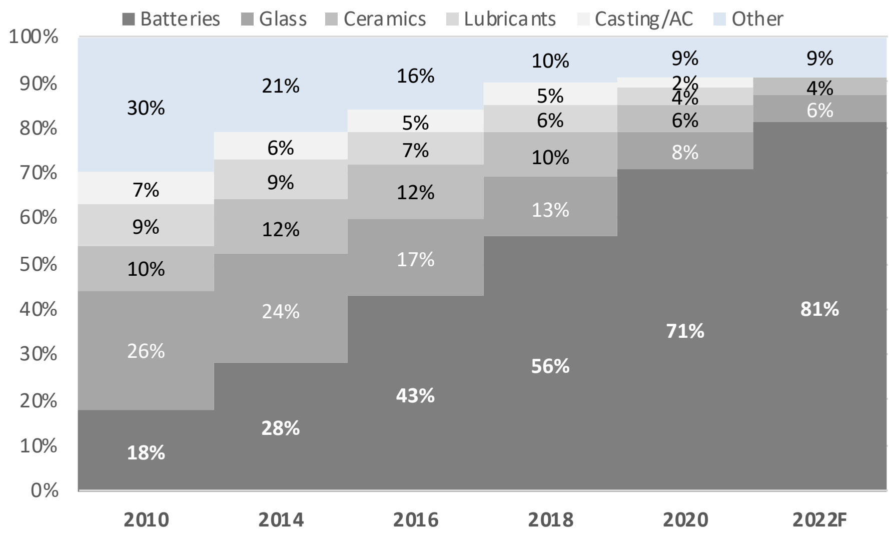
Figure 4: Chilean Li_2CO_3 annual export prices (USD/tonne).



Source: Bloomberg (2019), Metalary (2019), Lithium Benchmark Intelligence (2018), BP Energy Review (2018), sigumBox (2013), Servico de Aduanera (2011), Battery University (2019), USGS (2021), FD

After peaking in late 2018, prices fell >50% (on an annualised basis), the result of significant growth in primary supply outstripping underlying demand, which was compounded by the Covid pandemic where global car sales fell -16.5% (est.) in 2020. Spot prices have strongly rebounded >60%, as oversupply is now increasingly being replaced by fears of a looming deficit as early as mid 2022. Pricing, however, is more difficult than for many other commodities, and at one point, Fastmarkets[1] stopped quoting prices temporarily due to market opaqueness. Typically sold in quarterly contracts, primarily around contracted volumes, prices are typically set within a band, with LCE pricing within China often substantially lower (up to 40%) than other international pricing contracts; although we expect this arbitrage to completely disappear as deficits appear within the next 12-18 months.

Figure 5: Growth in Li-ion battery demand has risen from 18% in 2010 to 71% in 2020, with a 2022 forecast using current segmental growth trends.



Source: USGS (2011-2021), Roskill (2021), TRU Group (2010), FD

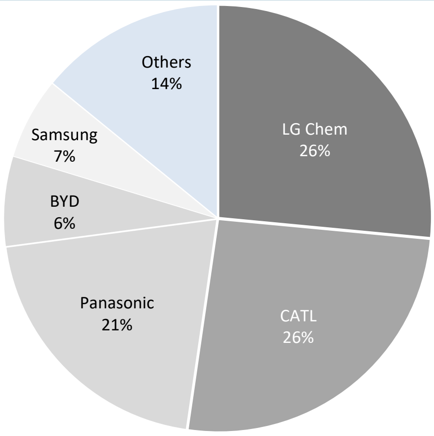
The future of Lithium demand is now fundamentally tied to the continual growth of the EV and hybrid transition which is dramatically impacting the demand for lithium (see Figures 2, 3 & 5). At the end of 2020, there were at least 50 BEVs (battery electric vehicles) available to buy from various UK suppliers, which is set to grow considerably with sales of new petrol and diesel cars banned from 2030. In addition, there are more than 150 different hybrid models from various car makers due to be released over the next three years. Hybrids increase fuel economy by >25%, with most newer models allowing a pure EV for short distances (<20km). Best suited for city driving, they are at their most efficient when stopping and starting regularly; although, over long-distances, their electrical systems add little to the efficiency of the engine.

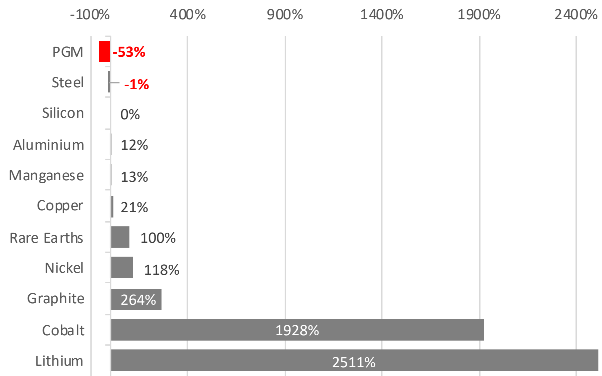
In Europe, the rapid increase in current regulatory restrictions will ensure further government incentives and penalties to support BEV sales growth. Starting in 2020, new passenger cars sold in Europe are permitted to emit no more than 95g CO_2/km (collectively); this is legislated to fall another 15% by 2025 (80g CO_2/km), decreasing

[1] https://www.fastmarkets.com/commodities/industrial-minerals/lithium-price-spotlight

again to 60g CO_2/km by 2030. According to data collected by JATO, covering 21 countries across Europe, the volume weighted average CO_2 emissions (NEDC) of vehicles registered during 2020 was 106.7 g/km – 12% lower than the average recorded in the pcp (the largest drop to date). However, it wasn't enough to save all of the major manufacturers from incurring fines. The Volkswagen Group faces a €100 million (£89m) penalty after it "narrowly missed" its EU CO_2 target; while Peugeot have disclosed that to have met its 2020 objective[2] , seven percent of all its vehicles sold would have had to be BEVs, three times higher than its current level.

Figures 6 & 7: 2020 EV producer battery market share (left); and incremental commodity demand assuming all vehicles sold globally were 2017 Chevrolet Bolts; implied massive growth in demand for lithium, cobalt, rare-earths and graphite markets, whilst PGMs, primarily used in auto-catalysts, are impacted negatively. (right).





Source: Global X ETFs, Korea Herald (2021), UBS, FD

The only headwind we foresee facing EV demand in the short-term is the global semiconductor shortage that has forced various automakers (*e.g.* Toyota, Volkswagen, Ford, Peugeot, Fiat, Jeep, Honda, Jaguar, Land Rover) to idle production lines when they temporarily run out of supplies. These Computer processors are critical for engine management systems, automatic braking, airbags, automatic parking and the infotainment systems, *etc*. The main manufacturers include TSMC in Taiwan (suffering from drought) and Samsung and SK Hynix in South Korea, with smaller operations in the United States and Europe.

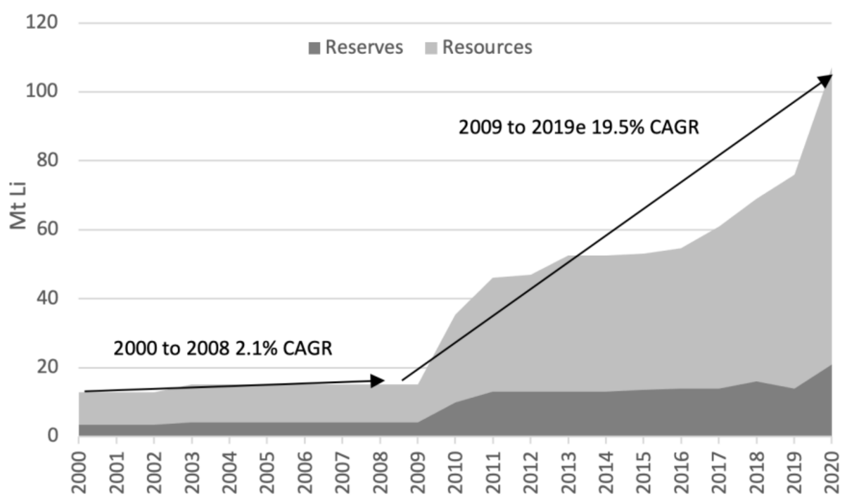
This semiconductor shortage is also affecting products such as TVs, mobile phones, game consoles, and was initially the result of lost production during the pandemic (a fire at a Japanese chip manufacturer[3], Renesas Electronics, didn't help either). A new surge in chip demand driven by changing habits fuelled by the pandemic, however, has exacerbated existing shortages that are not expected to be resolved until mid 2022, or early 2023.

[2] https://www.jato.com/jato-dynamics-analysis-of-eu-co2-emissions-in-2020/
[3] https://www.reuters.com/article/us-japan-renesas-taiwan-idUSKBN2BM09M

Lithium Shortages? Not in our Lifetime!

