The Battery War

Extrapolation of strong battery demand growth in future triggered a gold rush, resulting in oversupply. This led to a drop in global battery utilization to 50%, bloated inventories and losses for all players across the supply chain. Nevertheless, these global headwinds shouldn't be a deterrent for on-shoring of battery supply chain. India can draw lessons from the US, which is amidst a battery construction boom thanks to IRA and solar module chain where India has used trade protection to build strong manufacturing base. India is targeting 100GWh battery cell capacity by 2030, which would require $13-15bn capex (including for mid-stream). But we estimate PLI subsidy, capped at 20% of sales, is unlikely to be sufficient. We expect >=10% BCD to start with. Ola Electric (NR), Reliance (SELL), JSW Energy (NR) and Amara Raja (NR) are likely to take an early lead in downstream, while Himadri (NR), GFCL (NR), Neogen NR) etc. appear set to benefit from investments in mid-stream.

Capital cycle at play

Global battery demand has clocked 45% CAGR since 2020. But producers extrapolated demand into perpetuity, triggering a gold rush. Many new players entered (including Chinese pureed food company). Demand growth started slowing down around the same time all this new capacity came online. This led to a drop in LiB (lithium ion battery) utilization to just 50% and bloated inventories across the supply chain. Thus, Chinese producers will need to dial back their plans. Abermale recently cut Australian lithium capacities, while the Chinese government has enforced restrictions on cell expansions.

Bleeding across the entire value chain

Chinese capital cost for cell is almost half of that of developed countries ($80mn/Gwh). Nevertheless, most players across the value chain are bleeding at current levels. Current LFP prices imply erosion in implied processing fee for LFP producers. Most battery cell makers are incurring losses. Raw material cost, which is typically >50% of cell cost, has dropped to an estimated $30-35/kwh. We estimate battery pack price of $70/kwh and all-in ESS cost of $120/kwh.

India: Battery on-shoring can draw on learnings from solar module chain

China has managed to secure 70-80% share in almost every post-lithium mining process. While there is global over-capacity, and India lacks lithium reserves and R&D, that shouldn't be a deterrent. Despite similar shortcomings, India has established a strong domestic solar cell/module supply chain, while the US is amidst a massive battery construction boom (aided by Inflation Reduction Act (IRA) benefits). PLI benefits, with 20% cap on sales, are unlikely to be sufficient – so GoI will need to increase PLI benefits in subsequent rounds and/or erect trade barriers in the form of basic custom duties. BCD of 10% as proposed by Niti Aayog may be sufficient to start with, but will need to be dialled up once there is greater need for domestic raw material sourcing. There is a clear case study in solar value chain (PLI initially followed by BCD and then ALMM) that battery chain is likely to follow.

Companies positioned to capitalize across downstream and mid-stream

India is eyeing >=100Gwh of domestic battery capacity by 2030. Indian players such as Ola Electric (NR), Reliance (SELL), Amara Raja (NR) and JSW Energy (NR) have announced ambitious plans to set up battery cell capacity in India, which could capitalize on adjacencies/balance sheet. For 100GWh capacity, we estimate $13-15bn capex, including $9bn on downstream (cell+module+BMS) and $5-$6bn on mid-stream. The US intends to de-risk its mid-stream battery supply chains by diversifying import sources away from China. That could possibly present opportunities for Indian mid-stream producers. Himadri (NR), GFCL (NR), Neogen (NR), Epsilon (NR) appear set to benefit from investments in mid-stream.

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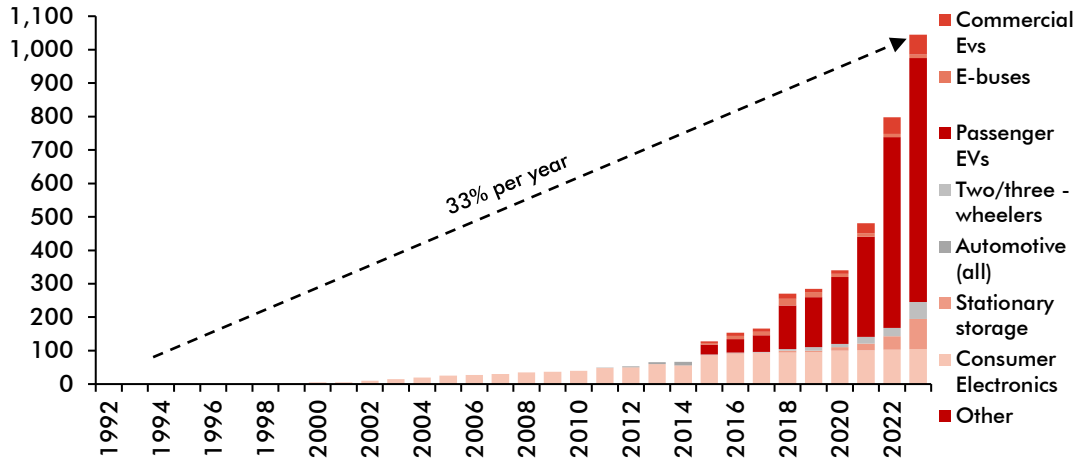
Capital cycle at play

There's a typical capital cycle at play in batteries. Till 2 years ago, everyone was worried about demand outstripping supply, driving shortage of batteries. Everyone from lithium refiners to cell makers started committing capital to capacity expansion. But demand started moderating around the same time this large capacity came online, resulting in oversupply across the value chain, 50% capacity utilization for global cell makers, bloated inventories, and a result losses (and even some bankruptcies) for EV companies, LFP cathode and battery cell manufacturers. Announced capacity expansion by Chinese, European and US battery makers will be more than enough to meet any possible 2030 demand scenario even if were to assume 100% of new car sales would be EVs. Thus, Chinese producers will need to dial back their plans. We have already seen Abermale cut lithium refinery capacities, and China enforce restrictions on expansions. Ultimately, as is with all capital-intensive businesses, supply discipline will coincide with demand rebound, catalyzing a recovery in margins.

Batteries have had a stellar run so far

Demand for batteries has increased at 33% CAGR since 1992. But after Covid, demand has grown at a phenomenal 45% CAGR fuelled largely by increased penetration of EV vehicles. EVs now account for 50% of new vehicle sales in China, up from just 7% three years ago. In the past 3 years, Chinese auto market, the largest in the world, has made great strides in building EV supply chains. It is this demand growth which had fuelled over-optimism amongst battery makers that this growth will sustain into perpetuity.

Exhibit 1: Global demand for batteries has been on an upswing the past few years

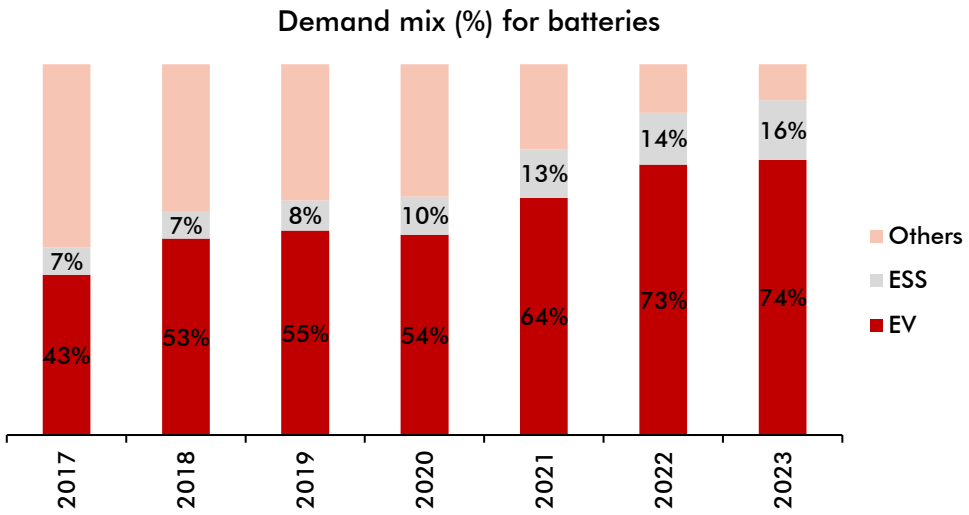


Source: Ziegler and Trancik (2021), Placke et al. (2017) for 1991-2014; IEA, *Ambit Capital research*

Battery demand - EV still account for 75% of total battery demand

Batteries have two main demand centres - EVs and stationary storage (largely for energy shifting for grid). Both these have witnessed strong uptick but EVs still continue to account for 75% of total battery demand. The cell lines/configurations for both EVs and storage applications are difficult, so there is some customization that is required. For EV, energy density is important as higher density = lower weight of vehicles = increased range. Energy density has no real significance when it comes to stationary storage.

Exhibit 2: EVs account for 75% for battery demand

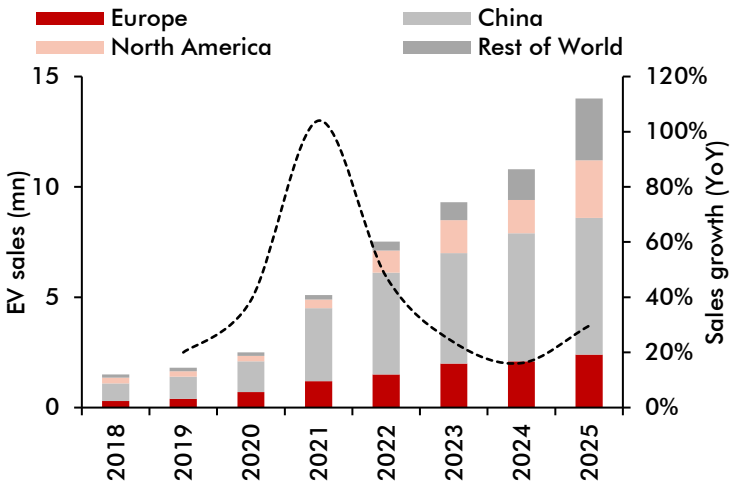


Source: Daiwa Capital Markets, Ambit Capital research

It's the rate of change of growth that matters

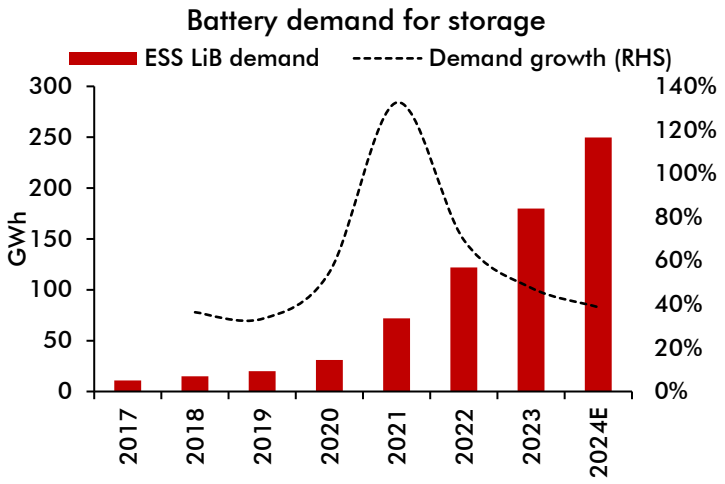
It's not just growth that matters. In certain high-growth industries, it's the rate of change in that growth which holds more significance. There has been a moderation in the growth rates for global EV sales at the same time when there is proliferation of new battery capacities. There has been a multitude of factors at play – in the case of the US & Europe it's been high interest rates, uneconomic uncertainty, lack of charging infrastructure and end of certain subsidiaries for EVs. All of this happened at a time when EV sales make up 50% of new car sales in China – two years ahead of stated forecasts. But lower battery prices are now turning EVs relatively more affordable vs internal combustion engines – so that is an invisible hand that needs to be monitored.

Exhibit 3: But there has been a slowdown lately in the rate of change of demand from EVs



Source: Rho motion, Ambit research

Exhibit 4: It's been a somewhat similar story for energy storage system (ESS)



Source: Daiwa Capital Markets, Ambit Capital research

Typical capital cycle at play

As is the case with any capital-intensive industries, suppliers extrapolate current growth rates into future and commit capital to capacity expansions. By the time capacity comes, expected demand growth doesn't materialize. That is how capital cycles have always played out, from iron ore to steel to cement. In response to strong demand and state's spending plans on this sector, there was a "gold rush" into energy storage in China. Reports indicate that the number of Chinese enterprises registered as energy storage companies doubled. In one storied example, China's largest pureed food manufacturer

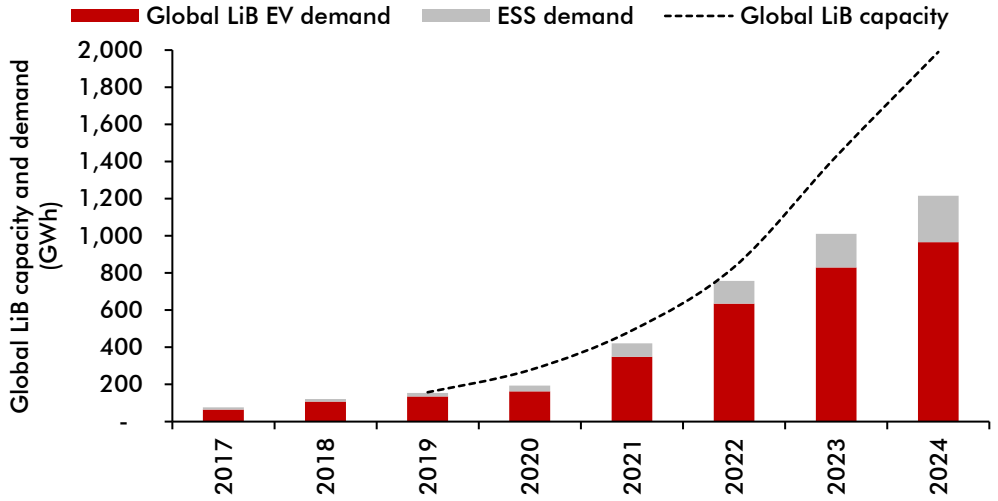
Nanfang Black Sesame Group announced plans in 2023 for one of its subsidiaries to pivot from food to energy storage, by investing $500mn.

Exhibit 5: China has ~73% market share of global battery capacity

Source: S&P Global, Ambit Capital research

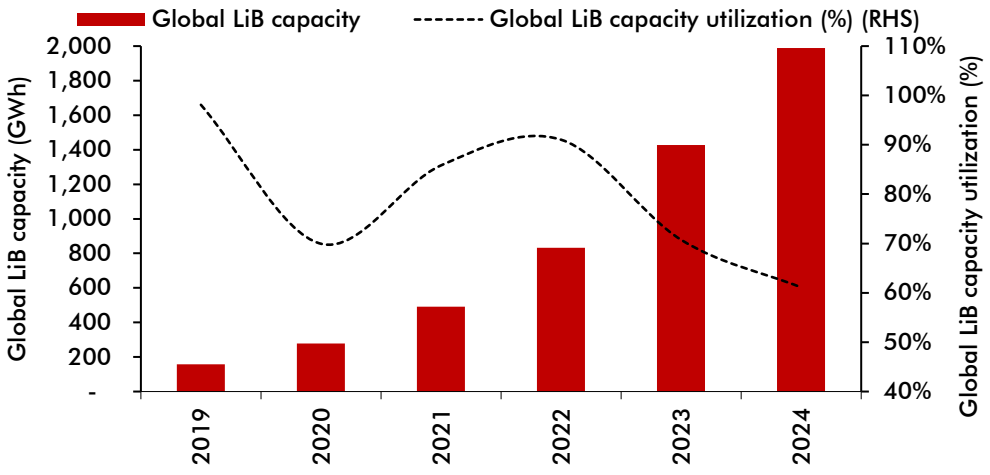
For batteries, the slowdown in the rate of change of global demand growth has forced bankruptcies/curtailments for Chinese EV startups such as Evegrande New energy auto, Aiways and Nituron. This moderation in EV and thus battery demand growth has coincided with a sea of new battery capacity in the market. As a result, supply growth has far outstripped demand growth in the past couple of years. Battery capacity has grown at 66% CAGR since 2020 vs 45% demand CAGR. As per Daiwa Securities Group ("Daiwa"), a minority shareholder in Ambit Private Ltd, the holding company of Ambit Capital Private Ltd, global LiB (lithium ion battery) capacity stands at >2,000GwH as against demand of 1,100-1,200GWh, resulting in capacity utilization of just 50%. This low utilization has resulted in bloated inventories across the value chain and intense price war in the market in order to liquidate excess supplies. Excess lithium carbonate (LiCo3) and LFP cathode inventories are driving lower implied processing fees/negative margins for upstream players, as well as for mid-stream cell manufacturers.

Exhibit 6: The pace of supply growth has overshot demand growth, resulting in oversupply of batteries



Source: Daiwa Capital Markets, Ambit Capital research

Exhibit 7: Capacity utilization of global lithium-ion batteries has dropped to almost 50%



Source: Daiwa Capital Markets, Ambit Capital research

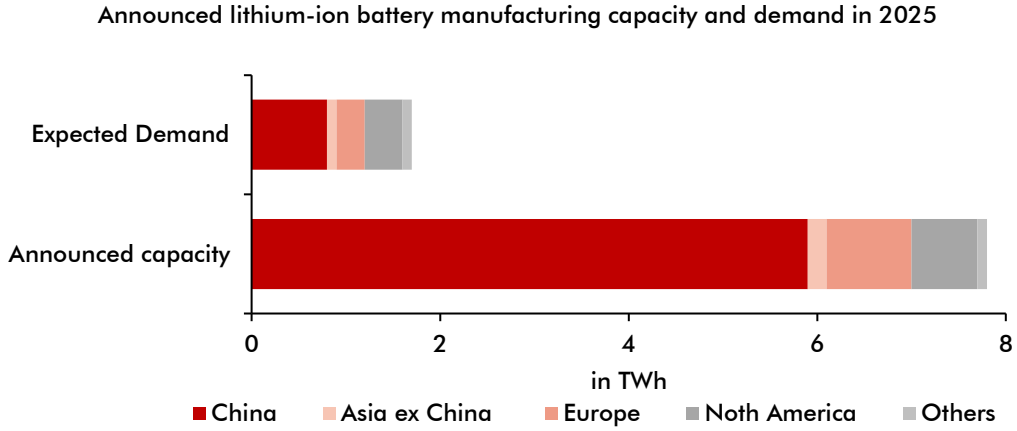
Chinese capacity growth plans need to be tempered

Chinese companies have already announced capacity expansions, which will take Chinese battery capacity well ahead of 2030 global battery demand of 3.8Twh (terra watt hours) outlined by IEA. So, as per Chinese expansion plans, Chinese capacity alone will be more than sufficient to meet 2030 global demand for batteries.

But both the US and EU have operational + committed capacities that can potentially meet their domestic demand, while India is also planning to boost domestic advanced chemistry cell (ACC) battery manufacturing capacity. These countries would also try to protect their domestic manufacturing industries, and some have already started erecting trade barriers. Given how Chinese players are undercutting prices and selling batteries at losses, other countries are likely to boost their defenses, especially given there is a learning curve in terms of productivity and efficiency for new players.