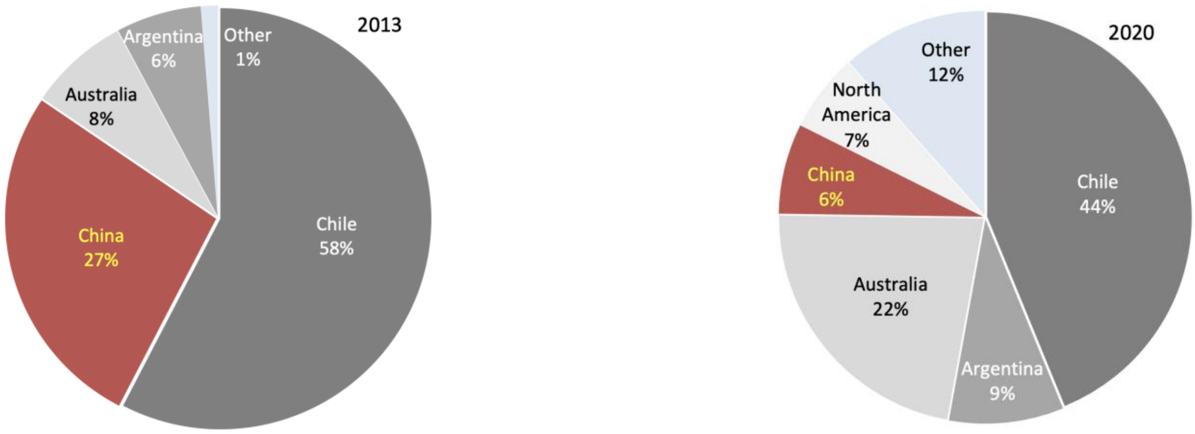
Primary lithium demand began to grow from 2007 onwards as the demand and manufacture of lithium-ion batteries required an immediate supply reaction. Exploration success quickly followed, using existing geological models, targeting salars and pegmatite operations. Displaying a classic supply response, from 2009/10 onwards, additional Lithium Reserves and Resources were being delineated (displayed cumulatively – see Figure 8)[4].

Figure 8: Growth of lithium Reserves and Resources over time.



Source: USGS (2021), FD

Figures 9 & 10: Global lithium Reserve distribution from 2013 (left) to that in 2020 (right).



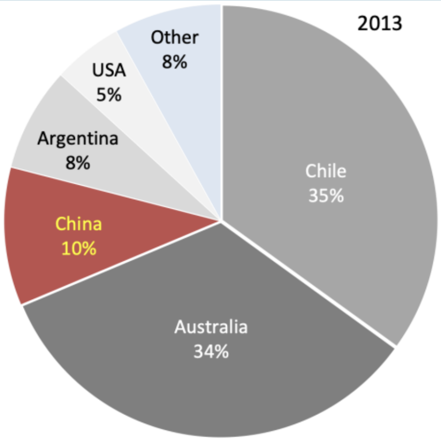
Source: USGS (2014-2021), FD

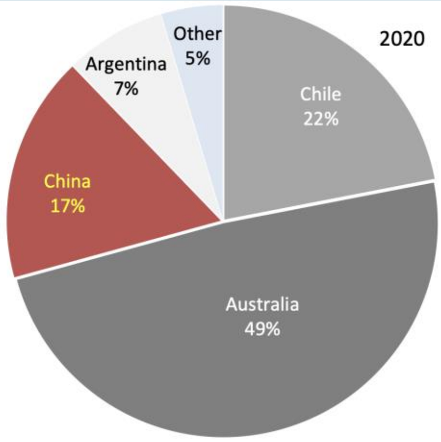
Taking a snap shot in time, production in 2013 was dominated by Chile and Australia (see Figure 11), however, substantial nameplate capacity was added from 2015

[4] Although this Reserve/Resource compilation is not necessarily JORC or 43-101 compliant, it is based on audited cumulations, and is, therefore, conservative and reasonably accurate.

onwards, in particular a threefold increase in output from Greenbushes has meant that global production is increasingly dominated by Australia (see Figure 12). This position is expected to be challenged in the near future by new and existing facility expansions, primarily in South America. These include SQM expansion at its Atacama salt flat operations, Australia's Wesfarmers (ASX: WES) FID on the Mount Holland project, Albemarle (NYSE: ALB), readjusting plans to add about 125kt of processing capacity, while IGO Ltd (ASX: IGO) sold its 30% stake in Tropicana, to fund its lithium expansion plans.

Figures 11 & 12: Global lithium production, comparing 2013 (left) with 2020 (right) abundances.





Source: USGS (2014-2021), FD

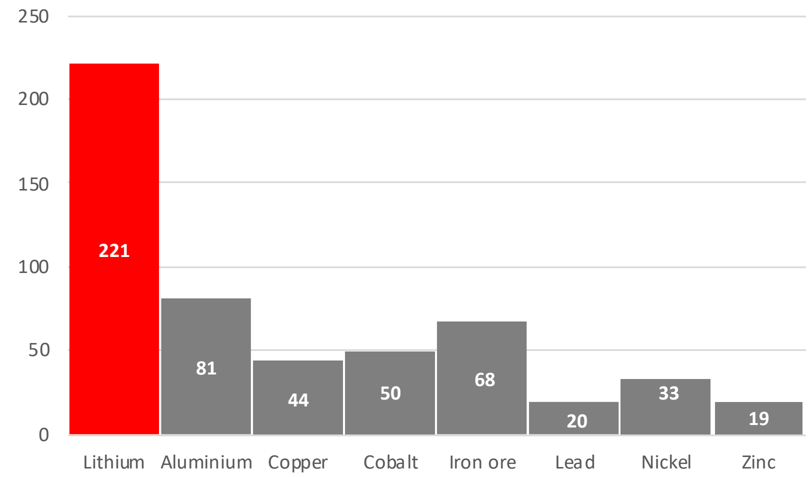
Reserve numbers equate to >220 years supply at current production rates (see Figure 13). If we include Resources, we have an additional ~1,150 years of supply at current demand[5]. However, these kinds of numbers show nothing regarding supply and demand dynamics, or the economics behind extraction. For example, at the height of the last iron ore boom, BHP and Rio were spending, on average, US$200m per Mtpa additional capacity, despite hundreds of years of proven Resources. Despite record prices, only a single company joined the ranks of the seaborne Oligopoly (*i.e.* Fortescue), and much of that can be attributed to a unique individual, an unconventional and (at the time) unproven mining technique.

The key takeaway in understanding future Lithium supply is that the quantum of global resources is meaningless. Despite a 200% increase in global lithium output as a result of various mergers, particularly led by the Chinese, the market has continued to consolidate the existing oligopolistic market structure (see Figures 16 & 17). Lithium supply has to be viewed within certain economic parameters, that the theoretical wave of supply about to inundate demand, will never eventuate; as explained in the following section titled, the "Bow-wave Effect". Not unlike the seaborne iron ore market, the oligopoly market structure allows producers to cut or expand output quickly according to perceived demand or supply, in turn providing a

[5] Geologically speaking, salars and pegmatites remain the most important lithium deposit types in terms of production and undeveloped resources, however, there are some relatively undocumented clay deposits and unconventional brine concepts that could easily add substantial tonnages. Lithium remains relatively under explored globally.

disincentive for other potential participants (*i.e.* Greenfields explorers) to secure developmental funding.

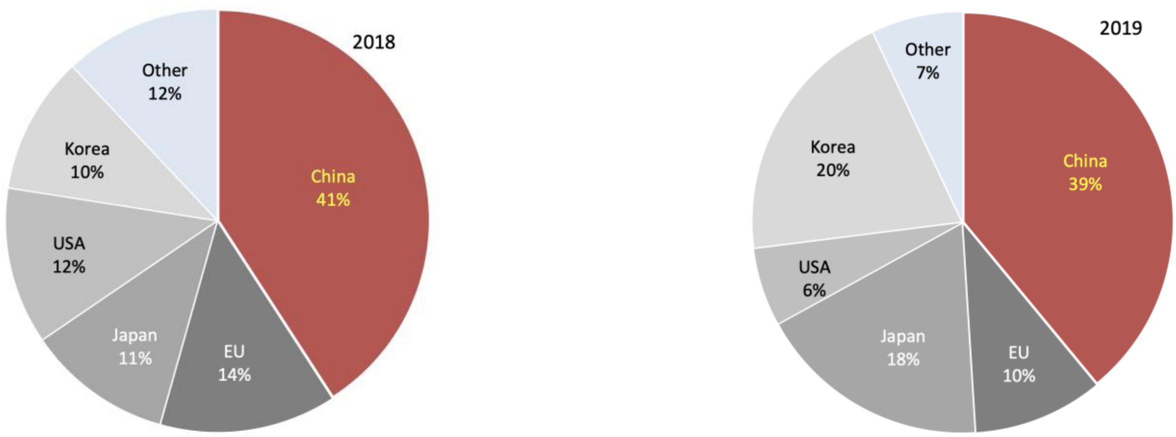
Figure 13: Current Lithium Reserves into comparative context, dividing Reserves over current production (in Years).



Source: USGS (2021), FD

Recent production capacity increases have been driven more recently by Japan and Korea, propelled by EV Li-ion battery demand, accounting for >71% of global sales (see Figure 5). Historically, China's dominance in the lithium market has, in large part, been the result of it being the world's largest EV market in 2020 making up >56% of vehicles sold globally, and >95% of the commercial vehicles in operation; collectively, substantially larger than the rest of the world combined.

Figures 14 & 15: Global segmental lithium consumers in 2018 (left) versus those in 2019 (right), illustrating very recent capacity increases by Korea and Japan.

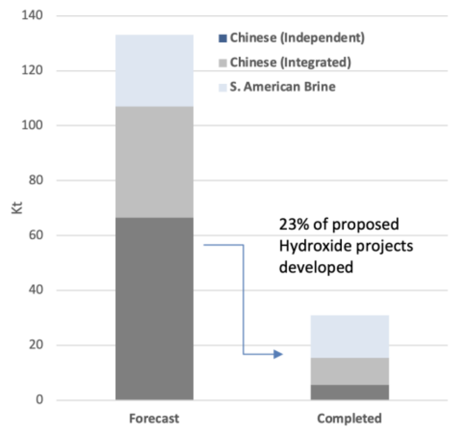


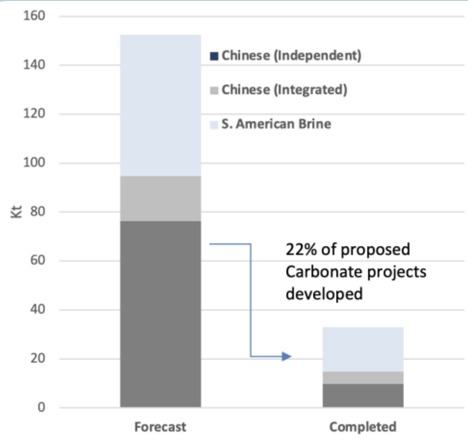
Source: USGS (2019), Statista (2021), FD

"Bow-wave Effect"? Production always less than Forecast!