In that scenario, there is no option for Chinese players but to throttle their expansion plans. China has issued new regulations, ostensibly to control overcapacity in the system. China's Ministry of Industry and Information Technology (MIIT) recently issued revised guidelines for LiB industry, setting higher standards for cycle life, energy density etc. In response, some smaller Chinese battery makers have started curtailing some of their expansion plans. China's pureed food manufacturer has cancelled its plans for foray into battery manufacturing.

Exhibit 8: Chinese players have aggressive expansion plans that could potentially aggravate the oversupply situation – these expansion plans are likely to be re-evaluated

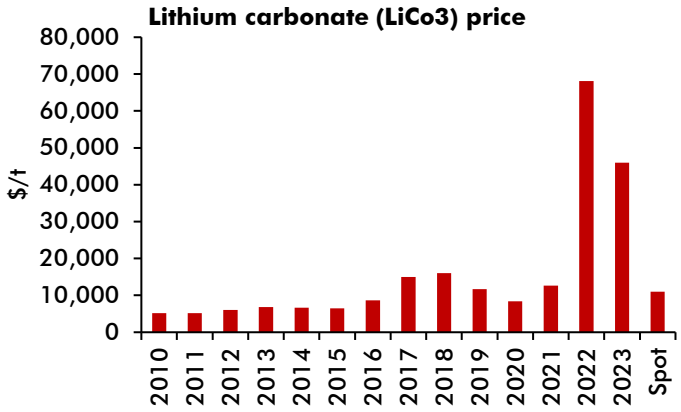


Source: Bloomberg, Ambit Capital research

Oversupply across the entire value chain

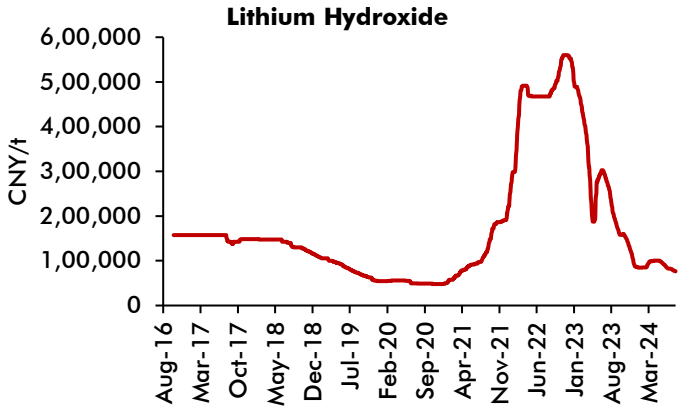
It's not just battery makers, but players across the entire value chain which have over-expanded in response to demand surge during 2020-22. The story is similar for lithium miners, lithium carbonate refiners, cathode and anode producers. For lithium mining, Chile has had plans to double its output over the next decade. When it comes to lithium refining, record high prices in 2021-22 of lithium carbonate/hydroxide spurred massive production growth. But lower-than-anticipated demand growth has resulted in oversupply of lithium carbonate. As a result, there is a drop in process of both raw lithium (spodumene) and lithium carbonate/hydroxide. Current prices suggest lithium refineries are likely incurring losses at current spreads. Electrode manufacturers use lithium carbonate and iron phosphate to make LFP power (cathode) for batteries. Current implied processing charges for LFP also indicate negative margins – a function of oversupply in LFP cathode as well. In response to current weakness in margins for lithium refining (lithium carbonate), Abermale (leading producer of lithium carbonate) recently announced shutdown of half of its processing capacity in Australia. It's also put its expansion plans in Australia on hold.

Exhibit 9: After the post-Covid shortage, LiCO3 prices have moderated sharply on oversupply of refining capacity



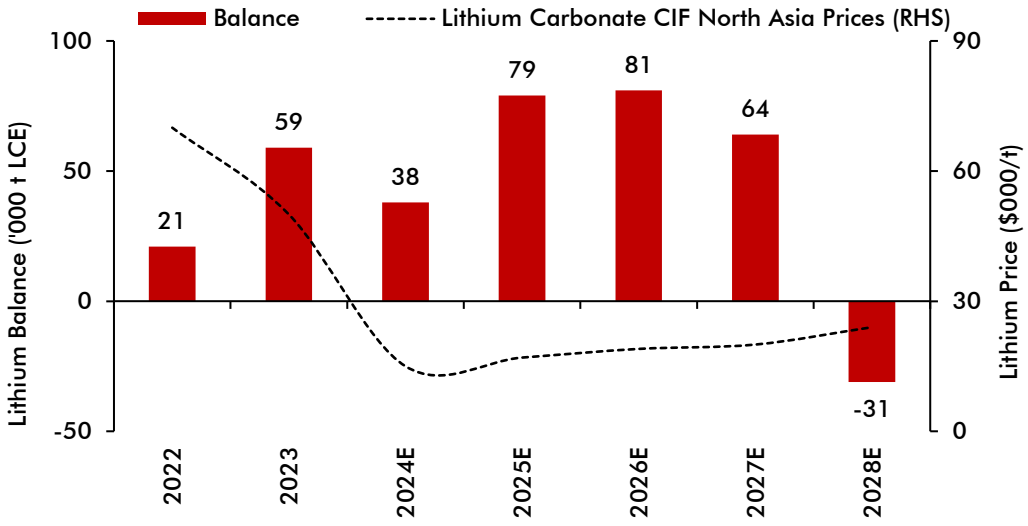
Source: Company, Ambit Capital research

Exhibit 10: Lithium hydroxide prices, key substitute for LiCO3 in cathode (LFP), have also moderated sharply



Source: Bloomberg, Ambit Capital research

Exhibit 11: Oversupply across the board, including upstream refining, where there is expectation of continued oversupply unless some players curtail expansion plans



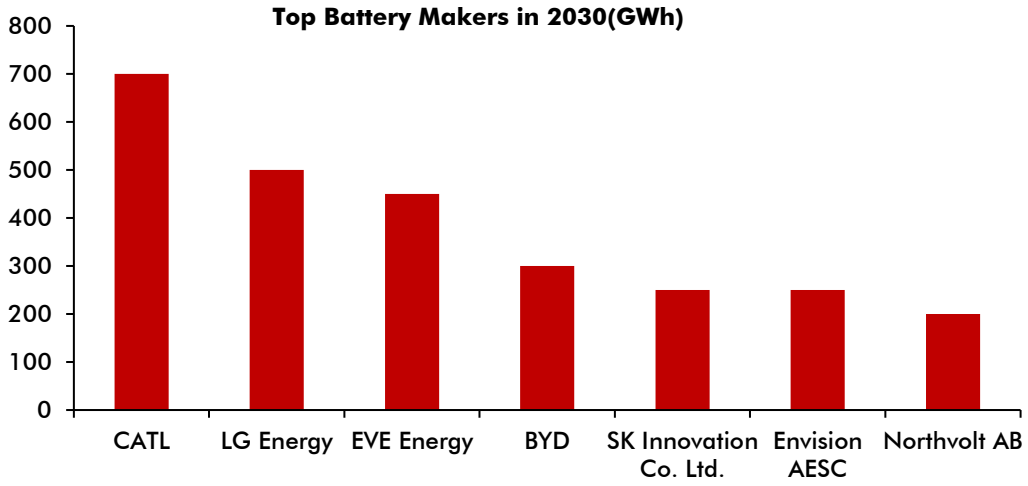
Source: S&P Global, Ambit Capital research

Consolidation is the most likely scenario

The Chinese battery market is divided, with larger players such as CATL and BYD on one hand and smaller players on the other. Bigger players like CATL, BYD, LG, Samsung etc. have the B/S to keep investing in research and development. That's important in sectors such as batteries and solar modules, where technologies keep updating, and old technologies get redundant. Smaller players will struggle to service debt obligation at current prices and utilization, and find cash for R&D.

Larger players have sizeable cash and interest obligation of just 2.5-3% on gross debt. They can fight it out longer than most expect. Low interest cost is a function of savings glut in China. Oversupply of savings keeps interest cost low for Chinese enterprises. It has long been believed that China saves more and consumes less because of lack of social security net (though China economists such as Michael Pettis have debunked that theory). Ultimately savings = investment + current account surplus. If there is excess savings, that needs to be directed to 1) domestic investment and 2) net lending to other countries (through current account surplus). That worked for as long as it did. But if domestic investment goes down, that would require even higher current account surplus. And that becomes incrementally more and more challenging. Ultimately, China will have to pivot away from investment to consumption, and that is already happening. Higher consumption-lower savings, and higher interest cost. There should be capacity rationalization, forced exits – but nobody knows how long this entire process could take to play out.

Exhibit 12: This oversupply and thin margins/oversupply is likely to drive increased consolidation in the Chinese battery production space

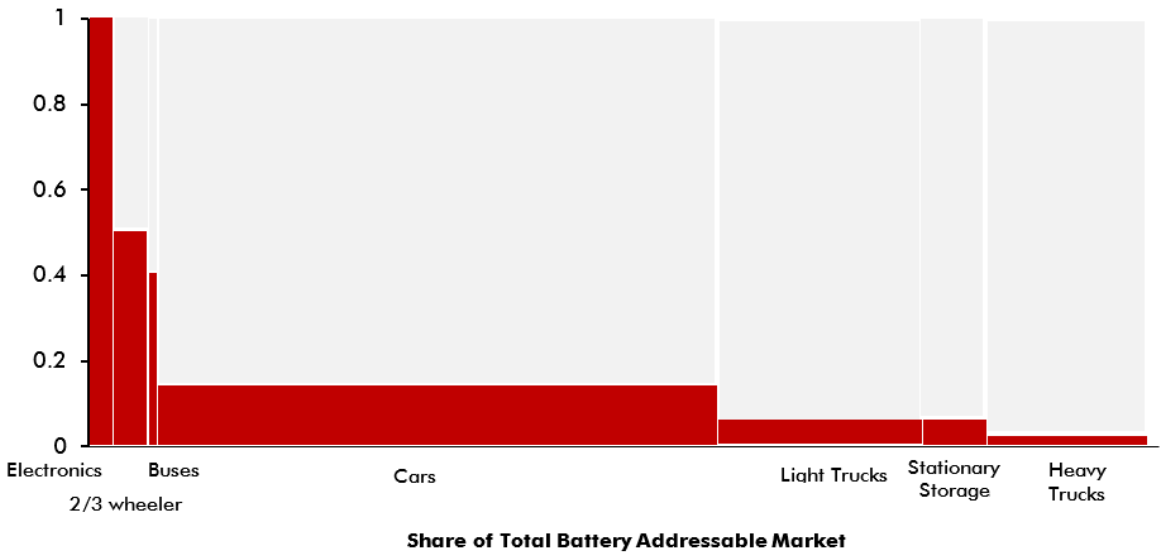


Source: S&P Global, Ambit Capital research

There could be demand revival as well at some point

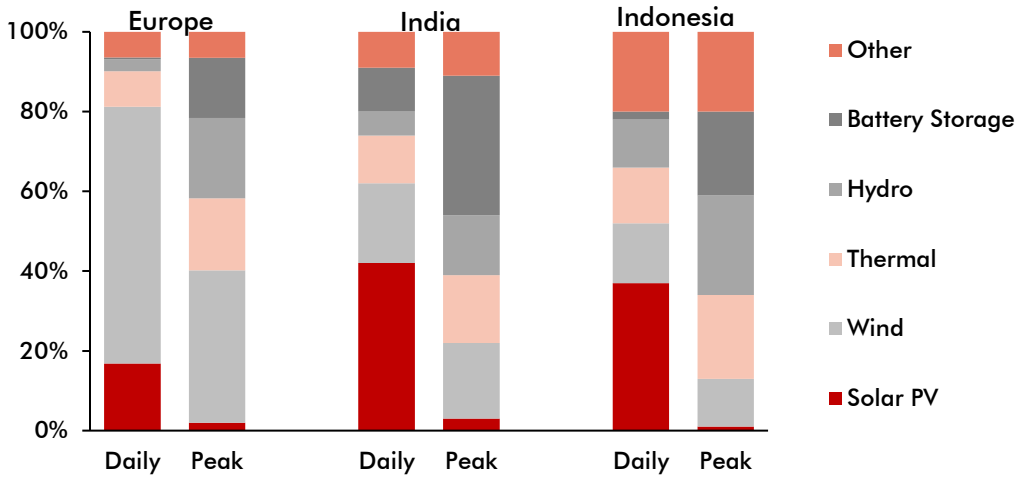
Ultimately, there is a price elasticity of demand. Lower battery prices are turning both EVs and renewable energy+ energy storage (ESS) more competitive vs the alternatives. Lower prices could potentially help increase adoption of batteries in both EVs and ESS. There is a fairly large total addressable market (TAM), much of which still remains untapped.

Exhibit 13: Batteries have so far captured just a small % of overall addressable market – so battery S/D and this prices would be function of how fast batteries are able to capture that TAM



Source: RMI Analysis, Ambit Capital research

Exhibit 14: Within storage as well, batteries have a huge potential, potentially accounting for 35% of India's peak demand by 2050

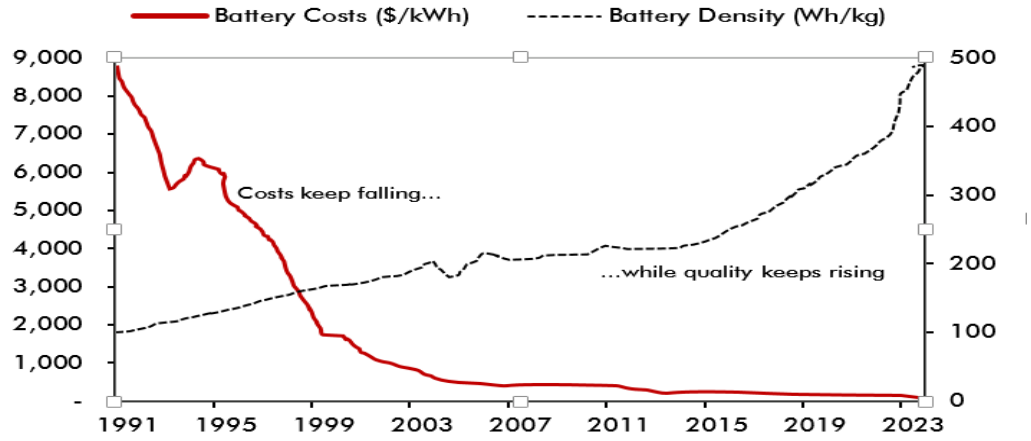


Source: IEA, Ambit Capital research

Batteries – Moore's law at play here as well

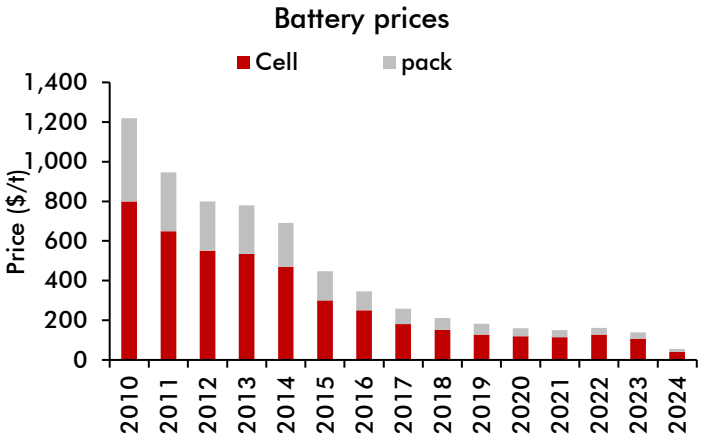
Current margins for battery players are clearly not sustainable. At some point, and nobody knows when, this oversupply should correct and given way to undersupply. That would be driven by supply rationalization and higher demand, resulting in margin recovery. But higher margins may not necessarily translate into higher lithium battery prices. To some extent there has been Moore's law at play in both solar modules and batteries. Moore's law is the observation that the number of transistors on an integrated circuit will double every two years with minimal rise in cost. As a result, semi-conductors have continued to become more efficient and cheaper over time, enabling greater public use (not just defense). A similar story has been at play in batteries to some extent. There have been efficiency gains stemming from bigger giga-factory size (resulting in operating leverage), higher energy density, higher current etc. And these trends are likely to continue. Drop in prices of batteries is a function of both 1) lower margins across the entire value chain and 2) technology improvements. Even if margins improve at some point, it may not necessarily translate into higher battery prices negated by efficiency improvements.

Exhibit 15: Battery prices vs grades - While battery prices dropped, energy density continued to improve; batteries are getting more efficient as well as cheaper



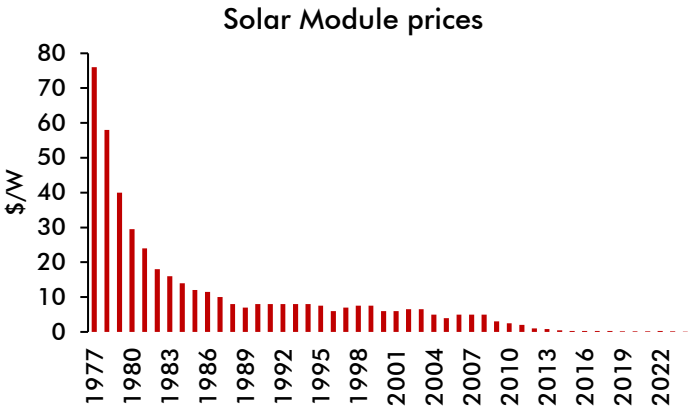
Source: : Ziegler and Trancik (2021), Placke et al. (2017) for 1991-2014; IEA, Ambit Capital research

Exhibit 16: Battery pack prices are now down >90% vs 2010 levels...



Source: IEA, Ambit Capital research

Exhibit 17: ...there has been similar trajectory to that of solar modules, where prices are down 99.9% since 1977



Source: IEA, Ambit Capital research

Battery manufacturing process explained

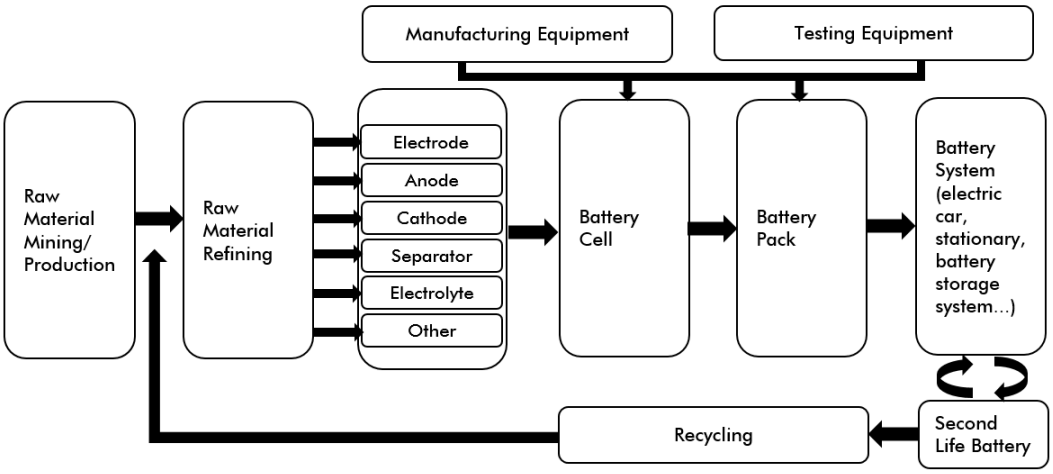
There are three stages to the battery manufacturing process: 1) upstream (mining and extraction of lithium and other minerals); 2) midstream, which includes refining of raw minerals (such as raw lithium into lithium carbonate/hydroxide), and then cathode/anode power production (such as LFFP powder) and 3) downstream, which includes manufacturing of electrodes (cathodes, anodes) and subsequently cells, followed by assembly into battery pack. Downstream process also includes end-of-life lithium battery recycling. The process remains primarily same, whether it is LiB, LFP or NCM batteries. The only difference is the composition of cathode in cell – LFP will have more lithium and iron phosphate while NCM will have nickel, cobalt and manganese. Over the past few years, Chinese producers have increasingly adopted LFP over NCM, resulting in higher share of LFP in global cathode mix (%).

Three stages in a battery manufacturing process

There are three stages:

- **Upstream** - Mining and extraction of lithium and other minerals. Lithium can be either extracted from brines (highly concentrated salt solutions typically found in places such as Chile) or from spodumene (hard-rock found in Australia). At the end of this stage, one gets lithium concentrate which has 6% lithium.
- **Mid-stream** – This process has following sub-processes
  - Refining of lithium concentrate into lithium carbonate (LiCo3) or lithium hydroxide.
  - Production of cathode and anode power. Lithium phosphate power (LFP) is a combination of lithium, iron phosphate and other materials. Anode power is made primarily from synthetic/natural graphite.
- **Downstream** – this stage has the following sub-processes
  - Cell manufacturing – this is further sub-divided into electrode manufacturing and cell assembly
    - Manufacturing of electrode (cathode and anode) – LFP powder is mixed with binder and solvent and pasted on aluminum foil, resulting in cathode while anode material on copper foil resulting in anode.
    - Cell assembly – Assembles cathode, anode, separator and electrolyte to manufacture a cell.
  - Pack assembly – Battery cells are assembled into a pack.
  - Battery container - This is primarily used for ESS. A battery container or unit includes PCS/inverter and cooling system (gas or liquid).
  - Battery recycling - This includes reuse and recycle of end-of life (or even fabricated scrap) batteries.

Exhibit 18: Battery system value chain - from upstream (lithium mining, lithium refining, electrode manufacturing) to downstream (battery pack assembly)

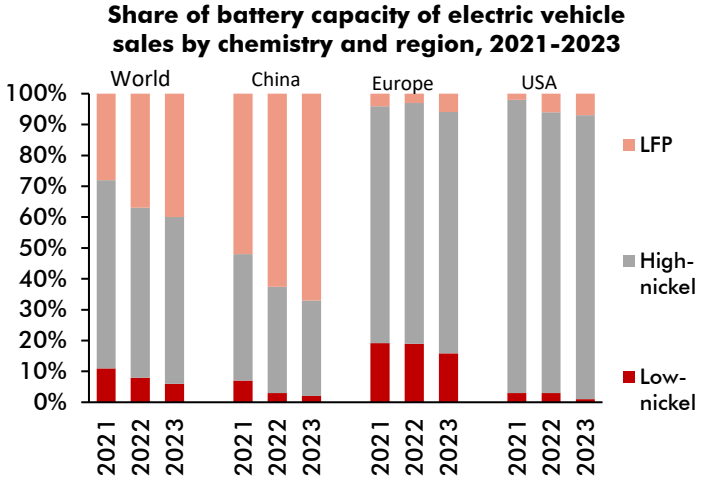


Source: CTVC, Ambit Capital research

LFP has emerged as the dominant chemistry for cathode

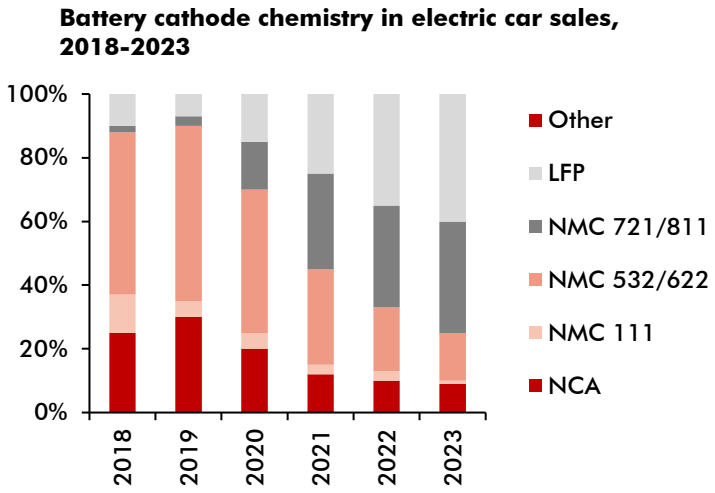
Nickel Cobalt Manganese (NCM) batteries are known for higher energy density vs Lithium iron phosphate (LFP) batteries. Energy density is a key variable for electric vehicles as lower weight helps extend the driving range. High-end EV cars will typically adopt NCM batteries given the higher energy density – but that market is relatively small. Outside of high end EVs, LFP is gaining an upper hand over NCM. Despite relatively lower energy density, LFP has emerged as the dominant chemistry for batteries for China, taking market share from NCM. LFP has emerged as the chemistry of choice given 1) lower cost and 2) stable and safe performance for LFP batteries. Nickel and cobalt tend to be relatively more expensive, thus higher production cost for NCM vs LFP. Economics tends to favour LFP for most uses. Most ESS applications use LFP batteries, as energy density is anyways not a big driver for stationary storage.

Exhibit 19: LFP dominates CAM chemistry in China, and is thus taking market share from NCM globally



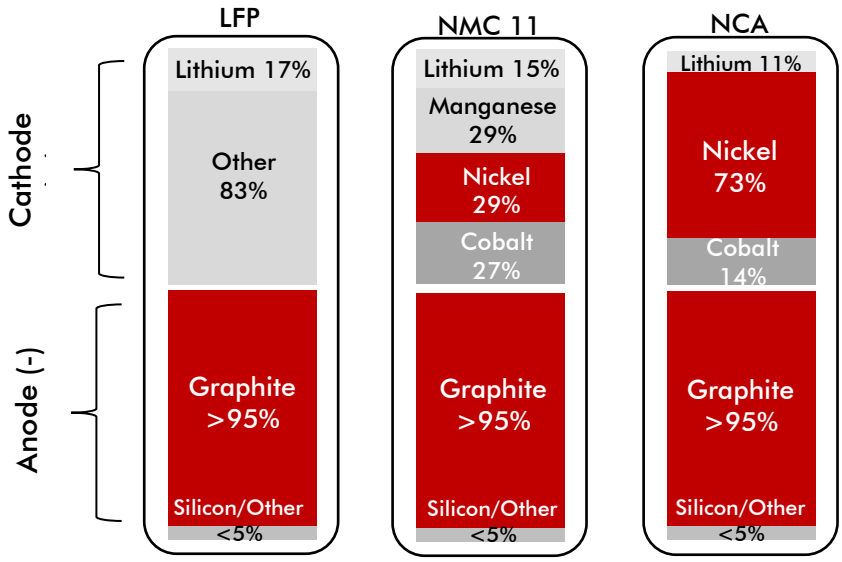
Source: IEA, Ambit Capital research

Exhibit 20: LFP now accounts for 40% of cathode chemistry in global EV sales vs 10% in 2018



Source: IEA, Ambit Capital research

Exhibit 21: There are various possible compositions for cathode, but there is hardly any substitute for graphite in anode making



Source: Pallinghurst-Traxys battery analysis, Epsilon, Ambit Capital research

For our analysis, we have used LFP chemistry as a proxy for batteries.

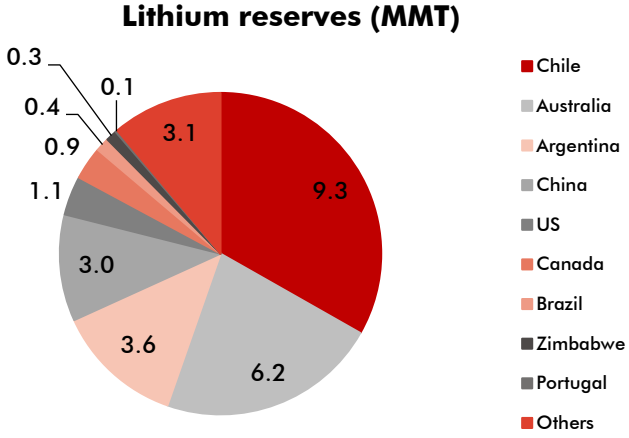
Upstream process

Lithium can be either extracted from brines (highly concentrated salt solutions typically found in places such as Chile) or from spodumene (hard-rock found in Australia).

- **Brine** – Lithium is extracted through solar evaporation from ponds (found in places such as Chile), where brine is naturally concentrated as water evaporates. Lithium extracted from brines undergo multiple treatments like a) adding lime to remove metal traces, b) treatment with soda ash to get lithium carbonate (2kg soda ash used for every 1kg of lithium carbonate) and c) filtrations. But this process requires more time, land area and is more expensive to refine.
- **Hard rock mining** - Hard rock mining process extracts lithium from spodumene but is more energy intensive process than brine. It's usually more effective to refine raw lithium into lithium hydroxide in this stage.

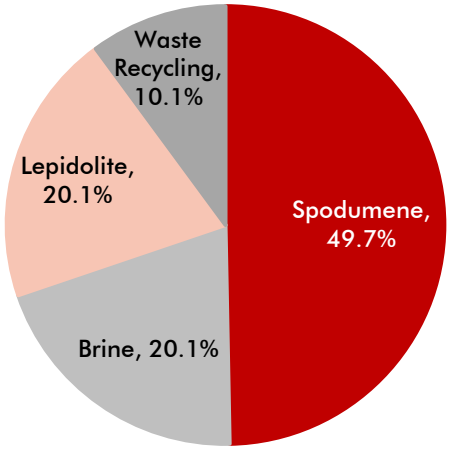
The end-product of this upstream process is a lithium concentrate with 6% lithium. This lithium concentrate is then shipped to refiners in China, where is further processed into lithium carbonate or lithium hydroxide.

Exhibit 22: Global lithium reserve of 28MMT; annual mining of 180KT in 2023



Source: Company, Ambit Capital research

Exhibit 23: Source of China's lithium – hard-rock spodumene (most of which from Australia) accounts for half of lithium source for Chinese lithium refiners, while brine (usually from Chile) accounts for 20% of lithium source



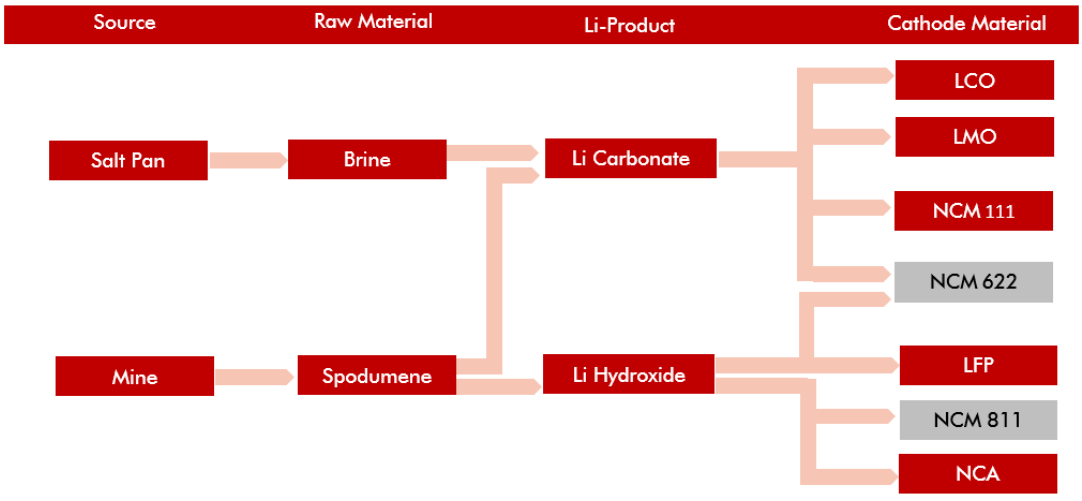
Source: Mining.com, Ambit Capital research

Mid-stream process

Midstream process includes 1) lithium refining as well as 2) production of LFP powder.

- Lithium refinery is the process of converting lithium concentrate into lithium carbonate/hydroxide- which has higher concentration of lithium.
- LFP (cathode) powder (LiFePO4) is formed in an electric hearth furnace by combining lithium carbonate (LiCo3), iron phosphate and some other chemicals. Each tonne of LFP cathode requires 0.15-0.25 tonnes of LiCo3 with the remaining being ion phosphate and other chemicals. The end-product is a carbon-coated LFP power.

Exhibit 24: Stages to Lithium process – from mine/salt (upstream) to concentrate to finally LFP power in cathode

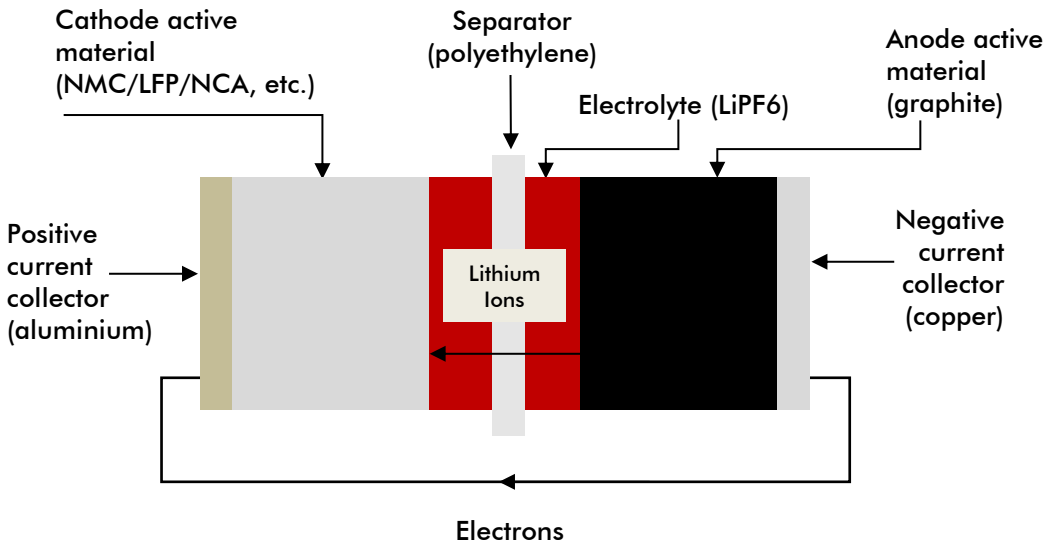


Source: Volkswagen, Ambit Capital research

Downstream process

A lithium cell is characterized by the type of electrode (mainly cathode) and the shape of packaging (cylindrical, pouch or prismatic). Key components include a) cathode active material (CAM), b) anode, c) electrolyte, d) separators, and e) body material. Electrolytes are further divided into a) salt, b) solvent and c) additives.

Exhibit 25: Components of Lithium Ion Cells – it consists of cathode, anode, separator, electrolyte and current collectors



Source: Kwade et al. 2018; Miao et al. 2019, CEEW, Ambit Capital research

Here are the components of a battery cell:

- **Cathode – a positively charged electrode**: Cathodes are the highest-value component of a lithium cell, and is the source of energy within a lithium cell. A battery is usually named after the type of cathodes used in its lithium cells. Key CAM (cathode active materials) include LFP (Lithium Iron Phosphate), NMC (Nickel Manganese Cobalt), LCO (Lithium Cobalt Oxide), NCA (Nickel Cobalt Aluminum Oxide) etc. CAM comprises carbon black, organic solvents and binders (PVDF) which hold the active materials together. Generally, 2kg of LFP cathode active material is used per kWh of battery cell. Thus, 100Gwh of battery would require 200,000 tonnes of CAM. Since CAM has 15-25% lithium carbonate composition – 100Gwh battery requires 30,000-50,000 tonnes of LiCo3.
- **Anode – a negatively charged electrode -** As current flows from cathode to anode (opposite of electron flow), anodes have current collectors coated with graphite and silicon. Generally, 1kg of anode is used per kWh of battery cell. Given graphite forms 95% of anode, 0.95 kg of graphite is required per kwh of cell. 100Gwh would require 95,000 tonnes of graphite.
- **Electrolytes** are salts and additives (vinylene carbonate etc.) suspended in a solvent (carbonate based solvents). Salts and additives are about 50% of the electrolyte cost but 15-20% of its weight. Solvents are large-volume chemicals accounting for ~80% of electrolyte's weight. Electrolytes are critical to the life of the battery and its endurance. Additives help in stability of the lithium cells.
- **Separators** are porous (allow flow of ions) but the insulating barrier between anode and cathode. Polyethylene, polypropylene and PTFE membranes are usually used as separators. Most of the packaging companies in India like SRF, Polyplex, Uflex etc. may extend their value proposition by developing special battery-grade films for such applications.