The phrase "Bow-wave Effect" describes the pattern behind the addition of productive capacity for any commodity (with the exception of gold), which bears little or no relation to the underlying quantity in Resource base. As the analogy implies, the boat that follows behind never quite catches the "bow-wave". Not unlike many other commodities, there is always the appearance of an enormous "wave" of potential Lithium supply about to engulf the market. However, what inevitably comes to fruition, is merely a fraction of stated/planned capacity, and in lithium's case, the vast majority of additional capacity/new projects has been brought online by existing, not new, producers (see Figures 16 & 17).

Figures 16 & 17: Hydroxide-lithium forecast vs 23% actual delivery of plant/project expansions (left); and Carbonate-lithium forecast vs 22% actual plant/project expansions (right).





Source: Source: ORE (2019), FD

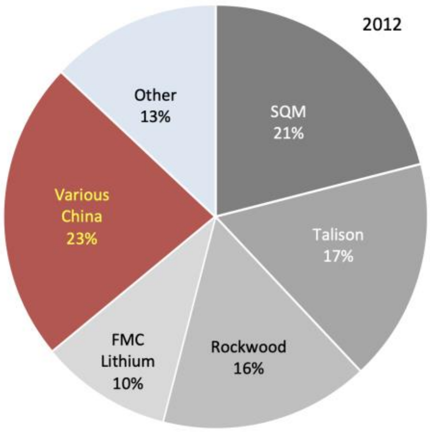
This "bow-wave" analogy has several important market implications, namely:

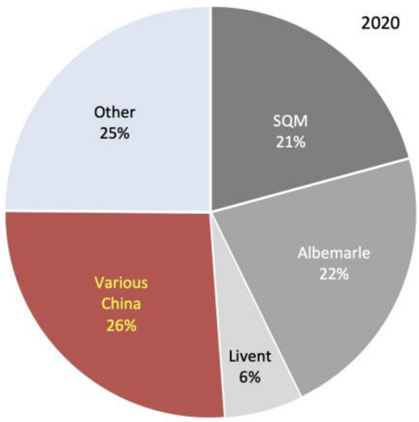
- Only existing (or very few new) lithium entrants will add to primary supply.
- Until recently, there was excess capacity among existing brine producers (rumours that some salar operations were operating at 60% nameplate capacity) will dissuade the debt markets from providing developmental funding to new entrants. This will suit existing market participants, who will continue to actively manage supply to align with perceived demand growth, for at least the next several decades.
- The large existing Resource base (see Figure 8) and surplus capacity from recent developments, coupled with the industry's ability to increase production rapidly, will continue to deter Greenfields investments; and is the primary reason why the lithium market has retained its oligopolistic structure.

The above oligopoly market structure is not dissimilar to what we observe in the iron ore sector, that despite seaborne iron ore tonnages increasing >275% over the past two decades, with the sole exception of Fortescue Metals, virtually all of the additional global seaborne capacity came from three existing iron ore-based Mining Houses; the Australian BHP and Rio, and Brazil's Vale.

In 2012, global lithium production was dominated by four producers (and China). In the intervening eight years, despite global production increasing 100%, primary supply is arguably even more concentrated (see Figures 18 & 19). We believe that this market consolidation will continue to occur despite the fact that we believe that Lithium demand will double over the next decade (see Figure 30). As evidenced with Australia's Orocobre buying Galaxy for $1.4Bn; creating the world's fifth largest lithium miner, combining hard rock, brine, and chemical assets across Australia, Argentina, Canada and Japan. Superficially, there are very few corporate or operational synergies to be gained, other than strengthening its balance sheet (~$487m cash), improving access to finance and streamlining product marketing. Critically, it will allow plans for the merged entity to more easily finance its increased production to >130kt LCE (lithium carbonate equivalent), up from ~40kt currently. Particularly interesting is Rio Tinto's entrance into the sector, following a breakthrough production process at its Boron mine, recovering Lithium from waste piles accumulated over the past 90 years; with a FID pending ($50m capex for 5kt pa lithium carbonate). Critically, Rio has another borate project in Serbia that may also begin to produce lithium as a co-product. If these projects are successful, expect Rio to make a major acquisition.

Figures 18 & 19: Comparing global lithium producers in 2012 (left) with 2020 (right).





Source: SQM (2019), Roskill (2013), RKE (2021), FD

Several existing producers with favourable expansion prospects include:

- **Sociedad Quimica y Minera de Chile** (NYSE: SQM): guidance is 120kt of lithium carbonate and 21.5kt of lithium hydroxide production rate by the end of Q421; to be expanded to 180kt of lithium carbonate and 30kt of lithium hydroxide by the end of 2023 from their Chilean assets. In addition, SQM have made the FID (50/50 JV with Wesfarmers) for the Mt Holland project, involving the development of an open-pit and a processing plant at Mt Holland and a refinery at Kwinana, Western Australia; targeting 50ktpa of lithium hydroxide.

- **Orocobre/Galaxy Limited** (ASX: ORE/GXY): ambitious expansion plans (see above).

Whist we propose that the sector will remain highly concentrated, there are a number of potential unconventional suppliers that we think are worthy of investment consideration. The creative and industrious “potential” for all of these junior projects is that they are either using an existing capex advantage, and/or an uncorrelated income model, which will allow them to enter a market, whilst not having any geological barriers per se, certainly has market and financial moats (*i.e.* barriers of entry).

- **e3 Metals Corp** (CVE: ETMC): utilising existing O&G holes in Alberta, targeting the Leduc Reservoir hosting lithium enriched brines;

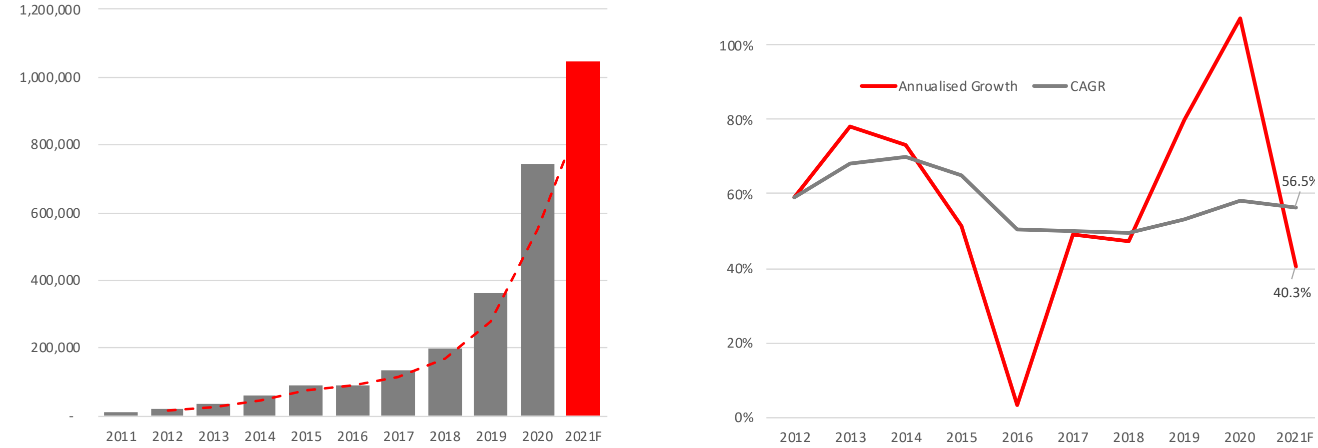
- **Vulcan Energy** (ASX: VUL): plans to harness geothermal energy to produce lithium in the Upper Rhine Valley, Germany; and

- **Cornish Lithium**: unlisted, but we feel it could be a future small company Rockstar, assets include lithium, tin, copper and geothermal (deep and industrial) prospects.

Global BEV Sales Trends

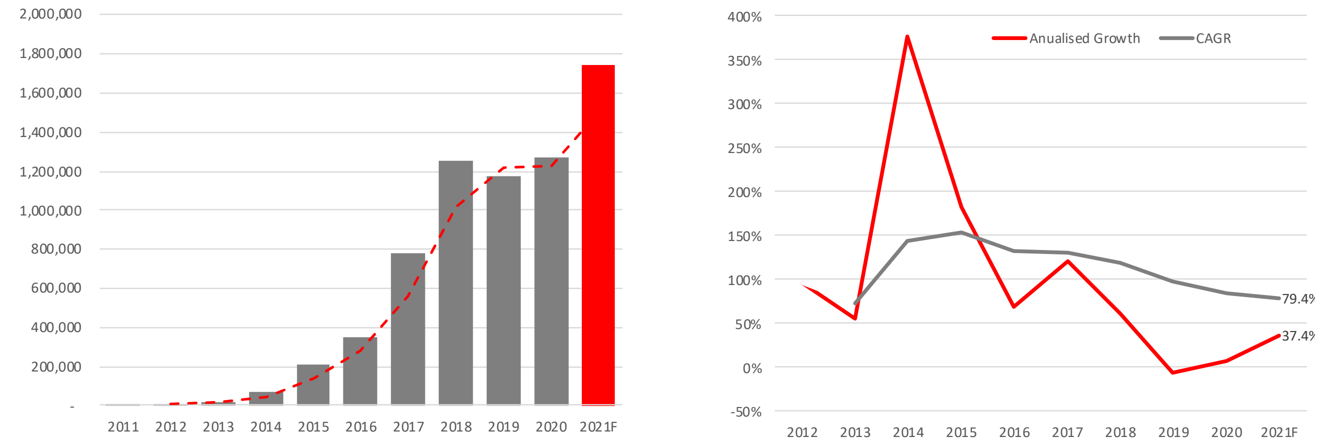
Approximately six percent of new vehicles sold in Europe is now a BEV (nearly 11% if you include plug-in hybrids); with 745k sold in 2020 (see Figure 20), consensus suggesting that BEV sales will increase >40% to ~1.05m in 2021. Unique and unlike China and the US, compound growth has been relatively stable (see grey line in Figure 21). In a market that sold ~9.9m units in 2020, plug-in EV market penetration was ~7.5%, helped by significant State subsidies. Moreover, at its current growth trajectory, there is a chance that the European BEV market will be larger than China's inside three years.