Exhibit 26: Costing usually varies based on chemistry but broadly CAM is the largest RM cost component of a lithium cell

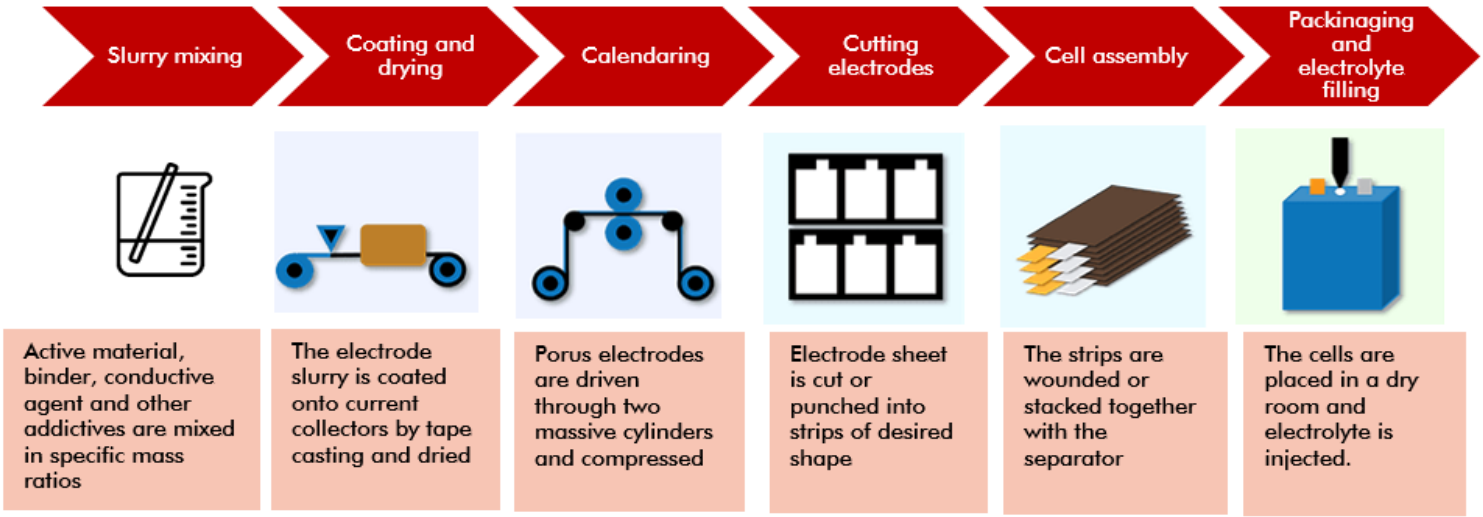
Materials	Cost contribution	Remarks
Cathode	30-35%	▪ Cathode active material generally defines the lithium cell and its characteristics. ▪ Some of the most common lithium-ion variants are NMC, LFP, NCA, LMO, and LCO.
Anode	15-20%	▪ Carbon graphite of high-purity grade with fluoropolymer binders.
Electrolyte & salts	10-12%	▪ Electrolytes are liquid carbonate-based organic solvents. ▪ Solvents comprise lithium salts and additives.
Separator	8-10%	▪ PP/PE or PTFE film of a dielectric nature offering a) stability, b) strength, and c) porosity.
Copper foil	15%	▪ Acts as current collector on anode
Other	15%	

Source: Neogen, Niti Aayog, Company, Ambit Capital research

Here are two key stages of cell manufacturing:

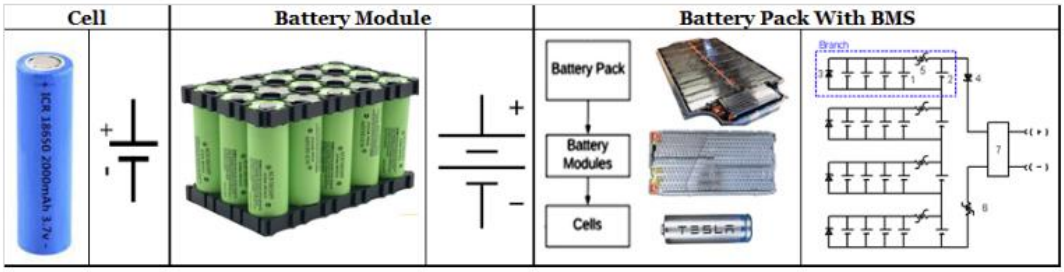
- **Electrode fabrication** - This involves two stages 1) mixing and 2) coating. Cathode/anode materials are dissolved separately in a solvent and mixed into a wet slurry. This wet slurry is then coated on a metal foil surface - cathode on aluminum foil and anode on copper foil.
- **Cell assembly –** This involves calendaring, slitting, cell formation and then cell testing and packaging.

Exhibit 27: Production steps for lithium-ion battery cell - from electrode manufacturing to battery packaging



Source: Company, Ambit Capital research

Exhibit 28: Cell is the unit power source of a battery pack



Source: EV reporter, Ambit Capital research

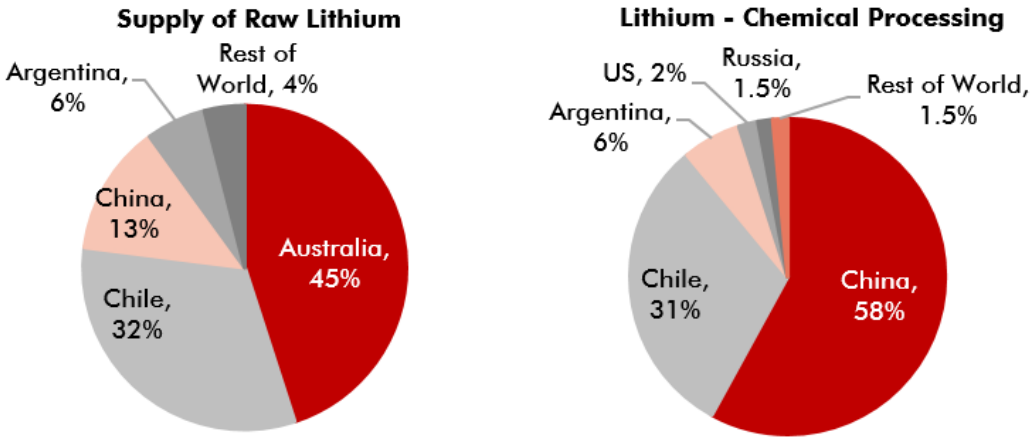
Exhibit 29: A BESS system consists of a container that houses several battery packs as well as PCS/inverter and cooling system

Source: Jinko Solar, Ambit Capital research

China's dominance across the value chain

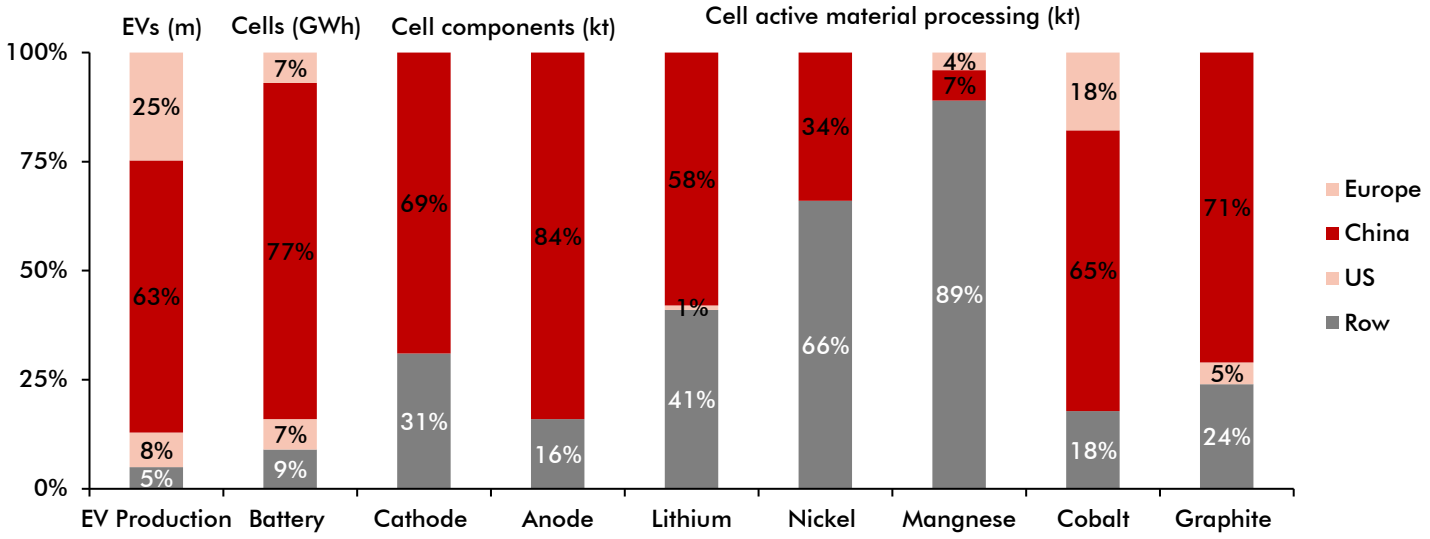
Even though China owns <7% of the world's lithium reserves, the country has managed to secure 70-80% share in almost every single post-lithium mining process - lithium & graphite refining, cathode & anode production and cell manufacturing. These are all capital-intensive processes, in certain cases energy-intensive and labour-intensive as well. These process require constant research and development (R&D). Like most manufacturing industries, China has built a dominant position across the entire battery value chain.

Exhibit 30: China has limited reserves of lithium, but it dominates processing/refining of lithium into lithium carbonate/hydroxide



Source: Benchmark Mineral Intelligence, Ambit Capital research

Exhibit 31: China is dominant across the entire battery value chain, commanding 60-90% market share in various stages of battery production



Source: IEA, USGS, ABB, Ambit Capital research

LFP pricing is dissuading progress on sodium-ions

LFP and NCM have very similar cell structures; the only difference is in the chemistry of cathode active material (CAM). Otherwise, both have similar anode, separator, electrolyte etc. But sodium ion and solid-state battery have slightly different cell structures vs LFP. Sodium-ion deploys a sodium-based cathode, and has hard-carbon anode. Solid-state batteries have a solid electrolyte vs liquid for both LFP and sodium-ion. But the sharp decline in LFP price is dissuading investment on not just NCM, but also on sodium-ion batteries. LFP batteries have higher energy density vs sodium-ion; thus sodium ion appears less amenable to adoption in EVs (barring maybe certain high end EVs). Also, sodium-ion cells were historically known to have longer cycle life. But LFP has made massive strides on that front as well.

Exhibit 32: Lithium-ion vs sodium-ion and solid-state batteries – current LFP prices have turned sodium-ion unviable for now

	LFP	Sodium-ion	Solid-state battery	Comments
Cathode	lithium based	Sodium based	Same compounds as LFP	
Electrolyte	Liquid electrolyte	Liquid electrolyte	Solid electrolyte	
Anode	Graphite	Hard carbon	Lithium metal	
Anode current collector	Copper foil	Copper foil	Aluminum foil	
Energy Density	200 wh/kg	150 wh/kg	>300 wh/kg	Sodium-ion is unlikely to find many takers in EVs, given lower energy density
Life cycle	7,000-10,000	5,000	>10,000	LFP used to have shorter cycle life, but has improved past few years (Indian KPIT has unveiled technology with longer cycle life)
Cost	Low	losing edge to LFP	High	The sharp drop in LFP prices has turned sodium-ion uncompetitive
Commercial scale	Well adopted	Still limited commercial adoption	Very nascent	

Source: Company, Ambit Capital research

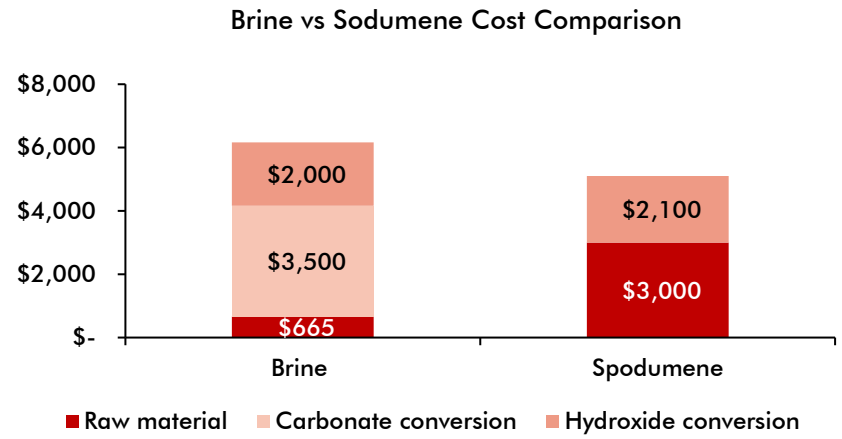
Bleeding through the entire value chain

Battery economics would vary based on location. Chinese producers enjoy lower labour cost (vs developed nations), lower finance cost (pre-tax interest cost of 2.5-3% for many borrowers), state incentives/subsidies. Chinese capital cost for cell is almost half of that of developed countries as some of the existing plants have brownfield potential, thus lower capex cost. Nevertheless, most players across the value chain are bleeding at current levels. Raw material cost, which was typically >50% of cell cost, has dropped to estimated $30-35/kwh (now >=70% of cell cost). We estimate $80 mn/Kwh cell greenfield capex for a large gigafactory ex-China, with China being 40-50% lower. Chinese players have the benefit of 3% pre-tax interest cost and at this stage of business cycle they are not worried about replacement value (0 depreciation) and are not earning RoE given losses. Hence, we estimate battery pack price of $70/kwh and all-in ESS cost (including EPC) of $120/kwh.

Lithium processing – it's cheaper to refine from spodumene

Brine-based lithium is cheaper, but entails higher processing cost. That's why it's not surprising to see spodumene account for almost 50% of raw material feed for Chinese lithium refiners.

Exhibit 33: It's usually cheaper to produce lithium carbonate/hydroxide from spodumene

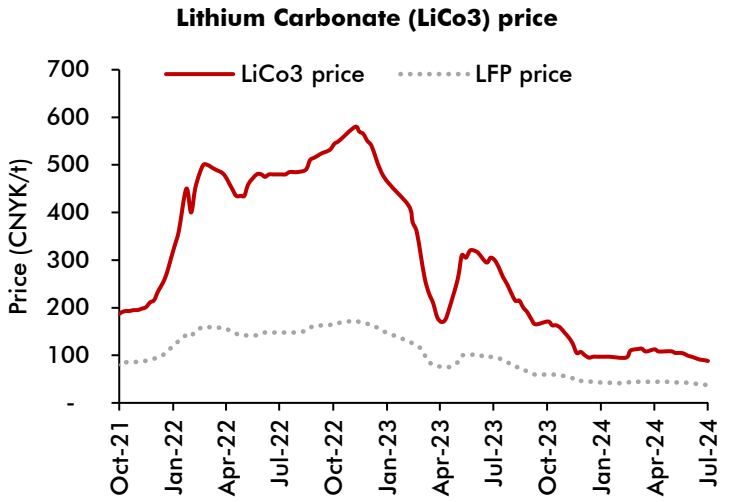


Source: McKinsey & Co., Ambit Capital research

Cathode active material (CAM) economics

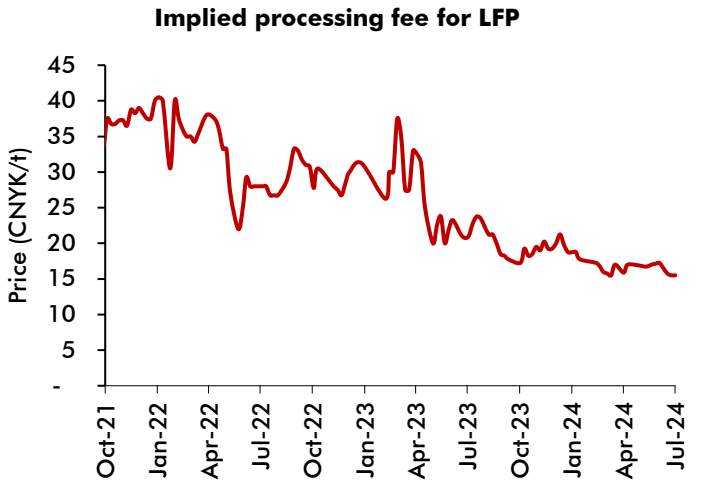
Cathode active material (CAM) production would require lithium carbonate (LiCo3) and iron phosphorus as key raw materials. Capital cost for setting up an LFP plant in China is CNY10,000/tonne while current selling price for LFP is <CNY40,000/t. A good rule of thumb in industry is sales/capex of >=4x for players to earn decent returns. Implied processing fees for LFP is calculated by taking LFP price and subtracting raw material cost of lithium carbonate. LFP prices have dropped not just because of lower LiCo3 prices, but also due to lower margins for LFP producers. Current LFP prices imply erosion in implied processing fee for LFP producers. At current prices, Daiwa Capital Markets notes that most LFP players in China are bleeding with the exception of top LFP player Yuneng.

Exhibit 34: Lithium carbonate prices have dropped on lower lithium as well as lower refinery margins



Source: Company, Ambit Capital research

Exhibit 35: LFP prices imply lower processing fee for LFP cathode manufacturers



Source: Daiwa Capital Markets, Ambit Capital research

Battery cell raw material cost has witnessed a sharp decline

Raw material cost typically accounted for >50% of total battery cell cost. The key raw material is cathode active material (CAM), the cost of which dropped to <CNY38,000/t or just $5/kg. That's a sharp drop of 76% in past one year - a function of lower LiCo3 price and lower processing fees/margins for LFP players. Most LFP players are incurring losses at current levels. And that's the case with anode active material, electrolyte and separators too. As a result, we estimate current battery cell raw material cost of just $30-35/kwh, now accounting for >=70% of cell cost as Chinese cell producers are not recovering cost of capital and depreciation at these levels.

Exhibit 36: Current raw material cost for battery cell manufacturing – sharp correction in LFP cathode has been the main driver of the fall in battery cell prices

Bill of materials	kg/kwh	metrics	$/unit	$/m2	cost/kwh
Cathode active material	2.16	kg/kwh	5.0		10.8
Cathode binder	0.04	kg/kwh	16.0		0.6
cathode additive	0.05	kg/kwh	10.0		0.5
Anode active material	1.07	kg/kwh	6.0		6.4
Anode binder	0.02	kg/kwh	2.0		0.0
Anode additive	0.02	kg/kwh	10.0		0.2
Liquid electrolyte	0.46	L/Kwhr	8.0		3.7
Separator	15	M2/Kwhr	0.2		3.0
					0.0
Positive current collector (aluminum foil)	4.4	m2/Kwh	0.2		0.9
Negative current collector (copper foil)	4.6	m2/Kwh	1.2		5.5
Battery tab, positive	0.02		5.0		0.1
Battery tab, negative	0.06		15		0.9
Tape	0.01			1.75	0.02
Pouch	0.04			3.75	0.15
Total					**32.8**

Source: Argonne National Laboratory, Ambit Capital research estimates

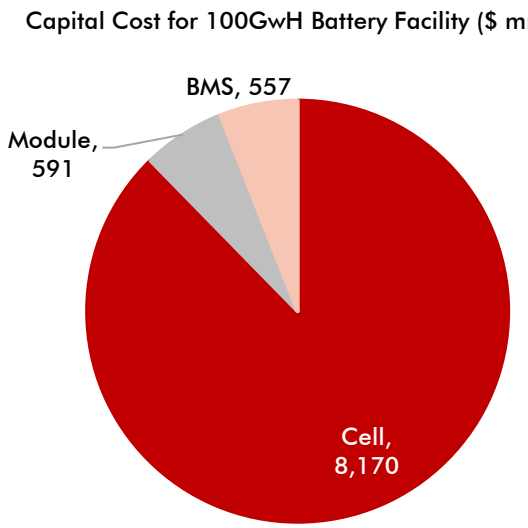
Capital cost for setting up a battery cell plant

Cell manufacturing plants are increasingly getting bigger and better. Economies of scale is important in order to lower capital cost in this business. The definition of giga-factory has now gotten stretched to >=20Gwh in most cases. Chinese capital cost for giga factory 40-50% lower vs that for EU and the US. For this analysis, we have assumed a 50GWh gigafactory ex-China.

Almost $9bn capex cost for setting up 100GwH cell manufacturing capacity

For this analysis, we have used the battery cost model shared with us by Argonne National Laboratory, USA. The most capital-intensive process is battery cell manufacturing (both electrode manufacturing and cell assembly), where capital intensity is $80mn per GwH. Pack assembly is not that capital intensive.