Figures 20 & 21: Newly registered EVs (including plug in hybrids) in Europe from 2011 to 2020E (left); and annualised versus CAGR growth rates over the same period (right).



Source: Forbes (2021), Bellona (2021), FD

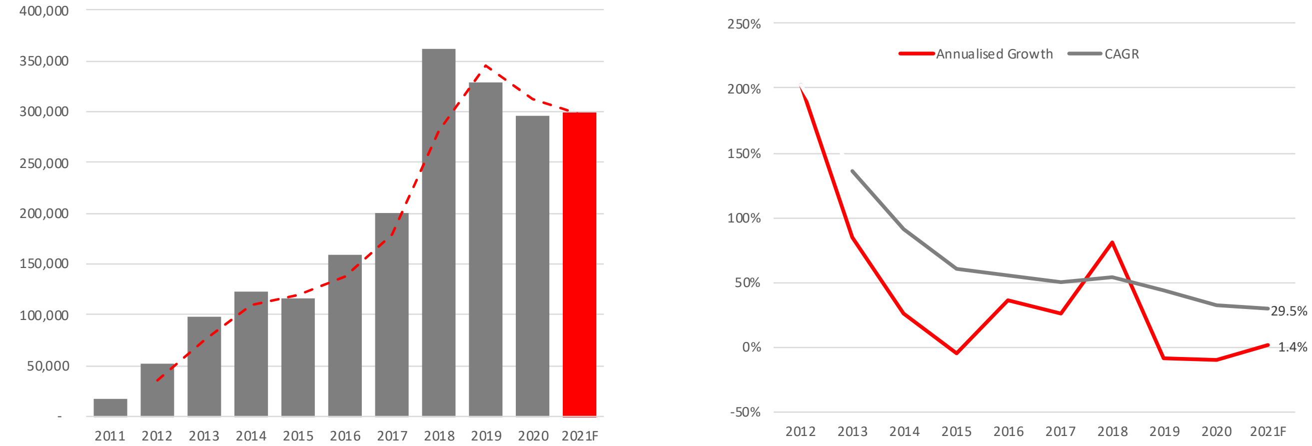
Figures 22 & 23: Number of newly registered EVs in China from 2011 to 2020E (left); and comparing annualised versus CAGR growth rates over the same period (right). 2020 growth in Chinese BEV sales was ~10.5%, recovering from a -6.2% decline in 2019.



Source: WSJ (2021), S&P Global (2021), SCMP (2020), FD

Historically, China has been the largest EV market globally, accounting for half of the world's consumer EV vehicles sold and >95% of the commercial vehicles in operation[6]. Despite the official target for BEVs (including plug-in hybrids) and hydrogen fuel cell vehicles remaining at 20% by 2025, the government will cut current subsidies by 20% this year for private vehicles and 10% for EV public transport, including buses and taxis. Given that EV sales have largely plateaued over the past three years (see Figure 22), coupled with subsidy cuts, our earlier forecast assumed a drop in EV sales to around 2019 levels. However, for reasons largely unknown, possibly related to a combination of stable economic growth, stimulus policies on vehicle consumption, and numerous manufacturer promotions, Q121 EV sales are up ~37% (roughly in-line with ICE sales which are returning to pre-pandemic levels), a rate we have assumed will be maintained until the end of the year.

Figures 24 & 25: Number of newly registered EVs in US from 2011 to 2020E (left); and comparing annualised versus CAGR growth rates over the same period. Estimated growth in EV car sales is ~1.4% in 2021, compared with -10.1% in 2020 and a -8.9% decline in 2019. In a market that sells ~14.45m cars pa, EV market penetration in the US is 2.3% (right).



Source: S&P (2021), EV volumes (2021), Inside EVs (2020), FD

Not unlike China recently, for the moment it appears that BEV sales in the US have peaked, but this may be an aberration, and we await further environmental policies from the new Biden administration. Looking behind the rhetoric of Biden's recent $2.3Tn stimulus package (over a 15-year period), deducting amounts allocated toward manufacturing, semiconductors, job creation, research and utilities, which require little or no commodity input. Only one trillion dollars has a physical asset development bias. In particular:

- $620Bn on transportation including 20k miles of roadway and 10k new bridges; including:

[6] The irony being that China pollutes more than the US and all Developed Countries combined https://rhg.com/research/chinas-emissions-surpass-developed-countries/

- $174Bn dedicated toward EVs, in particular, building 500k charging stations[7];
- $80Bn to clear the repair backlog and modernise rail (passenger, freight trains, and public transit), in particular, the high traffic Northeast Corridor;
- $25Bn on airports; and
- $17Bn on ports, waterways and ferries;

The unifying demand feature of this stimulus package, therefore, is not metals, but cement, aggregates, asphalt and rail. Unlike China (<20%), more than 80% of the US steel production is from recycled sources, their last operating blast furnace was dismantled a decade ago. Moreover, the marginal increase in steel demand annually will only be in the vicinity of 20-30Mt pa, which can be covered by existing capacity. There is some additional demand for copper, but most stocks in that space are already over-hyped and have poor financial fundamentals.

As a result, we believe that by just establishing recharging infrastructure is insufficient to transform US EV sales. It will require either a large increase in fuel excise, and/or the introduction of a large subsidy programme.

[7] This compares favourably with the number of fuel pumps in the US, estimated to be ~920k, via ~115k petrol stations (https://www.marketwatch.com/story/how-many-gas-stations-are-in-us-how-many-will-there-be-in-10-years-2020-02-16), assuming eight pumps per station. It will be interesting to see the effect on encouraging future EV consumers with a rapidly expanded charging network. Although the above budget is spread out over 15-years, so meaning its effects may be hard to monitor.

EV Adoption Increasingly a Political, Not an Economic Narrative

WSJ reported[8] that various auto makers in Europe, including Volkswagen and Daimler have approached a number of European Governments to introduce the new taxes on CO_2 emissions from petrol and diesel-powered vehicles in order to make EVs more competitive; primarily targeting highway tolls or higher fuel taxes. In regards to the auto industry, government/corporate interaction is normal business practice in that engine technologies are strongly dictated by government policy. Diesel engines are not allowed in California as a result of coarse particulate matter generation. Whereas in Europe, as a direct result of German influence (despite the recent VW emissions scandal) diesel technology was strongly promoted via tax relief and subsidies throughout Europe. To a point where Angela Merkel enlisted David Cameron's support in 2013 to delay certain emissions targets, because none of the German car makers could meet them in time.

Table 1: A selection of countries with outstanding proposals to ban the domestic sale of internal combustion engines, and by what date.

France	2040
Germany	2030
India	2030
Ireland	2030
Israel	2030
Netherlands	2030
Norway	2025
Scotland	2032
UK	2040

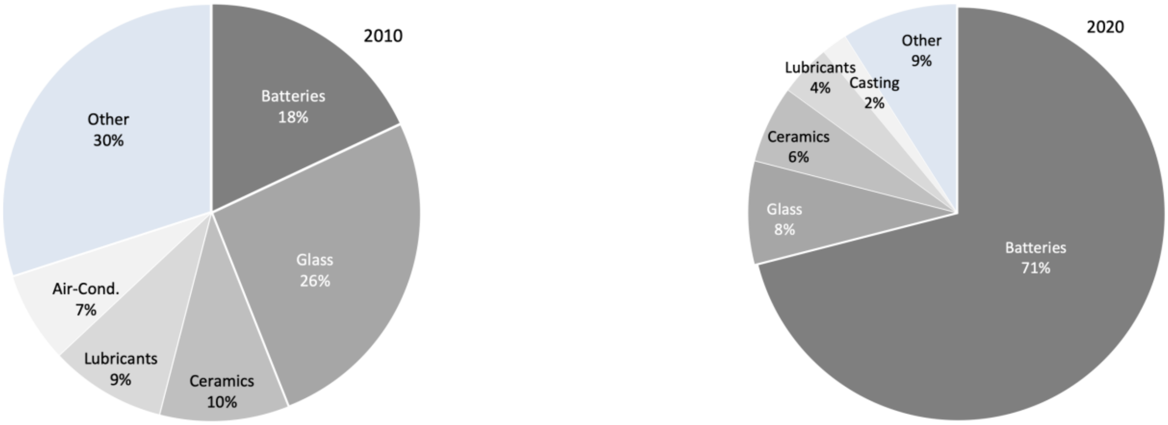
Source: FD

A decade after BEV introduction, however, general uptake has been (to-date) extremely muted, with adoption rates ranging from 2 to 6% in major markets. This is driving government policy to sustain existing subsidies, but increase penalties and legislation to induce consumers choices. Interestingly, there is a clear sales dichotomy between Southern/Eastern Europe compared with more the wealthier Northern Europe (*e.g.* Netherlands, and Nordic countries), with 30% of the total of all EVs purchases being in Germany where a subsidy of up to €9k exists per vehicle, while in Norway, 54% of all new cars sold in 2020 were BEV, aiming to become the first nation to eschew the sale of all new petrol and diesel cars by 2025 (see Table 1). Some of these regional differences can be attributed to more investment in recharge infrastructure, and offering greater cash and tax incentives in order to accelerate

[8] "To Win Electric-Vehicle Wars, Europe's Auto CEOs Want More Taxes on Gas Guzzlers ". *WSJ* https://www.wsj.com/articles/to-win-electric-vehicle-wars-europes-auto-ceos-want-more-taxes-on-gas-guzzlers-11618570821

adoption. But the largest determinant, we believe, comes down to wealth and relative affordability.