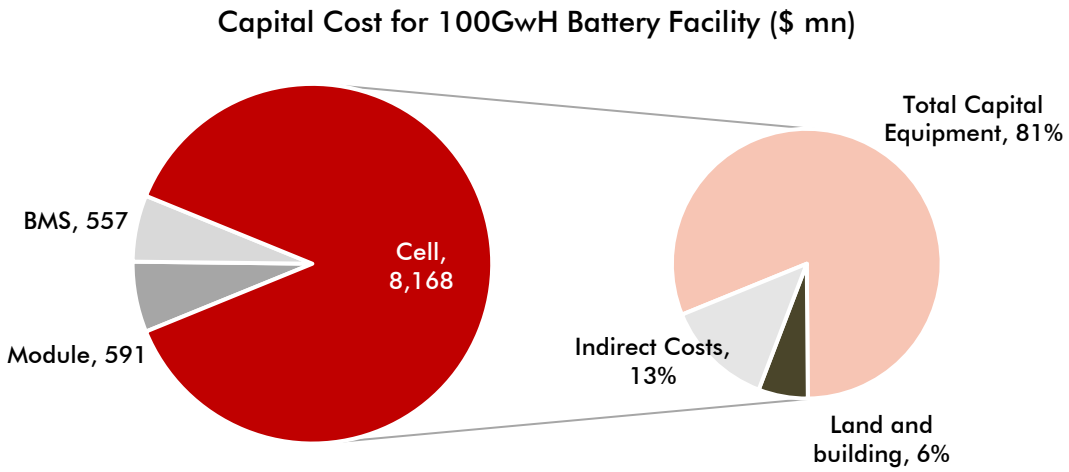
Exhibit 37: 100GWh battery capacity (mid-stream+downstream) will require almost $9bn capex



Source: Argonne National Laboratory, Ambit Capital research

Plant & equipment accounts for a bulk of cell manufacturing capex

Exhibit 38: Plant & equipment accounts for a bulk of battery cell manufacturing capex

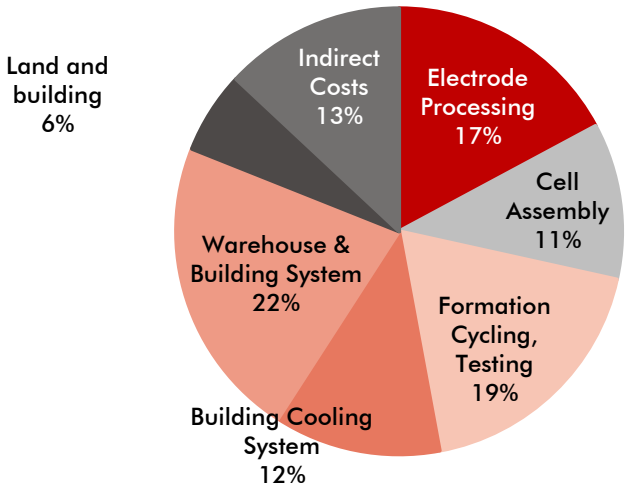


Source: Argonne National Laboratory, Ambit Capital research

There are 3 main stages in cell manufacturing:

- Electrode fabrication (known as front end in China) – accounts for 30-40% of total capex (40% capital expenditure)
- Cell assembly (known as Middle end in China) – accounts for 30% of total capital expenditure
- Cell testing & packing (known as Back end in China) – accounts for 30-40% of capex

Exhibit 39: Cell manufacturing capex is almost equally split between electrode fabrication, cell assembly and finally testing



Source: Argonne National Laboratory, Ambit Capital research

Current battery pack cost of $70/kwh, all-in BESS of $120/kwh

For this analysis, we have made 3 key assumptions:

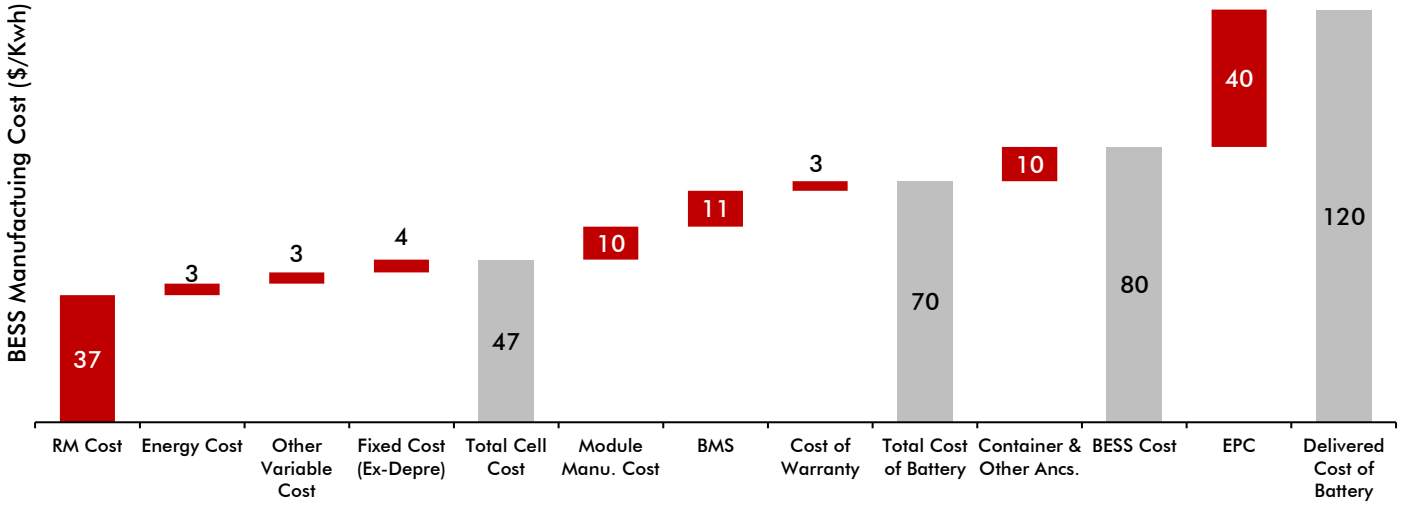
- Pre-tax interest cost of 3% for borrowing in China for capex.
- 0 depreciation, as in current conditions Chinese players are trying to focus on near-term cash, not on long-term replacement.
- 0% return of equity, as many players are anyways incurring losses at present.

We arrive at battery pack cost of $70/kwh based on current raw material cost, 3% borrowing cost, 0 depreciation and 0% return of equity.

From battery pack to all-in BESS cost

Battery pack is more relevant for EVs, but ESS requires a battery container, cooling, PCS/inverter, land, transformer etc. We estimate an all-in BESS container cost of $80/kwh at present and turnkey ESS cost of $120/kwh (includes PCS, transformer, land, transformer, 18% GST etc.)

Exhibit 40: China battery manufacturing cost – this is excluding depreciation, assuming no profit for LFP manufacturer as well as that of cell manufacturer

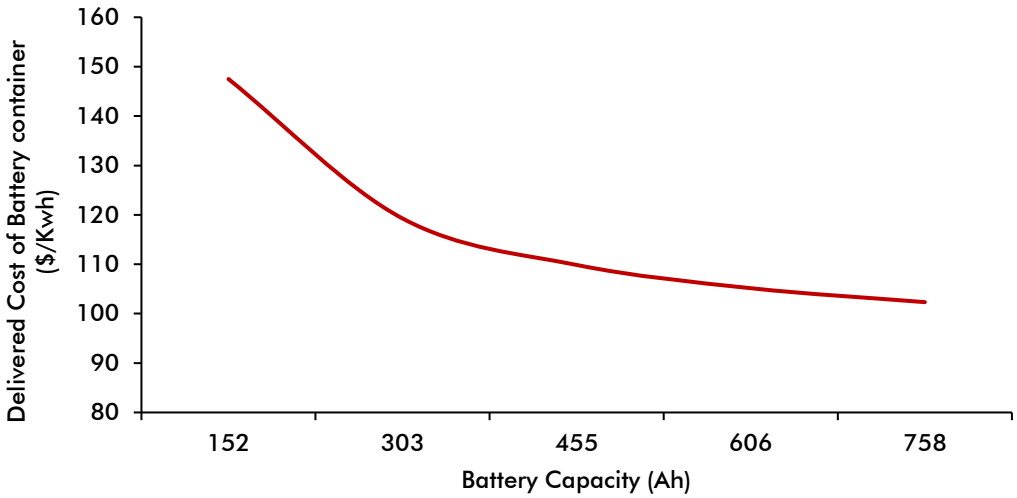


Source: Argonne National Laboratory, Ambit Capital research estimates

All-in cost is sensitive to electricity charge (Ah or ampere-hour)

The plants have got bigger and more efficient over time. Typically battery cells these days carry 300 Ah current. We show the sensitivity of all-in BESS cost to battery current (Ah). As per Moore's law, this journey should continue, implying further gains in efficiency.

Exhibit 41: There is technology improvement too – as batteries have become bigger and more efficient (lower energy density, higher current) over time



Source: Argonne National Laboratory, Ambit Capital research estimates

Onshoring: Solar Module learning curve

The Indian market is eyeing >=100Gwh of domestic battery capacity by 2030, aided by favourable government policies to support manufacturing ecosystem (PLI for advance cell chemistry) and boost consumer demand (subsidies by state and centre). Indian players such as Ola Electric, Reliance, Amara Raja, Tatas and Adani have announced ambitious plans to set up battery cell capacity in India. While there is global over-capacity, and India lacks lithium reserves and R&D, that shouldn't be a deterrent. Despite similar shortcomings, India has established a strong domestic solar cell/module supply chain, while the US is amidst a massive battery construction boom (supported by IRA benefits). PLI benefits are unlikely to be sufficient – so GoI will need to increase PLI benefits in subsequent rounds and/or erect trade barriers in the form of basic customs duties. There is a clear case study in solar value chain (PLI initially followed by BCD and then ALMM) that battery chain is likely to follow.

India is already assembling battery packs on a smaller scale

There are some smaller players that are importing LiB cells and assembling these into battery pack, and then further assembling into BESS units for ESS applications. There are EPC companies as well that provide EPC solutions, including turnkey. But these are relatively lower value-add, lower margin solutions.

India an importer of battery cells at present

China is dominant across the entire battery value chain, commanding 60-90% market share in various stages of battery production. India does have some mid-stream capacities in electrolytes, graphite/anode, cathode etc. but there is no battery cell manufacturing capacity in India at present (Ola recently started 1.4GwH – first-ever cell plant in India). India imports LiBs, primarily from China and the US, in order to fulfil its domestic demand. There is increased adoption of batteries in both EVs and ESS.

There is need for domestic manufacturing capacity

There is already global over-capacity in the entire battery supply chain at present. In addition, India doesn't have lithium reserves, and doesn't have R&D on batteries, where China has accumulated a wealth of process knowledge over time. But these headwinds shouldn't deter India from on-shoring the battery supply chain. India has overcome some of these challenges in the solar module supply chain. Despite certain shortcomings, the US is amidst a battery construction boom, supported by incentives under Inflation Reduction Act (IRA) and duties on imports from mainland China. If India doesn't set up its own battery manufacturing (upstream + mid-stream + downstream), it will remain a bystander and will have to continue to rely on imports – losing out on opportunities on both 1) employment and 2) current account. There is an opportunity for India to also export mid-stream supplies to the US as that country looks to diversify its supply sources away from China, at least till the time it sets up domestic capacities in mid-stream too.

Indian players have announced ambitious targets for battery cell capacities

Indian market is eyeing >=100Gwh of domestic battery capacity by 2030. GoI is also providing production linked incentives (PLI) for advanced chemistry cell (battery storage) – it had selected Rajesh Exports, Reliance Industries and Ola Electric in first tranche. Players were supposed to set up ACC capacity within 2 years of award of PLI in Apr'22. There have been delays on that end so far. Many players, including JSW Energy have bid for PLI incentives in second tranche earlier this year. GoI is also providing incentives to customers through subsidies/lower taxes in order to spur penetration of EVs in India.

100Gwh domestic manufacturing capacity will require $13-15bn investment

100Gwh battery cell manufacturing will require downstream capex of $8-9bn for battery cell manufacturing and module assembly. We estimate an additional $5-6bn investment to set up 100% domestic mid-stream capacities for LiCo3, LFP cathode, anode, electroytes, separators and aluminium foil collectors. These estimates exclude capex required on upstream (as India doesn't have much lithium at present and any new finds will likely take a while to get developed) as well as on certain mid-stream/downstream industries (graphite, BESS containers etc.) – so there could be an upside to the $13-15bn capex estimate.

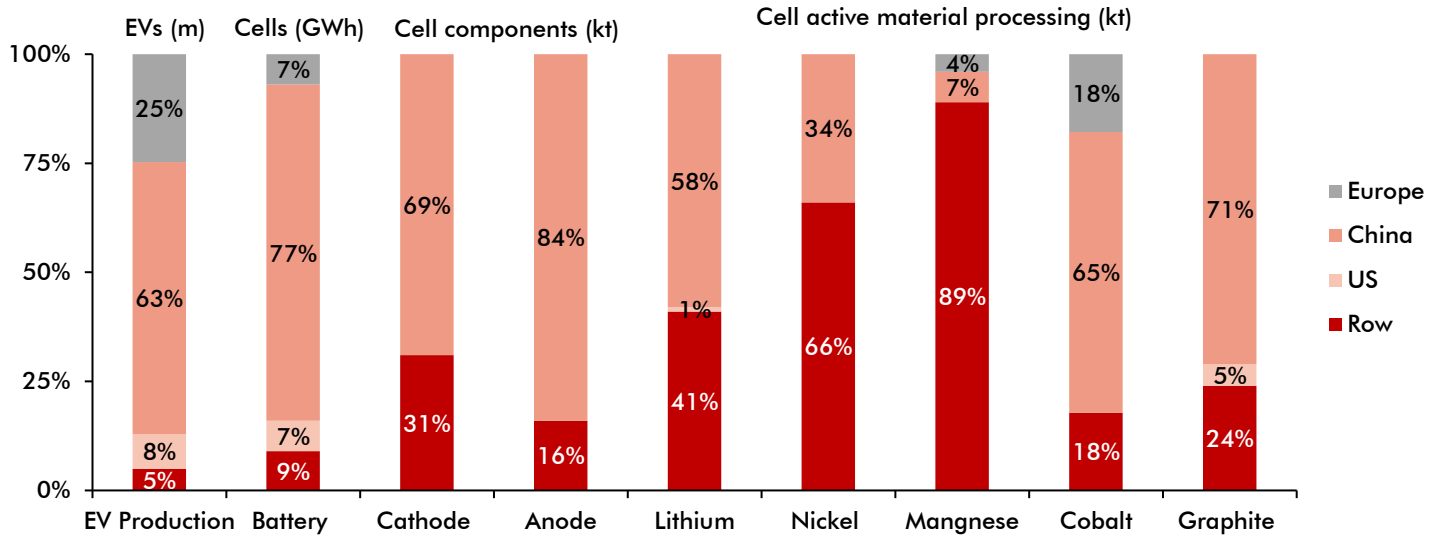
But PLI may not be sufficient

Our channel checks suggest global battery pack prices have dropped to <=$70/kwh. Our estimates suggest Indian players will require at least $110/kwh battery pack price (ex PLI subsidy and any BCD) to generate double-digit returns assuming mid-stream players such as cathode players also set up manufacturing in India and generate returns. PLI incentives are capped at 20% of sales price and are unlikely to be sufficient as current battery cells prices just about cover raw material and conversion cost.

Players may need trade protection as well in order to generate returns

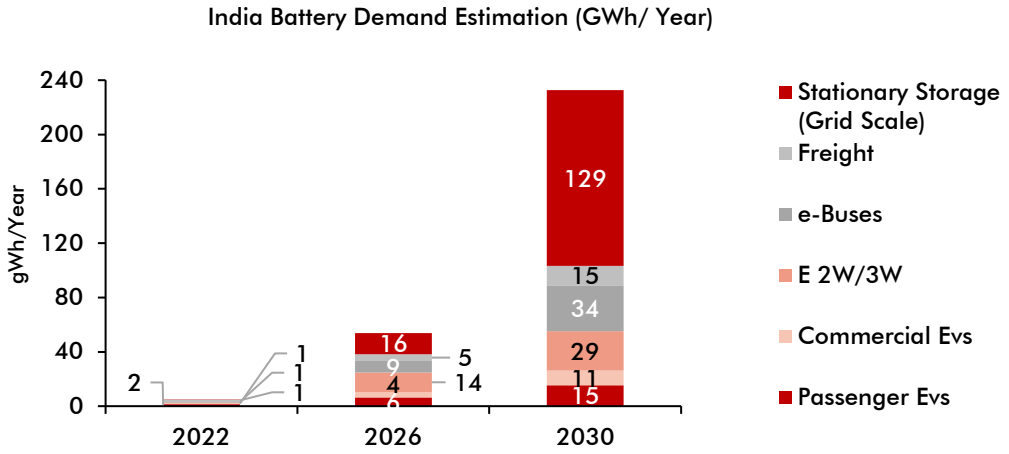
Niti Aayog had proposed around 10% basic custom duties (BCD) in a phased manner on 1) battery cells and 2) mid-stream components such as cathode, anode etc. There is no plan to introduce duties on packs as India already has domestic capabilities there. Even PLI, with a cap of 20% of sales, will not help Indian producers recover their cost of capital and need for replacement (depreciation). So, the government will need to either increase PLI support in future rounds and/or consider Niti Aayog's proposal for 10% BCD on batteries. 10% BCD could possibly be sufficient if we assume Indian cell manufacturers procure raw materials from China. As GoI looks to onshore mid-stream capacity as well in India, it would need even greater protection as Chinese producers are selling mid-stream products also at losses. Indian government has already provided support to solar modules in form of 40% basic custom duty (BCD) and approved list of module manufacturers (ALMM).

Exhibit 42: China is dominant across the entire battery value chain, commanding 60-90% market share in various stages of battery production



Source: IEA, USGS, ABB, Ambit Capital research

Exhibit 43: Indian battery demand growth is expected to witness a surge, primarily for energy shifting purpose in the grid



Source: Niti Aayog, Ambit Capital research

There are certain challenges Indian players have to contend with, but its capabilities in other sectors suggest it is possible to overcome these:

- **Dependency on Raw materials** – India lacks substantial reserves of key minerals such as lithium, cobalt, and nickel essential for battery production. But that's the case with China too though Chinese players have been scouting for mineral assets across the world. Indian agencies such as KABIL are exploring lithium and other rare mineral deposits. Also, for mineral such as copper, we don't have domestic raw material, but have still set up world-class processing facilities.
- **Lags peers in technological know-how** – Moving up the technology curve is crucial in industries such as semi-conductors, batteries and solar modules. This is where China, Japan and Korea have a massive lead. India will require investment in R&D, work-force skilling etc. in order to try and bridge some of this gap.
- **Infrastructure deficiencies** – Batteries will require stable power supply, efficient logistics network, skilled labor force etc. But we have built scale in chemicals, metals processing etc. despite some of these stated shortcomings. There is no reason why the country can't replicate that in batteries.
- **Environmental concerns** – There will be environmental concerns around the battery ecosystem, especially as it pertains to disposal and recycle of used batteries.
- **Financial constraints** – This is an industry where technology keeps evolving. What is a dominant chemistry now can become redundant two years from now. Thus, securing capital for these capital guzzling projects can be a challenge. Companies will need to keep investing in R&D, improve efficiencies – this is an industry where smaller players might struggle to compete with larger ones –given benefits of economies of scale, capital required for R&D etc.

Exhibit 44: Indian advanced chemistry cell (ACC) battery chain is in a similar position as solar module chain – domestic solar module sector is thriving on the back of government support (PLI, BCD, ALMM) – same should be the case with batteries

Parameters	Solar Module	Batteries	Comment
Global Overcapacity	●	●	Global capacity utilization would be 50% for both
Margins for global players	◔	◔	Global solar module/cell and battery value chain incurring losses at present
Indian R&D capabilities	◑	◑	These industries require constant technological/process innovation
Domestic mineral availability	◔	◔	It's debatable how much silica (building block for modules) India has, same with lithium for batteries
Barriers to entry for domestic players	◑	◕	Module has limited barrier to entry (cell and wafer higher), cell manufacturing is more capital intensive, requires more expertise. Battery pack is similar to module, solar cell similar to battery cell
PLI scheme	Yes	Yes	Both PLI and state incentives available
Trade barriers required to support domestic manufacturing	●	●	There is 40% BCD on solar modules (cells 25%), batteries will also require some trade protection

Source: Company, Ambit Capital research; Note: ● - Strong; ◕ - Relatively Strong; ◑ - Average; ◔ - Relatively weak.

The US is amidst a battery manufacturing boom

The US and Europe both have massive plans for on-shoring of battery manufacturing capacities. The US government has doled out incentives under Inflation Reduction Act (IRA) for setting up domestic manufacturing capacities for renewable energy and battery supply chain in order to support domestic manufacturing and jobs and to reduce reliance on China. US has also imposed duties on battery imports from mainland China (increasing to 25% in 2026 vs 7.5% now). As a result, the US is amidst a battery construction boom. And the US is witnessing this despite some of the challenges (lack of lithium reserves, battery manufacturing learning curve, and global overcapacity) that India has to contend with. The US battery manufacturing capacity is likely to increase to 30GW in 2024 vs 1GW five years ago. There have been many project announcements in the US led largely by LG, SK Innovation and Tesla, but also supported by others (including smaller players). Based on announced expansions, Argonne National Laboratory expects 1,200Gwh battery cell capacity in the US by 2030, enough to support 12-15 million vehicles. That seems too optimist given the scale of EV market in the US at present, but there is no denying the US is making significant strides towards on-shoring battery manufacturing capacity.

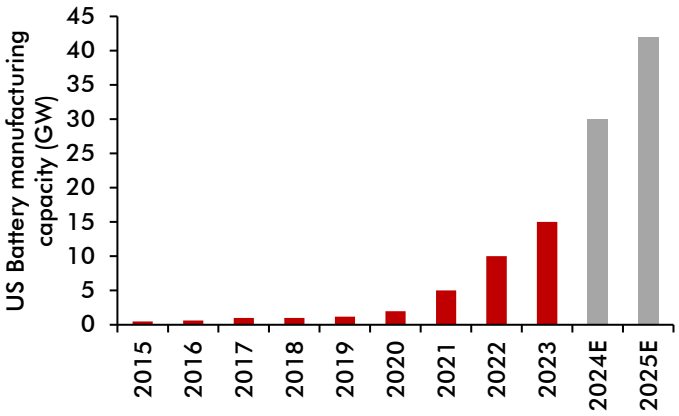
The US is looking to diversity its sourcing for mid-stream components

The US will take some time to onshore entire mid-stream value chain, including cathode active material (CAM), anode and separator. The US recognizes the dominance of China in the supply of these goods, but it intends to de-risk these supply chains by diversifying import sources away from China. That could present opportunities for Indian mid-stream producers, just as it has been the case with solar cells, where Indian producers have seized the initiative.

Europe on the other hand has seen too many project cancellations

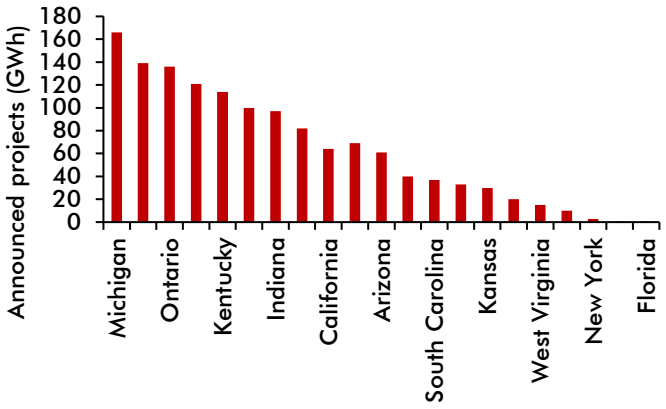
Europe has also been seen as a case study for on-shoring of battery manufacturing capacity. But there have been many battery project cancellations in Europe caused by bureaucracy in disbursement of subsidies/incentives, changes in technologies (earlier European producers were considering NCM based chemistry, but are not considering a pivot to LFP). It's the European example that India needs to avoid, and instead emulate what the US is witnessing.

Exhibit 45: US battery cell capacity has scaled up significantly mainly due to Inflation Reduction Act (IRA) benefits



Source: US EIA, Ambit Capital research

Exhibit 46: Project announcements in many states; Argonne expects 1,200GWh capacity in North America by 2030

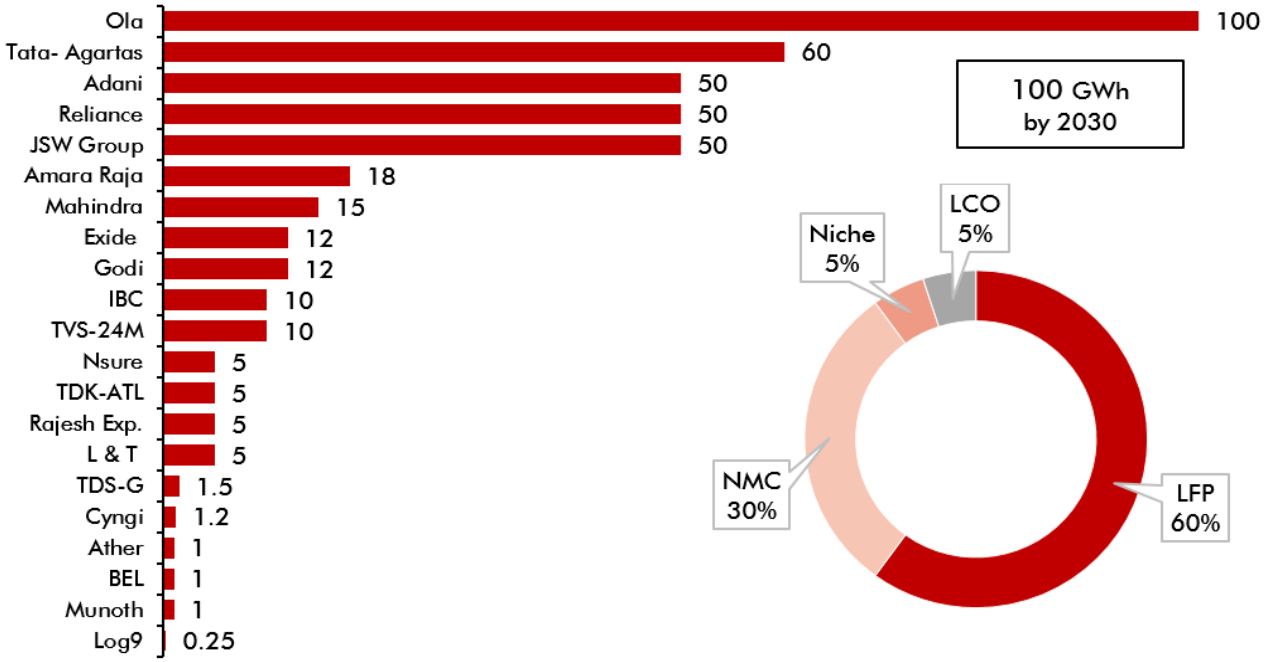


Source: US Department of Energy, Argonne National Laboratory, Ambit Capital research

Indian players have ambitious plans

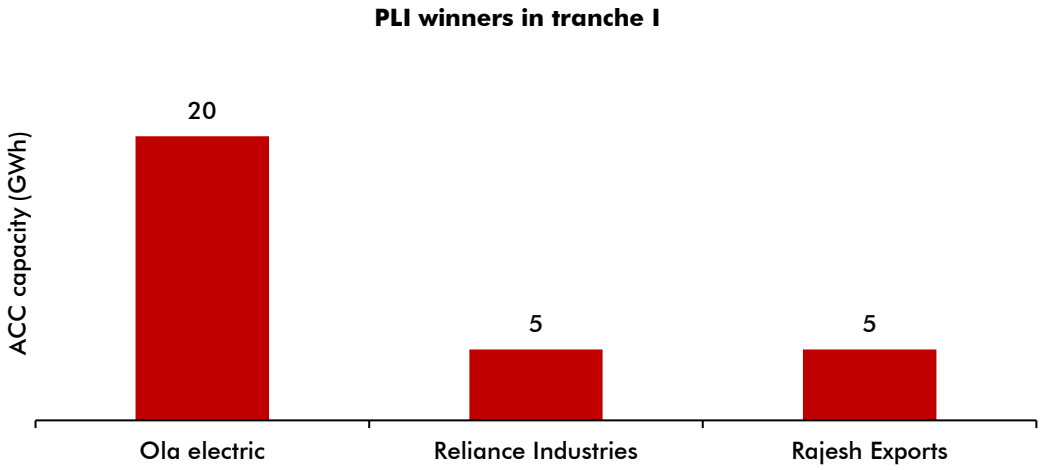
Indian market is eyeing >=100Gwh of domestic battery capacity by 2030.

Exhibit 47: Indian players do have aggressive capacity expansion plans, although the industry will have to contend with near-term uncertainty, delays etc. given dumping by China



Source: MolSynth Analytics, Ambit Capital research

Exhibit 48: 30Gwh capacity was awarded PLI incentives in Tranche 1, additional incentives to be doled out in future tranches



Source: Company, Ambit Capital research Note: 20Gwh awarded to Hyundai in Tranche 1 stands cancelled/withdrawn

Exhibit 49: Ola Electric has commissioned the 1st battery cell plant in India, expects 20Gwh battery capacity by 2QCY26

Phase	Additional capacity	Capex (Rs bn)	Capital Intensity ($mn/Gwh)	Cumulative capacity	Expected date of completion and commercialization
1a	1.4Gwh	12.2	109	1.4Gwh	May'24 (completed)
1b	3.6Gwh	10.2	35	5.0Gwh	Feb'25
2	1.4Gwh	12.2	109	6.4Gwh	Apr'25
3	13.6Gwh			20.0Gwh	2QCY26

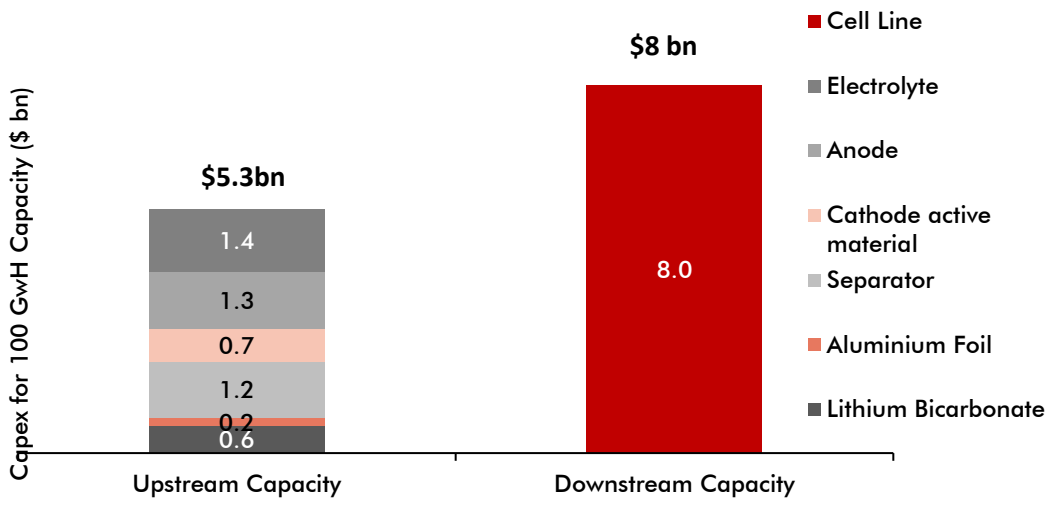
Source: Dun & Bradstreet project vetting cost report for Ola Electric, Ambit Capital research

Exhibit 50: 100Gwh battery capacity will require $5bn capex for various upstream capacities too

Materials	Requirement/KwH	Unit	Requirement /100GwH	Unit	Capex/Gwh ($mn)	Capex/ 100Gwh ($mn)
Lithium Carbonate (LiCo3)	0.3	kg	30,000	Ton	6	600
Cathode	2.0	kg	200,000	Ton	7	703
Anode	1.0	kg	100,000	Ton	13	1,250
Electrolyte	0.5	litre	45,000	Kilo litre	14	1350
Aluminium Foil	0.4	kg	40,000	Ton	2	160
Separator	7.0	m^2	700	m^2	12	1240
Total					**53**	**5,303**

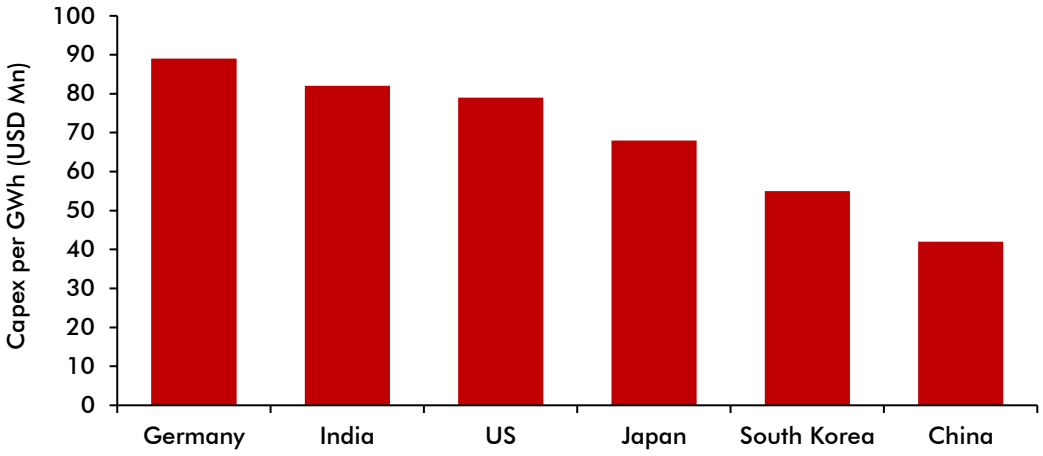
Source: Company, Ambit Capital research

Exhibit 51: There could be $13-$15bn capex opportunity across battery value chain in order to achieve 100Gwh domestic battery capacity



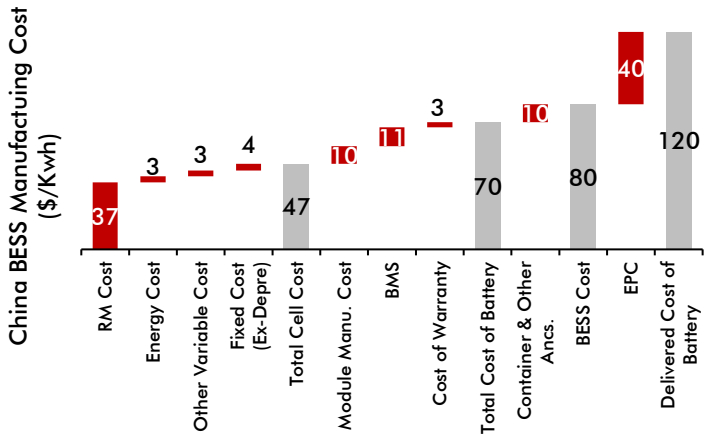
Source: Company, Ambit Capital research

Exhibit 52: China has the lowest capital intensity for battery giga-factories (a function of lower land, interest costs, gestation period etc.); Chinese gigafactories require half the capex vs most global peers



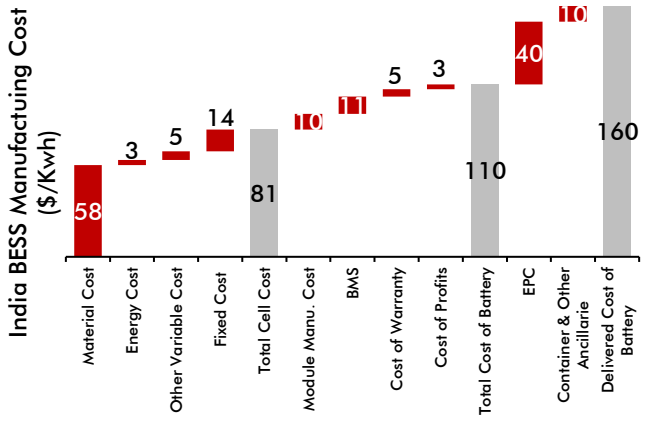
Source: Bloomberg, Ambit Capital research

Exhibit 53: We estimate spot global battery pack cost of $70/kwh and all-in BESS cost of $120/kwh



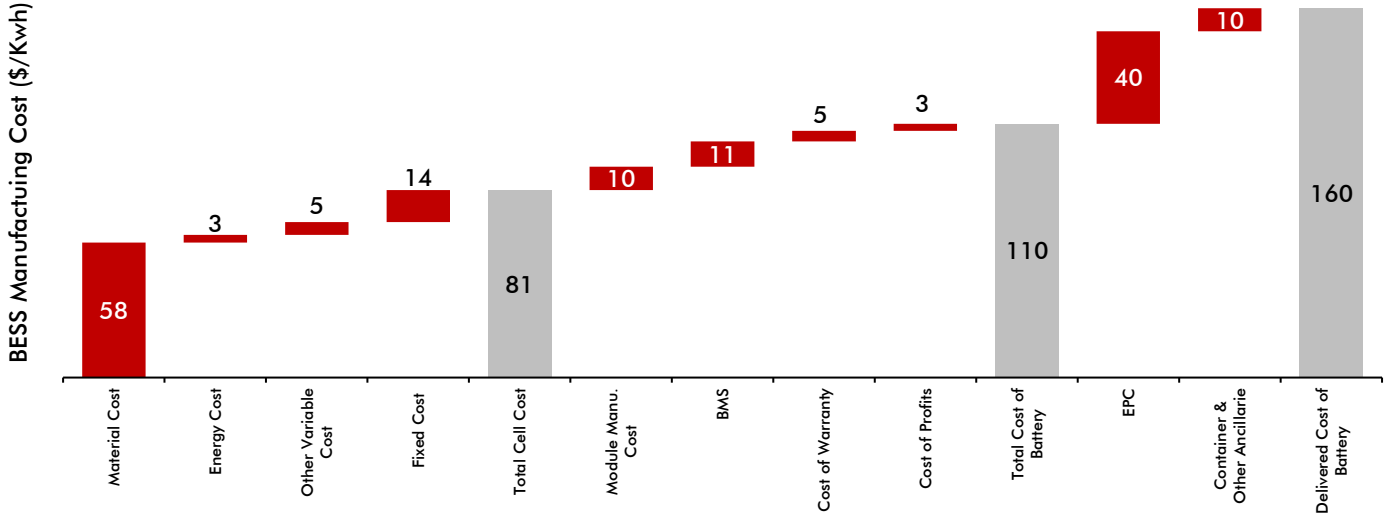
Source: Argonne National Laboratory, Ambit Capital research estimates

Exhibit 54: Indian players will require PLI+BCD in order to earn required rate of return



Source: Argonne National Laboratory, Ambit Capital research estimates

Exhibit 55: India Battery Manufacturing Cost – we are assuming LFP producers as well as cell manufactures earn requisite return, while also taking cognisance of higher interest cost in India



Source: Argonne National Laboratory, Ambit Capital research estimates

Existing PLI support unlikely to be sufficient

The government is providing subsidy through the sector in the form of production-linked incentives (PLI). But these need to be complemented with basic custom duties in order for players to generate reasonable returns.