Figures 26 & 27: Lithium segmental demand in 2010 (left), compared with 2020 (right) illustrating the growth in battery demand.



Source: USGS (2021), Roskill (2021), USGS (2011), TRU Group (2010), FD

Like all things in life, additional factors make this EV purchase divide more nuanced.

- **EV Prestige**: various studies examining early EV adopters suggest that the ideal demographic are younger London based professionals (UK) to middle-aged men living in rural or suburban multi-person households (Germany); with ownership levels strongly tied to income levels. In particular, their willingness to buy an EV was strongly associated with a perceived higher socio-economic status.

- **Premium Price**: numerous publications are quoting that batteries make up approximately a third of an eventual EV vehicle's cost[9], it begs the question, shouldn't we have seen EV prices fall by the equivalent quantum of the battery input overtime? Yet, according to JATO (2019), EV sales prices in Developed Nations have increased (on average) 42%-55% over the past eight years. Arguments to explain this discrepancy cite consumer demand for luxurious interiors and more sustainably sourced materials, but this rationale fails any simple Empirical test. Does a Tesla use more leather than it did eight years ago? Have LCD centre console screens quadrupled in price? Despite Tesla's unit production increasing 2,100% over the past eight years, has it suffered production cost dis-economies of scale? In all cases, the answer is No!

- **Corporate Fleets**: critically, fleet and businesses, not private consumers are the largest purchasers of BEVs in Europe (JATO, November 2020); therefore,

[9] According to Bloomberg (2020), battery pack prices have recently been cited at less than $100/kWh, by comparison prices were >$1,100/kWh in 2010, implying a price drop of ~88% in real terms. Meaning, if the Tesla 75kWh battery that currently costs around $11,700, would have cost $97.5k a decade ago (if that particular battery existed!). The quoted average ~$US137/kWh or ~$126/kWh on a volume-weighted average basis, ignoring chemistry differences. The greatest cost variance being the cathode, because of the compositional differences, *e.g.* cobalt, nickel and potentially, manganese.

implying that the growth in sales the result is of individual purchase decisions, is possibly misleading. Registrations in Q120 by businesses and fleets accounted for 59% of the EV total, which is not dissimilar to Q119, whereby 54% of BEV transactions were also fleet and business sales. To put that into perspective, conventional European fleet sales as a percentage of total sales typically range from 5% in Belgium to 19.2% in Germany and the UK (Statista, 2021)[10].

We caution investors against accepting that these hard targets as expressed in Table 1, as actuals. They appear to have been imposed without regard to purchase costs, infrastructure or power network investment, and inherent operational limitations based on chemistry. As a result, there are a number of increasingly valid questions that policy administrators need to answer:

- Is total BEV adoption a realistic scenario?
- If not, why not?
- What is a more realistic/sustainable level?
- What type and levels of hybrids will be incorporated into the final sales mix?

The inherent risk with implementation of political ideals without regard to financial realities and/or mobility practicalities of the general populace, is that these policies can be undone via popular dissent. It is in this vein that we pay particular interest to French politics[11] and the election of its President in May 2022.

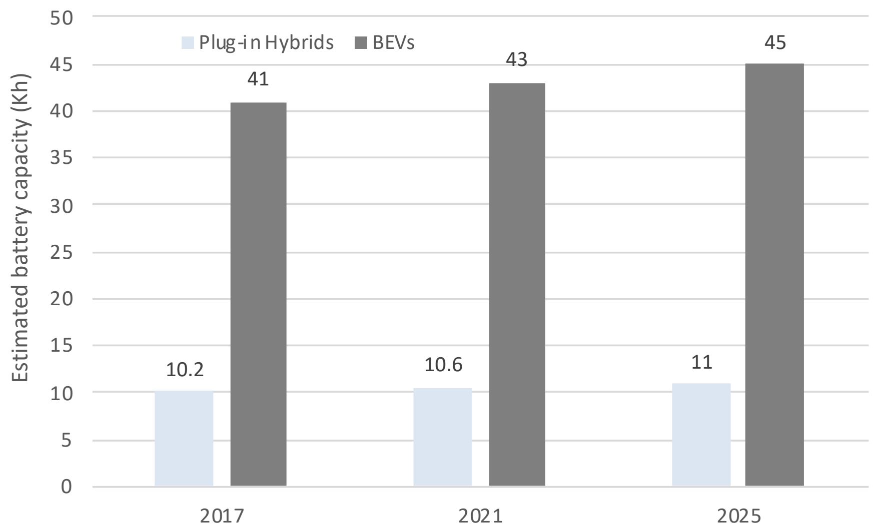
[10] Two possible reasons may include: (i) the rise of low-emissions zones across the continent is incentivising fleet operators to actively avoid the costs of operating an ICE (internal combustion-engine) fleet within a payment area. But the truth is, these low emission zones are not that wide-spread yet; and/or (ii) EVs theoretically require less servicing and lower maintenance than an equivalent ICE potentially lowering overall fleet expenditure. But we note that EV resale figures suffer substantially higher rates of depreciation, and given their higher initial cost of purchase, must considerably offset any conceivable maintenance savings.

[11] Rise of the "*gilets jaunes*" protest movement was initiated against high fuel prices resulting from "eco taxes" meant to dissuade the French from using cars; unfortunately penalised the poor disproportionately.

Effect of Hybrid vs BEV Uptake on Lithium Demand

Historically, it has been very difficult to accurately model future lithium consumption, not only to account for the variance of different BEV battery types and capacities, but to also incorporate the rapid growth in hybrids. A Honda Fit has a 20kWh battery, whilst Tesla S can now be specified to have a capacity of up to 90kWh. Looking at 11 different BEV models, the average capacity was ~39kWh, driven by the arrival of more recent cheaper models, typically with smaller battery capacities; with plug-in hybrid output typically 25% that of an EV (see Figure 28).

Figure 28: European car registration by fuel-type, updated to March 2021. Note, we have attempted to separate BEV and plug-in-hybrid numbers, attributing the latter to overall hybrid sales, believing it's a closer definition fit.



Source: Statista (2021), FD

Evaluating pure hybrid vehicle ranges, we found that they vary dramatically (13 to 50km), with battery capacities ranging from 4-15kWh. The mean/median from our compilation appears to be ~4 to 6kWh. Meaning, if we take a snap-shot in time, it takes approximately eight hybrid vehicles to equal the Lithium equivalence of a single in-situ BEV. The implication being, despite hybrids making up 18% of EU market sales (see Figure 29), in BEV-terms, they only add ~36% of additional overall battery demand, despite being >200% more prolific. Why is this distinction important? As previously mentioned, in the UK, hybrid cars are mandated to be outlawed by 2035, which if enacted, will dramatically increase underlying lithium demand.

To demonstrate the possible effect on lithium demand[12] using different EV types, we have assumed three scenarios assuming the UK continues to sell 2.2m vehicles per annum:

[12] A single Tesla S model 90kWh battery uses 63kg LCE, therefore assume 0.7kg LCE per kWh.

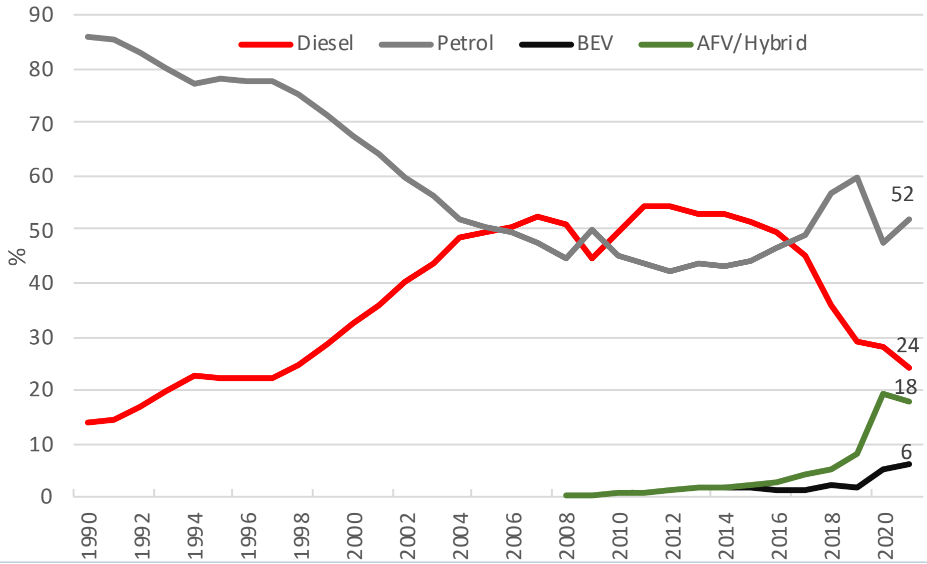
- **In the first scenario**, if 100% of unit sales were BEVs[13], annual UK LCE demand would be ~57kt pa.

- **In the second scenario**, if 20% of unit sales were BEVs, 20% plug-in hybrids[14], and 60% vanilla hybrids[15], annual LCE demand in the UK would be ~19kt pa.

- **In the third scenario**, we assumed 100% of sales in the UK were vanilla hybrids, annual LCE demand would be <8kt pa.