There are benefits under PLI scheme...

The government had already allocated PLI to Ola electric, Reliance and Rajesh Exports under PLI Tranche-1. There are several conditions for PLIC disbursement, including minimum commitment of capex, staggered targets for value addition etc.

In the tender, bidders had to quote applicable subsidy, details of which are not available in the public domain.

Subsidy under PLI = Quantity of cells sold (Kwh) x applicable subsidy as per programme agreement (Rs/kwh) x percentage of value addition

But notwithstanding anything in programme agreement, PLI subsidy is capped at 20% of revenue. It's likely that annual subsidy is lower than that, considering the bidding process, and various terms and conditions.

...however, the government will need to consider additional duties too

We estimate Chinese companies are selling battery cells at prices that cover just about their raw material cost and energy cost. And anyways finance costs are very low for Chinese players. So, at current prices, they are not recovering their cost of capital and depreciation. Even PLI, with the cap of 20% of sales, will not help Indian producers recover their cost of capital and need for replacement (depreciation). So, the government will need to either increase PLI support in future rounds and/or consider Niti Aayog's proposal for 10% BCD on batteries. 10% BCD could possibly be sufficient if we assume Indian cell manufacturers procure raw materials from China. As GoI looks to onshore mid-stream capacity as well in India, it would need even greater protection as Chinese producers are selling mid-stream products also at losses. India may need to consider its current GST of 18% on batteries, especially given there is only 5% GST on EVs.

Exhibit 56: Proposed Basic Customs Duty Matrix (2021–30) – GoI may need to consider BCD proposed by Niti Aayog, but even that may not be sufficient once there is greater requirement for domestic mid-stream content

	Goods	2020-2022	2022-2023	2023-2025	2025-2027	2027-2031	2031 & beyond
1a	ACC batteries including EV batteries, except for 1b and 1c	5%			15%		
1b	Lithium-ion batteries of cellular mobile phones				15%		
1c	ACCs and batteries used to manufacture goods under chapter 8471 of the custom tariff heading				0%		
2	ACCs (such as lithium-ion cells) for manufacture of battery packs	5%	10%	10%	10%	10%	10%
3	Parts such as anode, cathode, electrolytes, and separators required to manufacture ACCs	2.5%	2.5%	5%	10%	10%	10%
4	Goods (processed and unprocessed) required to manufacture parts of ACCs, such as graphite, cobalt, lithium, nickel, except for copper and any other product that is announced				2.5%		
5	Plant and Machinery required to set up a plant for manufacturing ACCs		0%	0%	0%	5%	7.5%

Source: Niti Aayog, Ambit Capital research

Exhibit 57: Even PLI incentives are unlikely to be enough; industry will require >=10% BCD to start with, domestic mid-stream capacity integration will require even higher duties for both mid-stream and down-stream

Parameters	Metrics	No PLI	assuming PLI (20% of sales price) on Cell	assuming PLI on Cell + 10% BCD on cell	Assuming PLI on cell + BCD on cell + mandated 100% domestic RM
Capacity utilization	%	85%	85%	85%	85%
Battery Cell price	$/kwh	47	47	52	52
Raw material Cost	$/kwh	33	33	33	53
Conversion cost	$/kwh	13	13	13	13
EBITDA	$/kwh	1	1	5	-15
EBITDA (capacity adj)	$/kwh	1	1	5	-12
Depreciation	$/kwh	4	4	4	4
EBIT	$/kwh	-3	-3	1	-16
tax	$/kwh	17%	17%	17%	17%
NOPAT	$/kwh	-3	-3	1	-13
PLI incentive (@20% of sales)	$/kwh	0	8	9	9
NOPAT (PLI adj)	$/kwh	-3	5	10	-5
Capex	$/kwh	80	80	80	80
ROCE (post tax)	%	-3.2%	6.8%	11.9%	-5.7%

Source: Company, Ambit Capital research Note: for simplicity, we have treated PLI like an operating subsidy, not capital subsidy, for this analysis

Indian chemical players - winds of change

Indian chemical companies with complementary product portfolio/technical know-how are scrambling to set up capabilities to cater to local/global demand which is expected to grow at ~40%/13% CAGR over the next decade. Key investment plan includes a) FLUOROCH's announcement of Rs60bn investment over 4-5 years across the battery value chain, b) NEOGEN's announcement of Rs15bn investment over 2-3 years in electrolyte and additives and c) HSCH's Rs48bn investment into cathode active materials over 4-5 years. Companies' GTM strategies include product development via R&D (FLUOROCH, HSCH) or expediting the process by tying up with global major (NEOGEN). Timely execution of these large investments remains a key monitorable together with timely rollout of local battery capacities.

Cathode – a positively charged electrode

Cathode, the highest-value component of a lithium cell, is the source of energy within a lithium cell. CAM comprises carbon black, organic solvents and binders (PVDF) which hold the active materials together.

Generally, 2,000-2,200tn of LFP cathode active material is used per GWh. Indian market at 100GWh of battery capacity will require ~200-220KT of LFP cathode active materials.

Exhibit 58: Key investment plans in CAM space

Cathode	Remarks
Himadri Specialty	▪ Rs48bn capex outlay for cathode active material LFP with an initial capacity of 40KT (operational by 3QFY27) which will be expanded to 200KT in the next 5-6 years.
Gujarat fluorochemicals	▪ PVDF (used in cathode binders) capacity of ~4.8KT will be increased to 9.6KT. ▪ Plans to start its first cathode plant by 2QFY25.
Epsilon	▪ Acquired Johnson Mattey's LFP cathode active material technology ▪ Plans to invest Rs50bn for greenfield capacity of cathode plant which is expected to scale up to 100KT by 2030
Altmin	▪ Planning to invest US$35-40mn to produce 9KT of LFP annually ▪ Additional investments of US$100mn over the next 6-7 years.
SRF	▪ Capex outlay of Rs6bn for new specialty fluoropolymers (~4.5KT for PVDF, FKM, FEP) which is expected to be operational by the end of CY25. ▪ PVDF can find applications in CAM as a binder.
IFFCO	▪ Signed an MOU with Aleees to set up LFP battery cathode plant.

Source: Company filings, News articles, Ambit Capital research

Anode – a negatively charged electrode

As current flows from cathode to anode (opposite of electron flow), anodes have current collectors coated with graphite and silicon. Typically, the surface area of the anode is critical to the cell's life cycle (number of charges and discharge). *Generally, 1,000ton of anode is used per GWh. The Indian market at 100GWh of battery capacity will require ~100KT of anode materials.*

Exhibit 59: Key investments in the anode space

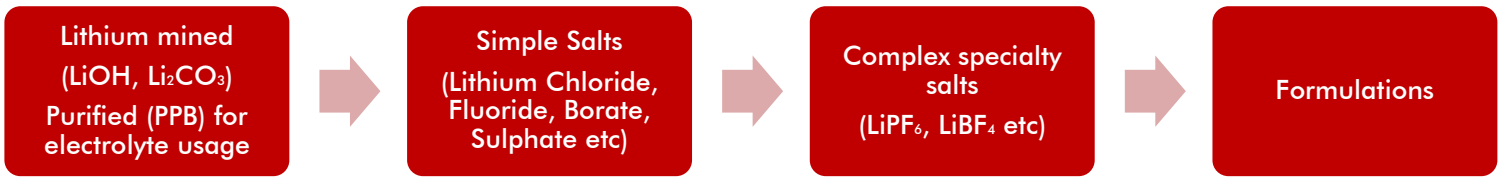
Anode	Remarks
Himadri Specialty	▪ Acquired 12.79% stake in Sicona (specializing in high-capacity anode) for Rs560mn.
Epsilon	▪ Capex plan of US$1.1bn for anode material. ▪ Plant will start its operations in FY26 with an initial capacity of 10KT. ▪ Capacities are expected to increase to 100KT in a phased manner till FY30.
HEG	▪ Setting up high-grade graphite anode powder plant of 20KT capacity (Rs18bn) which is expected to be operational by 2025 end.
Tirupati Graphite	▪ The company has current capacity of 4.8KT. ▪ It has large plants in Mozambique and Madagascar and aims to produce 400KT annually by 2030.

Source: Company filings, News articles, Ambit Capital research

Electrolytes – a medium for movement of ions

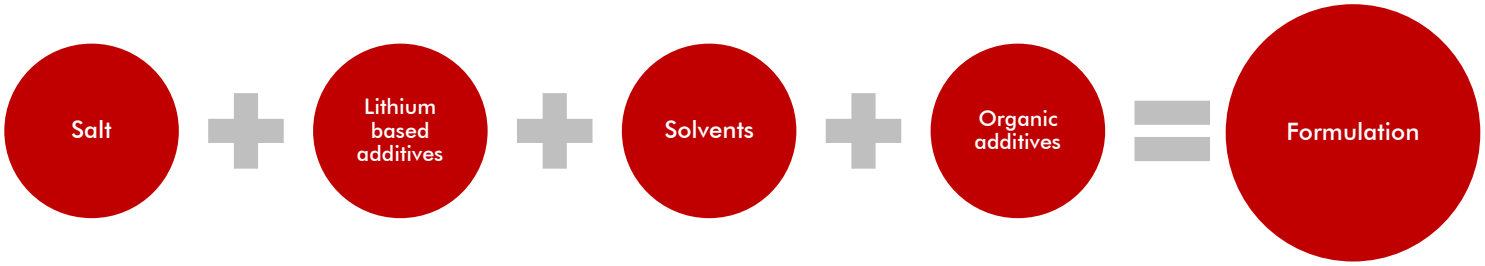
Electrolytes are salts and additives (vinylene carbonate etc.) suspended in a solvent (carbonate-based solvents). Salts and additives are about 50% of the electrolyte cost but 15-20% of its weight. Solvents are large-volume chemicals accounting for ~80% of the electrolyte's weight. Electrolytes are critical to the life of the battery and its endurance. Additives help in stability of the lithium cells with properties like preventing over-heating and short circuits from dendrite formations.

Exhibit 60: Value addition steps from mine to final formulations



Source: Industry experts, Neogen, Ambit Capital research

Exhibit 61: Components of an electrolyte



Source: Industry experts, Neogen, Ambit Capital research

Exhibit 62: Key investments in the electrolyte space

Electrolytes/salts/additives	Remarks
Gujarat Fluorochemical	▪ Total capex plan of Rs60bn for battery segment over next 4-5 years. ▪ Rs32bn is to be spent till FY26 (Rs8bn in FY24, Rs9bn in FY25 and Rs15bn in FY26) for LiPF6 (electrolyte salt) with an initial capacity of 1.8KT, which will be increased over the next 3-4 years. ▪ High purity grade electrolytes will be commercialized within the next couple of quarters.
Ami Organics	▪ Tied up with global MNC for electrolytes. ▪ Plans to invest Rs3bn. ▪ Rs1bn capex in FY25 for electrolyte additives with a capacity of 2.5KT. ▪ Commercial production of 400T of capacity started in FY24.
Neogen Chemicals	▪ Investment plan of Rs15bn for 32KT of electrolyte and 5,500tn of salt and additive till FY26. ▪ Initial capacity of 2KT electrolyte and 400tn of salt and additive has been commercialized ▪ Additive capacity will be increased to 2.5KT.
Balaji Amines	▪ 15KT of installed capacity of battery grade DMC (solvent) will get commissioned by FY25, primarily used in NMC chemistry
Tatva Chintan	▪ Supplying salts for super-capacitors batteries. ▪ Developing zinc salts used for zinc batteries. ▪ Plans for electrolytes required for Zinc and sodium batteries.
Aether Industries	▪ It entered into an agreement with a global manufacturer for additives.
PCBL	▪ Entered into JV with Kinaltek Pty Ltd which will develop nano-silicon additives to be used in anodes of Li-ion batteries. ▪ It is expected to invest US$28mn over next 1.5-2 years.

Source: Company filings, Media articles, Ambit Capital research

Separators – barrier to prevent contact between anode and cathode

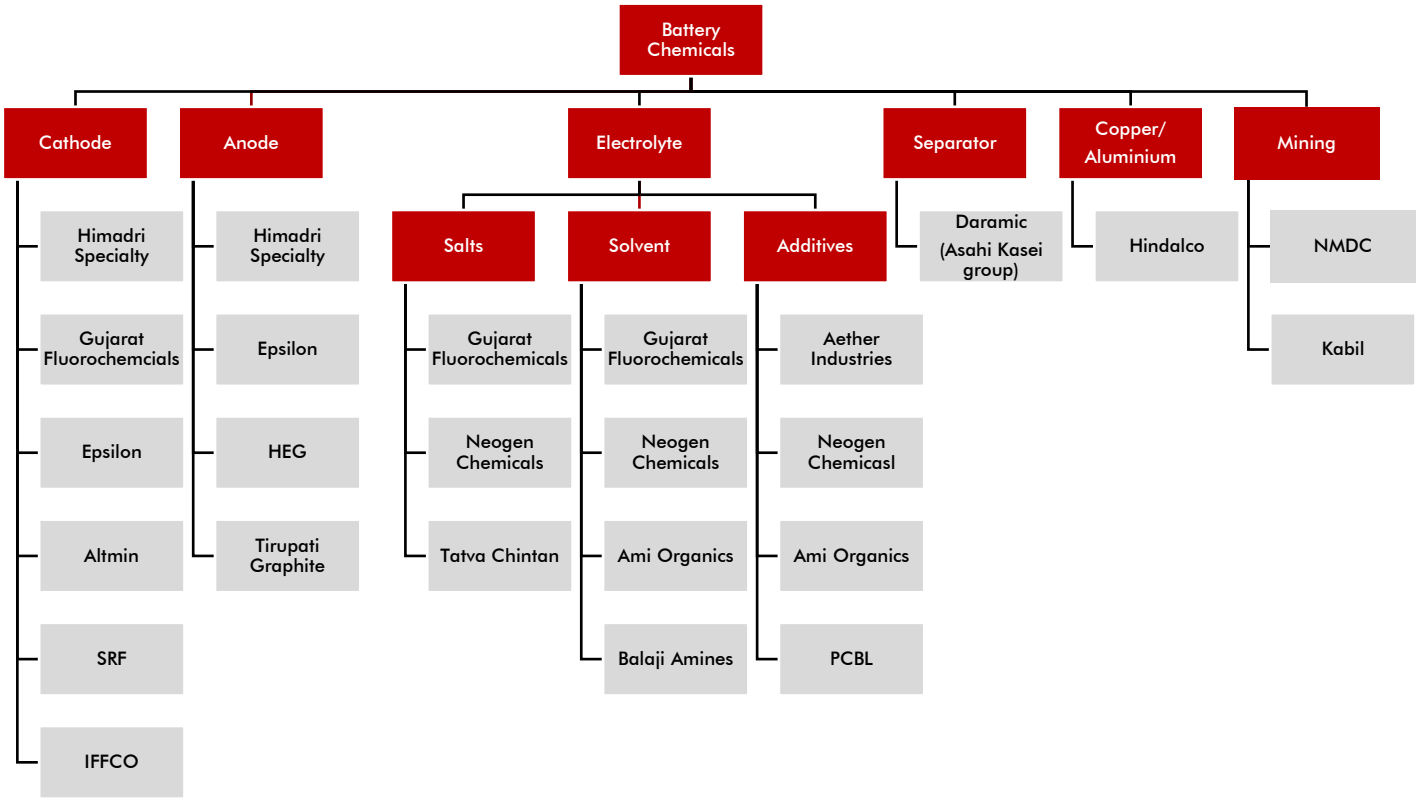
Separators are the porous (allow flow of ions) insulating barrier between anode and cathode. Polyethylene, polypropylene and PTFE membranes are usually used as separators. Most packaging companies in India like SRF, Polyplex, Uflex etc. may extend their value proposition by developing special battery-grade films for such applications.

Exhibit 63: Key investments in the separator space

Separators	Remarks
Daramic (Asahi Kasei group)	▪ Largest polyethylene separator and manufacturer of phenolic resin-based separators. ▪ Currently used in lead-acid batteries.

Source: Company filings, Media articles, Ambit Capital research

Exhibit 64: Summarizing the landscape of company positioning across the value chain



Source: Company filings, News article, MolSynth Analytics, Ambit Capital Research

Long duration storage (LDES) technologies

LiBs are usually short duration batteries relevant for EVs and some peak energy shifting. But when variable renewable energy (VRE) reaches a critical mass (around 60-70% share in bulk power systems), long-duration energy storage (LDES) becomes paramount in ESS for energy-shifting and achieving true FDRE (firm and dispatchable renewable energy). Various LDES technologies are at different stages of maturity and proof of concept/market readiness/commercialization. LDES technologies generally have lower energy density (which is not critical for ESS anyways), lower round-trip efficiency, but have much longer cycle life vs LiB. There is increased interest globally for these technologies, as was also evident in recent small NTPC tender for vanadium flow technology. Some of these technologies may go on to gain critical mass in future.

LiB is usually short-duration storage

Lithium ion battery currently offers a 2-hour cycle and can achieve 4-hour storage on running a battery for 2 cycles a day. LiBs have a shorter replacement cycle as current batteries have a 7,000 cycle life (which is a distinct improvement from 2,000-3,000 cycles till a few years ago). The longer replacement cycle is helping lower levelized cost of LiBs. But certain applications such as energy shifting require long-duration storage. LDES is typically defined as a technology that can provide >=8 hours of storage with certain technologies providing duration of weeks and even months.