The discrepancy between these three scenarios implies that the variation between different types of EVs (using current capacity averages) can have up to a 640% theoretical difference in the quantum of underlying Lithium demanded. We remind that EU hybrid sales have increased 700% over the past six years (without State financial intervention). By comparison, over the same period, BEV sales have risen a more modest ~163% despite substantial Governmental grants in the form of tax breaks and subsidies. Our working narrative that if a technology is useful and applicable, uptake is inevitable and usually rapid; conversely, subsidies only influence consumer choices whilst they endure.

Figure 29: European car registration by fuel-type, updated to March 2021. Note, we have attempted to separate BEV and plug-in-hybrid numbers, attributing the latter to overall hybrid sales, believing it's a closer definition fit.



Source: ACEA (2021), JATO (2021), Auxiliarie de L'Automobile (2020), European Automobile Manufactures Assoc. (2019), Cargreencongress (2020), FD

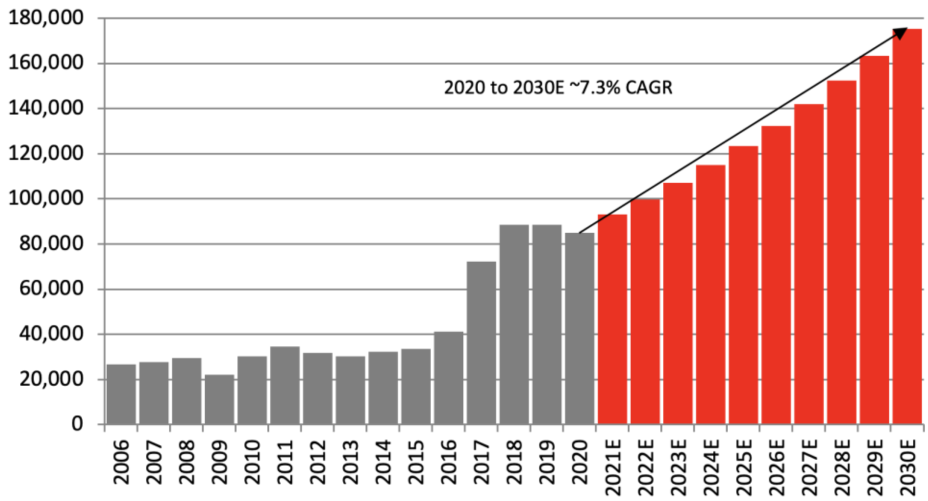
Although outside the scope of the analysis of this report, the growth of E-commerce, especially during this recent pandemic has led to a dramatic increase in demand for individual address deliveries, typically using the ubiquitous white delivery van. Previous analysis of their replacement hypothesised smaller electrified drones incorporating delivery, app and aerial-based autonomous services, although

[13] Assume a 39kWh capacity average.
[14] 10.6kWh capacity average – see Figure 28
[15] 5kWh capacity average

realistically, this appears to have stalled due to logistical difficulties and may now be a more distant aim. Volkswagen, Daimler, PSA Group and Fiat have commenced converting diesel vans models to electric drive, with quoted BEV ranges from 100 to 280km.

Critically, the UK Government is offering a plug-in van grant of up to £8k (£5k more than the equivalent car grant). Critically, real world range, however, is their greatest shortcoming, typically based on theoretical open road distances travelling at 100kmh, non-stop, with no air-conditioning, in summer conditions. Anecdotal evidence suggests that in winter, with frequent stop starts, many drivers struggle to reach 60% of quoted ranges. However, as battery prices continue to drop, capacities are likely to double to allow a realistic alternative to current diesel powerplants.

Figure 30: Global Lithium Production (metric tonnes of contained lithium) with forecast growth expected to double in the next decade.



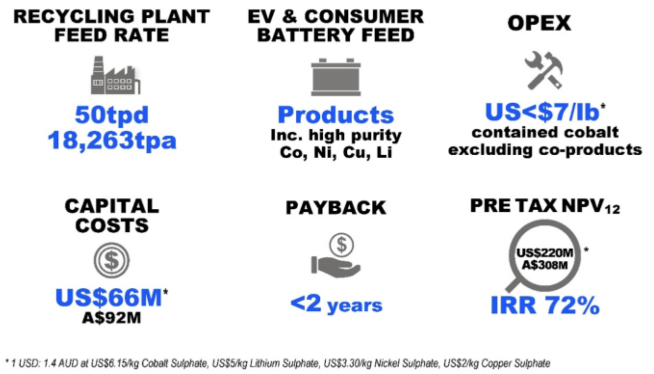
Source: FD

Near-term Recycling as a Secondary Source? Uneconomic!

It is a reasonable assumption to believe that recycling will inevitably play an important component in overall global lithium supply-chain, for example, an estimated ~90% of lead-acid batteries are recycled. Lithium batteries have the capacity to hold and generate considerable amounts of energy, and therefore, if left in storage indefinitely, would pose a significant fire and explosion risk. In Europe, over the past decade, lithium as a percentage of total portable battery takeback, has risen from one to more than six percent. There are two main routes for recovery available: (a) hydrometallurgical, via leaching, where cobalt, copper and lithium is extracted and recovered. The other is (b) a pyrometallurgical process, where the batteries are melted in a furnace then reprocessed. Despite this “inevitability”, as yet the recycling of Li-ion batteries effectively does not yet exist.

Unlike other battery types (*e.g.* Ni-metal-hydride) that are relatively homogenous, Li-ion battery heterogeneity is the result it being a relatively new industry, with various companies creating a plethora of different componentry and chemistries in an attempt to gain a competitive edge. Moreover, in regards to Li-ion batteries, the technology is continuously evolving, meaning that, apart from a generic hydrometallurgical process, extraction could be outdated inside several years. Whilst not presenting the same environmental hazards associated with lead-acid batteries, lithium-ion receptacles have inherent electrical charges, chemical dangers and burning reactants, particularly when exposed to water (*e.g.* UPS Airlines Flight 6)[16].

Figure 31: Summary of a Scoping Study for a Li-ion recycling plant, based in Perth, WA.



Source: NMT (2021)

A study released by Neometals (ASX: NMT) summarises the costs for a 50tpd plant (see Figure 31). It involves a two - stage shredding process, followed by drying and beneficiation to separate coarse metal and plastic from the feed for processing, utilising a hydrometallurgical methodology. The resultant metal materials to be sold as scrap metal. In the modelled financials, there is no allowance for tax, debt or any other type of funding; with an assumed 88% recovery of Co, Ni and Cu contained in

[16] https://aviation-safety.net/database/record.php?id=20100903-0

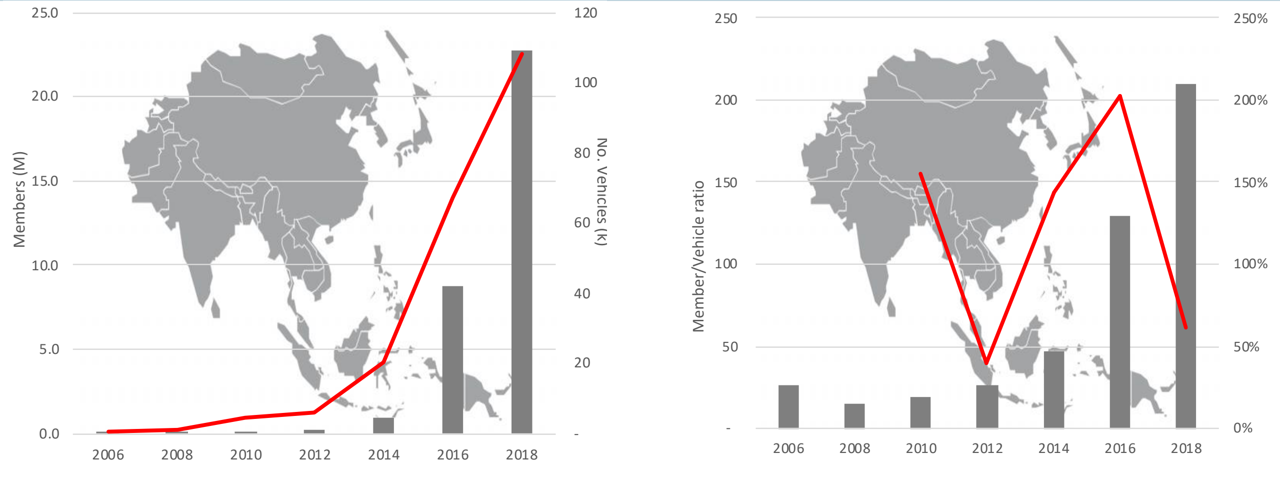
the battery feed material, and a 70% recovery for Li. Although this project is being marketed as a Li-recycling venture, Co contributes approximately 70% of the modelled revenue, underlying the importance of by-product credits. Overall, the modelling implies that the total cost of recycling lithium from batteries is ~400% higher than that from primary supply, underlying the financial challenge.

Economics aside, we cannot envisage a future reality whereby a modern society would allow Li-ion batteries to build up indefinitely without a disposal solution. Concluding that eventually some form of recycling will be mandated, with a likely impost levied Li-ion on the end-user.

Effect of Carpooling on Global Vehicle Growth? Substantial!

We have written extensively on Carpooling, largely based on quantitative research published by Shaheen & Cohen (2020). Not wanting to repeat ourselves, other than to point out that Lithium demand is strongly reliant on the future numbers of vehicles produced. The idea that in 2018 we could have reached global "Peak-Auto", until recently, would have been thought preposterous; with the introduction of several billion consumers from the rise and development of China and India, simultaneously. And yet, sales in many markets had either been stagnating or declining 12-18 months prior to this recent pandemic. To determine what sales projections were for 2030, before carpooling started having a material effect, we refer to McKinsey (2017)[17], who estimated that total annual global vehicle sales in 2030 would be ~115m units (including 10m shared vehicles!). This compares with 63.8m sold in 2019 (56.3m sold in 2020 under exceptional circumstances), not dissimilar to levels sold in 2013.

Figures 32 & 33: Asian number of rideshare members vs number of operated vehicles by providers (left); and number of members divided by vehicles, versus 2-year CAGR (right). With an overall 75% CAGR over the past 13 years, it demonstrated 61% CAGR over the past two-years, indicating market growth is still very strong. N = 10: China, India, Indonesia, Japan, Kazakhstan, Malaysia, Singapore, South Korea, Thailand, and United Arab Emirates.



Source: Shaheen & Cohen (2020)[18], Shaheen *et al*. (2018)[19], FD

What is carpooling? Carpooling and/or ridesharing, is a collective group arrangement that allows individuals to book time slots to use a single vehicle. The proliferation of

[17] Autovista Group (2017) "*Global auto revenue pool to almost double by 2030, with recurring revenue surging to 20% share, says McKinsey*." https://autovistagroup.com/news-and-insights/global-auto-revenue-pool-almost-double-2030-recurring-revenue-surging-20-share
[18] Shaheen S. & Cohen A. (2020) "Innovative Mobility: Carsharing Outlook; Carsharing Market Overview, Analysis, and Trends". UC Berkeley, DOI 10.7922/G2125QWJ. 6 p. https://escholarship.org/uc/item/61q03282
[19] Shaheen S., *et al*. (2018) Innovative Mobility: Carsharing Outlook. DOI 10.7922/G2CC0XVW. 7 p. https://cloudfront.escholarship.org/dist/prd/content/qt49j961wb/qt49j961wb.pdf?t=pa6fa3

UK platforms include Drivy, Zipcar and Liftshare, which underlies the fact that at various times, a vehicle is still a critical requirement. However, increasingly, for many, short notice transportation platforms are now the more flexible, affordable and realistic alternative to car ownership. Weighted-average carpool vehicle to membership ratio using data from Shaheen and Cohen (2020)[20] in 2018 was ~180; whilst Asian membership/vehicle ratios are already at 210. If we assume that 70% of these members forego the purchase of a vehicle, then increasing membership (we estimate 2020 membership at ~59m, see Table 2) will increasingly have a material impact on levels of global car ownership.

Furthermore, we hypothesise that the pandemic will, in fact, accelerate, rather than stymie the transition from car ownership to car use; primarily as a result of economic considerations:

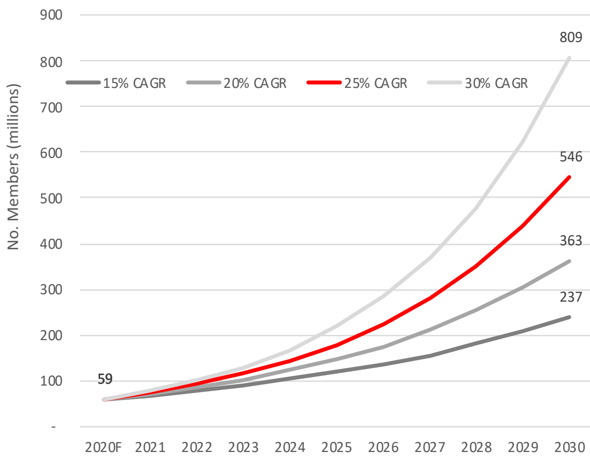
- The largest negative financial impact will be felt by younger adults and the less educated, whose jobs are often in the service and hospitality industries; businesses which in many instances, have either shuttered, and/or will need to reorganise operations to reopen.

- Vehicle ownership is increasingly no longer considered aspirational for younger generations. The reasons are multi-faceted and include increased debt levels, underemployment, inability to afford payments, petrol, insurance, maintenance, repairs; and

- The proliferation of App platforms allow carpooling members, at short notice, to utilise transportation that is flexible and affordable; in the long-term, this presents a realistic alternative to car ownership.

Table 2 & Figure 34: Growth of carpooling/rideshare globally, assuming membership ~59m by the end of 2020 (left); and graphical representation of Carpool/Rideshare members at different CAGR to 2030 (right). NB: 2018 CAGR was ~53%.

		CAGR		
Year	**15%**	**20%**	**25%**	**30%**
2020F	59	59	59	59
2021	67	70	73	76
2022	78	84	92	99
2023	89	101	115	129
2024	103	122	143	168
2025	118	146	179	218
2026	136	175	224	283
2027	156	210	280	368
2028	179	252	350	479
2029	206	303	437	622
2030	237	363	546	809



Source: FD

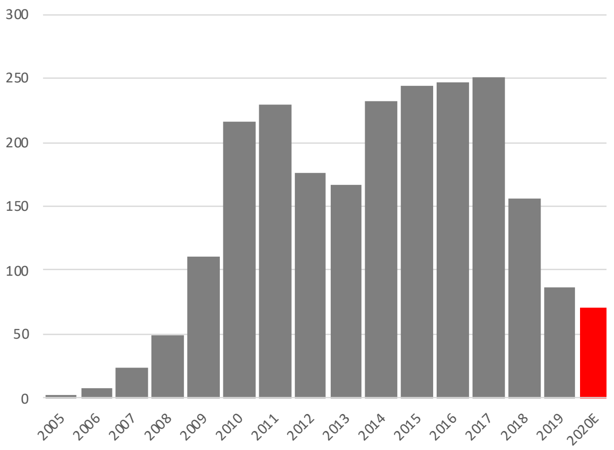
[20] *Op cit.*

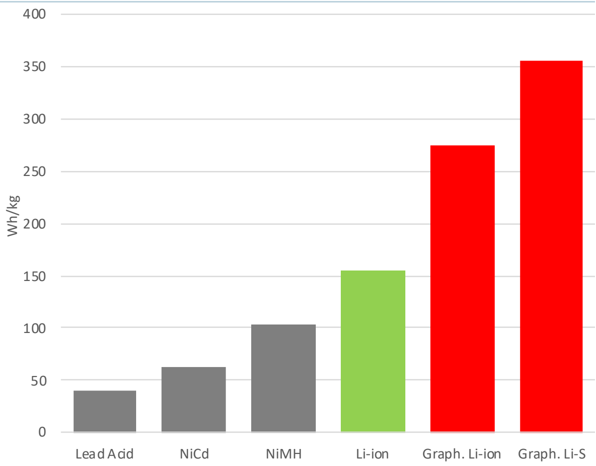
How is this important in regards to predicting future lithium demand? When forecasting future lithium demand, not only will it be critical to predict the levels of BEVs and Hybrids (and type), but increasingly, also the number of vehicles that will be manufactured. Underlying this global paradigm shift of "*car ownership to car use*".

Rise of Graphene/Solid-State Batteries? Not any Time Soon!

The reason why lithium-based batteries are not a certain long-term bet, is the enormous speed at which scientists and engineers are experimenting with new combinations of materials to lower the cost and boost capacity. As a result, it is entirely unclear what the base electric car battery will look like in several decades time, or even, which commodities they will rely upon?

Figures 35 & 36: Patents for graphene related applications (2005 to 2020E) over time have fallen out of favour due to the long development times and costs, and, we assume, technical difficulties (left); and comparing various battery types, in particular Li-ion with the new generation of graphene batteries (right).





Source: European patent office (2020). Bloomberg (2018), NanoGraphene (2019), FD

One the most potent future materials is graphene, the strongest material ever recorded, more than 300 times stronger than A36 structural steel and six times lighter; at 130 gigapascals, it is more than 40x stronger than diamond. The thinnest material known, its crystalline structure elastic, able to stretch up to 20% of its length. A very efficient electrical conductor at room temperature, it can sustain densities six orders of magnitude higher than that of copper; its charge carriers have the highest intrinsic mobility, having the best thermal conductivity of any composite. Lithium sulphur (Li-S) batteries have low toxicity, are low cost and potentially have an energy density of 2,567 Wh/kg^{-1}, five times higher than that of existing Li-ion batteries. Although challenges remain, including inorganic salt deposition at the cathode due to highly soluble reactants within the cell, and the inherent low conductivity of sulphur.

The advantages of a graphene batteries include it being lightweight, durable, suitable for high-capacity energy storage, and potentially, have dramatically shorter charging times (*e.g.* 80% recharge capacity in 8 minutes[21]) than the current generation Li-ion batteries. Li-ion batteries typically cannot handle more than 500 charge cycles, unlike graphene batteries which can handle 1,500 to 2,000. Cambridge scientists (a number of years ago) created a prototype lithium-oxygen battery with a theoretical

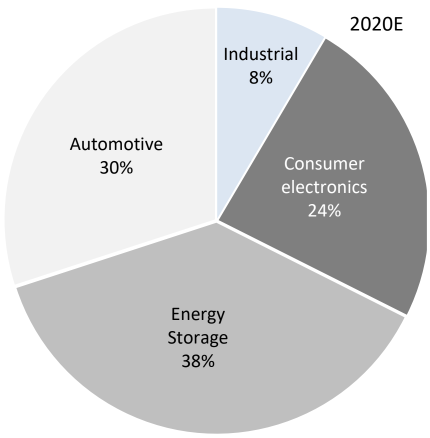
[21] https://www.graphene-info.com/gac-group-announces-its-aion-v-sporting-graphene-battery-will-start-production

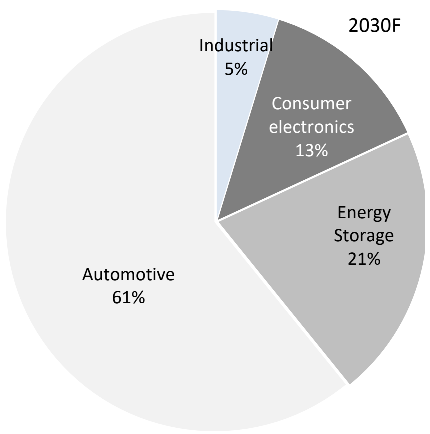
energy density up to 10x greater than that found in current generation lithium-ion cells; researchers claimed that if commercialised, the resultant battery would be 20% the cost and one-fifth the weight of current Li-ion batteries, yet able to travel the 650km (*e.g.* between London and Edinburgh) on a single charge.

The current global market for graphene is tiny by any measure, but it has the latent technical potential to transform macro sectors from batteries, mobile phones to electric cars, even energy harvesting. By contrast, Lithium has several key challenges, it is a relatively poor conductor and physically deforms as it discharges energy, resulting in shearing and cracking. Coating the lithium with graphene oxides reduces both issues, its high conductivity helps keep its shape, allowing the battery to last longer. As an interim step, Samsung engineers have developed a graphene Li-ion battery technology that could result in substantially longer-lasting power packs. Using a silicon anode, researchers grew layers of graphene on top to improve the density and longevity, experiments extending power outputs 50% to 80% greater than those commercially available; theoretically extending a current smart phone battery from 12 to 21 hours. Scalar in application, these batteries could equally be applied to electric cars, allowing them to match the range of their current petrol-powered counterparts.

The closest technological analogy is the transition from incandescent light bulbs to compact fluorescent lamps, which provided the same amount of visible light, but used 20-30% of the electric power, lasting eight to 15 times longer (ignoring health risks). A host of legislation was introduced in a number of developed countries to restrict or outright ban incandescent light bulbs as a matter of public policy, in favour of fluorescent lighting for environmental reasons. After the commercial introduction of LED lamps (which are significantly more energy-efficient than fluorescent lamps), the most efficient of which, are able to produce 200 lumens per watt (Lm/W) , fluorescent lamps became quickly obsolete, without a single Governmental directive anywhere globally. Which underscores our macroeconomic narrative, that less, not more, governmental intervention into technological innovation will ultimately result in better social and environmental outcomes.

Figures 37 & 38: Total lithium-ion revenue breakdown by application in 2020E (left); and application demand for 2030 if the current automotive demand growth differential is maintained (right).





Source: Semiconductor Engineering, Frost and Sullivan (2018), FD

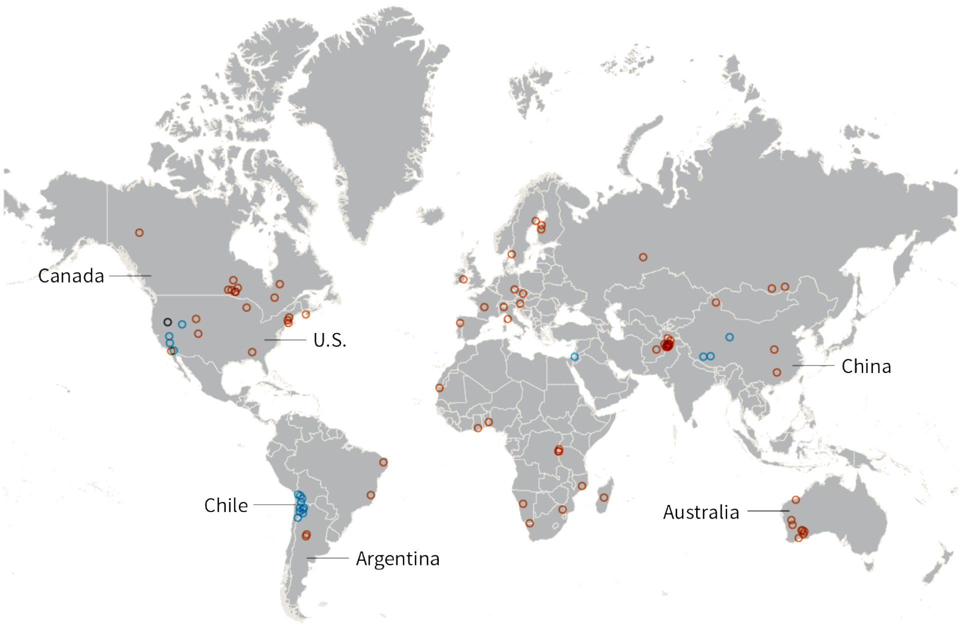
Figuratively speaking, graphene has been on the threshold of transforming our known universe for years, and still, we are waiting! Despite (well founded?) rumours that Tesla are actively developing and experimenting with a graphene battery presently; Samsung's experience is a salient lesson in subdued expectations, primarily centred around production costs and quality control. Despite spending billions in R&D, commercialisation of any of the purposed applications has proven to be far more difficult; with all the graphene applications mentioned in glitzy regular PR releases in years past, quietly shelved.

Li-ion batteries could be around for many decades yet. EV are not yet the largest segment for ion batteries (see Figure 37), but we believe that to be only a matter of time (see Figure 38).

Appendix A – Lithium Geology and Extraction

Global lithium production is approximately 90kt pa (see Figure 1) of contained metal. The two main sources are brine lakes and saltpans that produce the soluble salts, lithium carbonate and lithium chloride; and the extraction of a mineral termed spodumene (see Table 3), a silicate containing both lithium and aluminium. Lithium brine production bodies are found in salt lakes (salars), typically in hyper-saline regions within basins where the lithium is sourced from surrounding rocks (predominantly granites). Extraction involves pumping brines into a series of ponds, which are concentrated by solar and wind evaporation, with a single tonne of lithium requiring ~750t of brine, with the process typically taking 24 months. Further processing of this solution remove other minerals such as B, Mg and K, resulting in a lithium carbonate (Li_2CO_3) product.

Figure 39: Map of global lithium reserves and method of extraction. Orange circles designate pegmatite (hard-rock) lithium deposits, blue circles are lithium brine deposits, with black circles in the US and Mexico depicting lithium clay deposits.



Source: Reuters (2019)

The key Li-mineral in hard rock mining is spodumene (lithium aluminium inosilicate) which occurs within granitic intrusives called pegmatites. Unlike brines, hard-rocking mining is typically well constrained in grade and recoveries, whereby operating costs (excluding mining costs) are largely dependent on the price of raw materials, such as sulphuric acid, soda-ash and energy prices. The end product is typically lithium hydroxide (LiOH).

A third type of deposit (for which very little literature exists), not yet in production, is best exemplified by Hawkstone and their delineation of a clay hosted lithium deposit. Prior geological surveys have identified large areas of hectorite (a magnesium-lithium smectite) in a number of areas: western United States, and potentially, into northern Mexico. The current deposit of interest is interpreted to be a geological hiatus, where intensive historical evaporation occurred (not unlike modern-day Salars in Chile, Bolivia and Argentina). The potential resource tonnages of these deposits dwarf anything we currently know of. The lithium equivalent of oil shales. It doesn't require too much imagination for the development of an in-situ leaching operation extracting the lithium via pregnant solution[22].

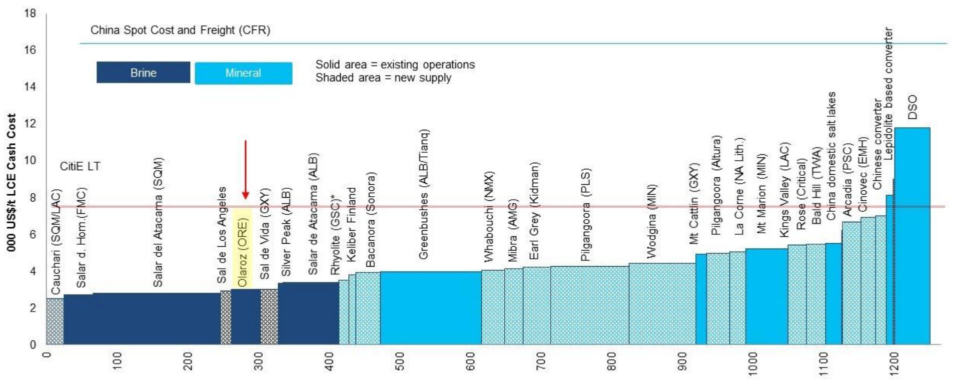
Table 3: Lithium minerals of commercial importance.

Mineral	Chemical composition	Li_2O weight percentage
Amblygonite	$(Li, Na)AL[(F,OH)|PO_4]$	10.0
Lepidolite	$K_2Li_4Al_2[(F,OH)_2|Si_4O_{10}]_2$	5.0
Petalite	$LiAlSi_4O_{10}$	5.0
Spodumene	$LiAl[Si_2O_6]$	8.0
Zinnwaldite	$K(Li,Fe,Al)_3(F,OH)_2(AlSi_3O_{10})$	5.0

Source: USGS 2010, FD

From a macro-sense, the cost curve can be deceptive, as the majority of brine producers, though with a lower C1, typically do not initially meet battery-grade specification (99.5% Li_2CO_3), therefore needing additional processing. Nor does the cost-curve account for royalties, which, dependent on jurisdiction and price, can be substantial. What is clear, amongst the vast majority of lithium producers, is that brine and hard-rock production have costs substantially below spot-price (~$12,000/t). Moreover, the cost curve is extremely flat, with little or no differentiation between various primary suppliers.

Figure 40: C1 Lithium cost curve, differentiating mineral and brine producers.



Source: Citi (2018), Roskill (2018), FD

[22] Similar to that in Kazakhstan uranium operations, with similar grades and related mineralogies.

Research Disclosures

Gaius L.L. King

Gaius L.L King has 25 years' experience in mining, exploration, corporate finance, mineral economics and as a resource analyst. As a geologist, he worked five years in various underground operations, and was involved in discovering and delineating ~2.6 Mt @ 3.5% Ni from a variety of ore bodies. Gaius has analysed fundamental supply and demand of iron ore, nickel, PGE, uranium, gold, REE, borate and lithium, among others. As an analyst, he has specialised in the mid-tier/junior sectors, covering mining stocks on the ASX and AIM.

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