There are various types of LDES technologies

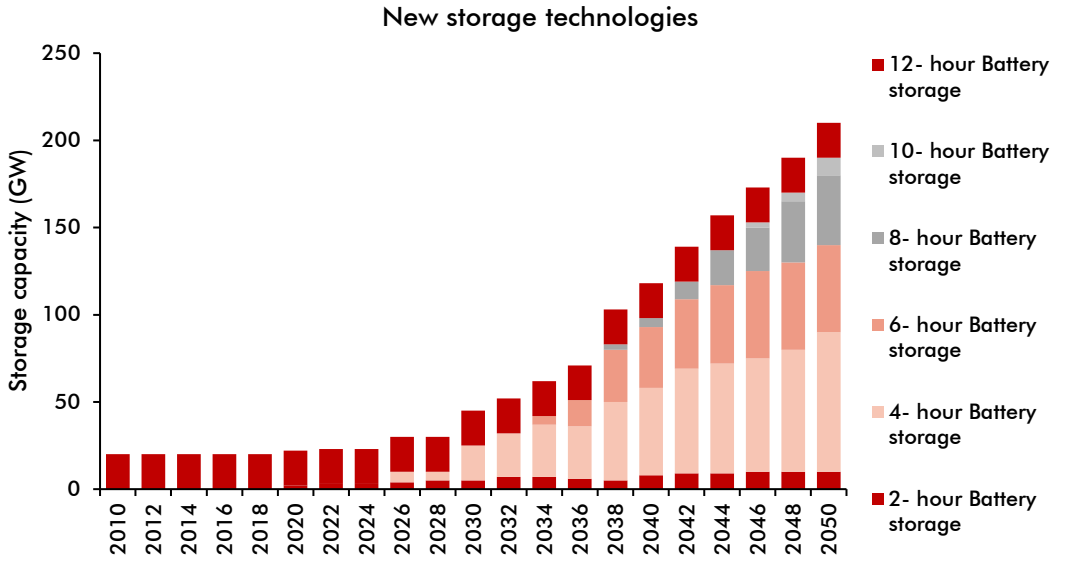
These can range from redox flow to metal air batteries, as well as some novel technologies such as compressed Co2, gravity based storage solutions:

- **Redox flow** – The fundamental difference between conventional and flow-based batteries is this – in conventional batteries energy is stored in electrodes, while in flow batteries its electrolyte that is used to store energy. Electrode has a coating and it gets worn off/degrades because of that. Electrolyte-based solutions don't degrade. Flow batteries are less dense, which means they have more weight and require more area. Hence they are not ideal for EVs – they are more suitable for stationary storage. The two most common flow-based technologies are 1) vanadium redox flow batteries (VRFB) and 2) zinc-bromine (Zn-Br). Flow batteries offer the distinct advantage of longer asset life, longer duration and increased flexibility. The main handicap at present is the much higher capital cost/kwh vs LiBs.
- **Metal air batteries** – Aluminium air and zinc air batteries would feature here. These batteries have high energy density vs LiBs and can provide storage that can last over multiple days. But this technology will need to fix volatility experienced vis-à-vis metal anode, air cathode and electrolyte.
- **Thermal energy storage** (TES) – This technology allows storage of surplus thermal energy for days, maybe months. Heat can be stored in cheap and abundant materials such as hot rocks, molten aluminium, rock caverns etc.
- **Mechanical storage –** Pumped storage (PSP) and compressed air are the two popular technologies in this category. Most of these technologies require suitable topography. In compressed air, high pressured air is compressed into a vault (including in large natural caves), and release of this air helps turn turbines. Other gravity-based solutions would also fall in this category. In these, instead of pumping water uphill, a mechanical process is used to lift weights (including in abandoned underground mines) in the air – when gravity pulls the object down, it helps move turbine and generate electricity.

There will be a learning curve for these technologies

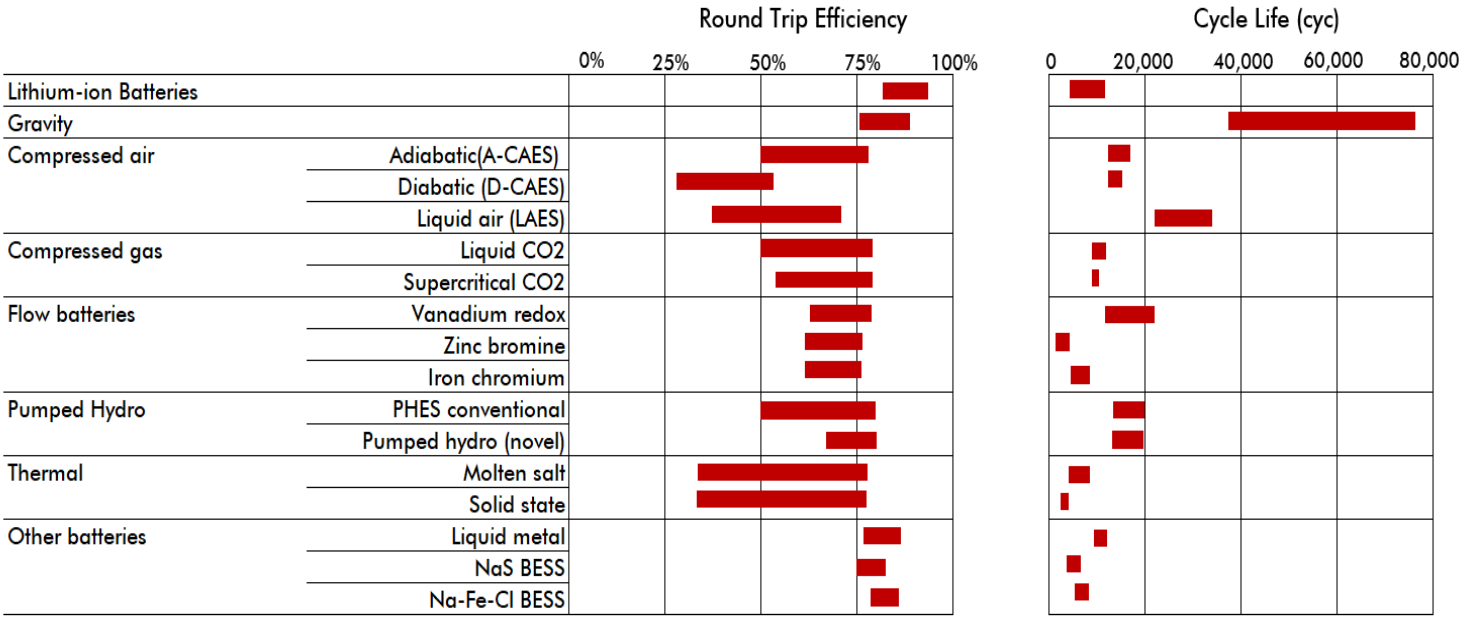
Some technologies still need proof of concept, while others are closer to or have already achieved commercial scale. Some of these technologies will also need economies of scale in order to achieve cost parity with LiB. But projections indicate efficiencies and cost moderation are possible and in line with what has been experienced in LiB, wind and solar. There is likely to be greater demand for LDES in future, especially as RE witnesses greater penetration in the grid. There will be winners and losers in these as not every technology will reach critical mass. Commercialization and cost efficiency will be key monitorables for these technologies.

Exhibit 65: Long duration energy storage (LDES) is likely to witness greater demand in the battery storage space



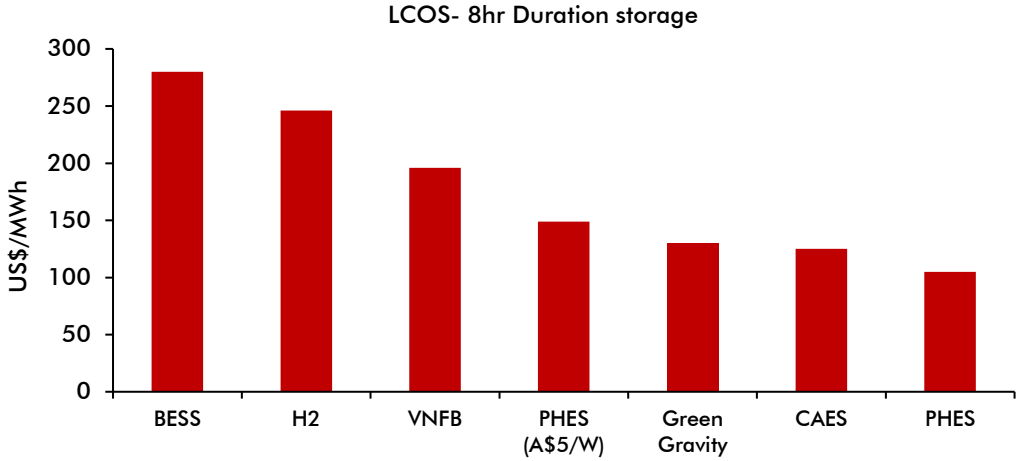
Source: Company, Ambit Capital research

Exhibit 66: LDES technologies in general have lower round-trip efficiency, but have longer cycle life than lithium batteries



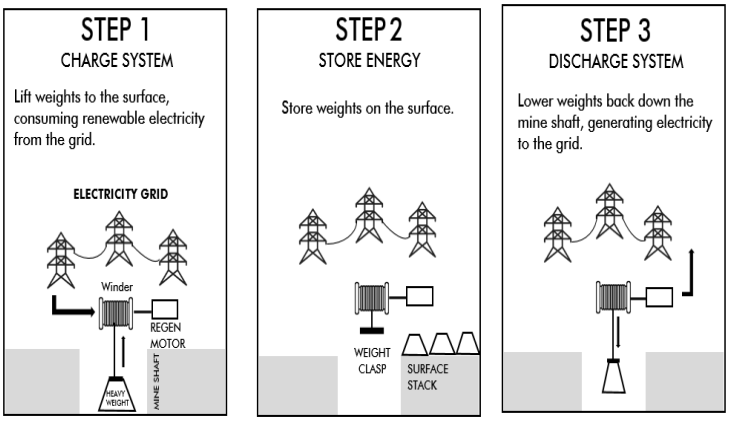
Source: Green Gravity Energy, Pacific Northwest National Laboratory, Ambit Capital research

Exhibit 67: On a 8-hour levelized cost of storage basis, certain LDES technologies are already more competitive than lithium-ion batteries



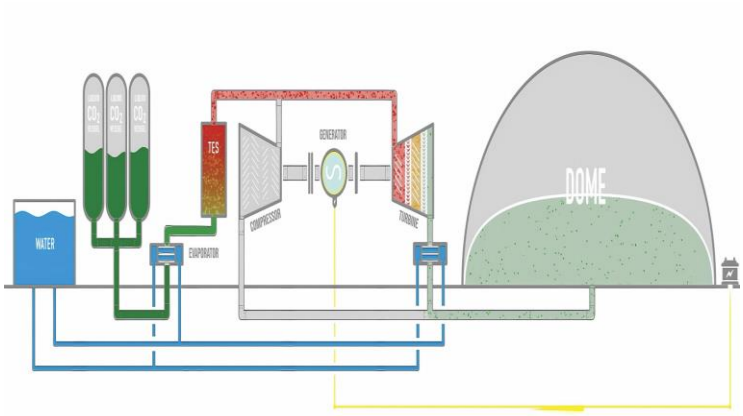
Source: Gencost, Hydrostor project, University College London, Green Gravity Ltd, Ambit Capital research

Exhibit 68: Gravity-based long-duration storage – process of pulling and releasing weights helps moves turbines



Source: Green Energy Gravity Ltd, Ambit Capital research

Exhibit 69: Co2 battery – Co2 liquefies at ambient temperature; eventual gas is used to move turbine



Source: Energy Dome, Ambit Capital research

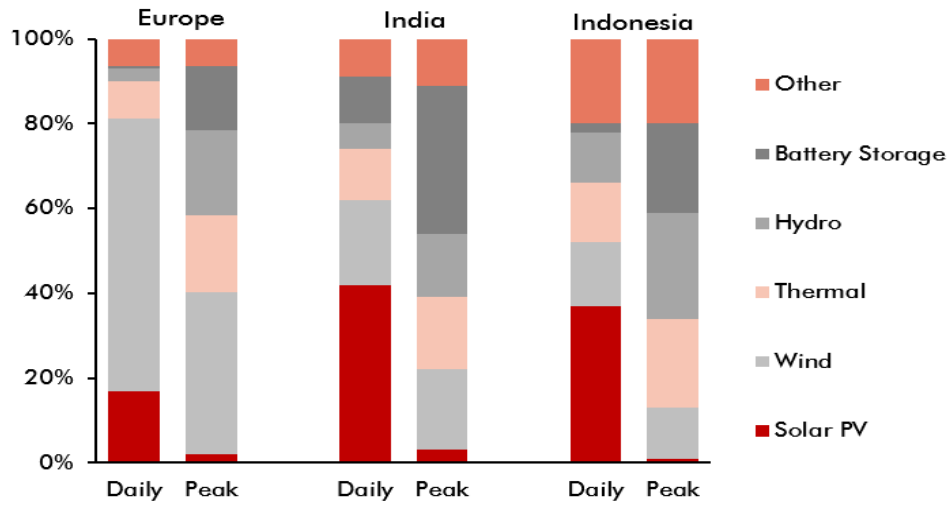
Implications for Indian utilities & metals

Lower battery prices help turn variable renewable power (VRE) firm (FDRE) at a more competitive rate. So, there is likely to be increased absorption of ESS given the steep correction in battery prices. At current $120/kwh all-in price for BESS, we see Rs6/unit cost for standalone storage. But if and when India were to erect trade barriers, it would imply higher battery prices. So, ESS will have to have continued efficiencies in order for it to maintain its cost competitiveness. Batteries use a variety of metals, with steel (including stainless steel), aluminium and copper being the main ones. If global battery demand were to grow from 1,000Gwh at present to 3,000Gwh in future, it would require 6% of current annual copper production and 2% of aluminium consumption. Like most emerging applications, even batteries reply on copper and aluminium.

Batteries help in energy shifting

IEA estimates that by 2050 India batteries would account for 10% of total energy supply, including almost 30% of peak power supply. Battery storage will play an important role in energy shifting, especially as the grid will have to accommodate a greater proportion of variable RE (especially solar power).

Exhibit 70: Daily average and peak hour electricity supply mix by region/country in the APS, 2050



Source: IEA, Ambit Capital research

Battery consumption is price-sensitive

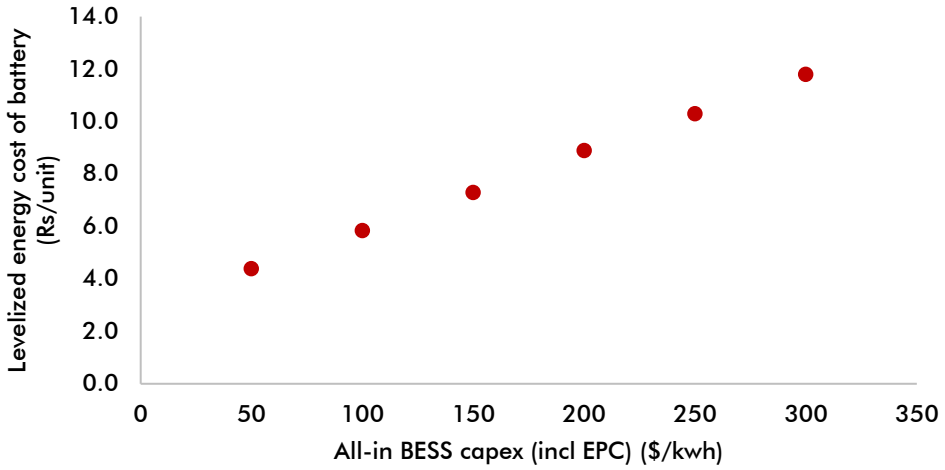
Till the time RPO obligations scale up and/or carbon taxes are mandatorily enforced, battery will have to compete with thermal power on a like-to-like cost basis. Battery adoption in ESS has been augmented by the sharp decline in global battery prices. At current all-In BESS prices, we estimate Rs6/unit levelized cost for BESS storage.

Here are the assumptions we have used:

- 7,000 cycle life
- Only 1 cycle a day, with each cycle being 2 hours
- Solar charging cost of Rs2.5/unit
- Equity IRR of 12%

But if and when the government erects trade barriers in order to boost domestic manufacturing industry, it would mean higher prices for batteries for domestic consumers. Thus, batteries will require higher efficiencies in order to offset the cost inflation stemming from trade protectionism.

Exhibit 71: Sensitivity of levelized cost of battery (Rs/kwh) to all-in cost of BESS ($/kwh)

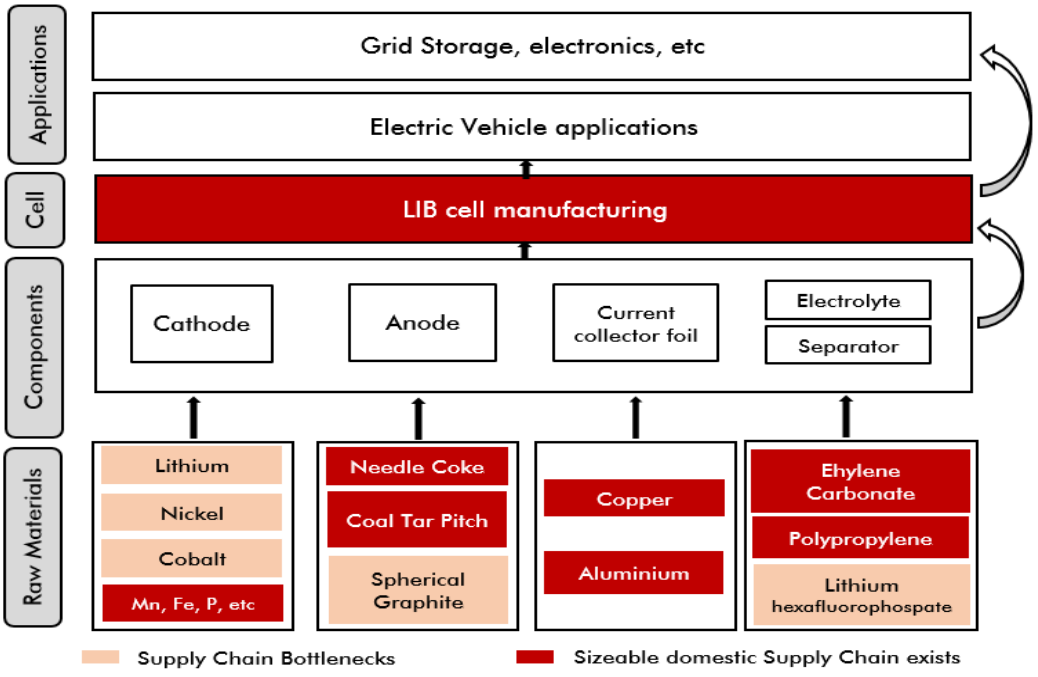


Source: Company, Ambit Capital research

Raw material requirements

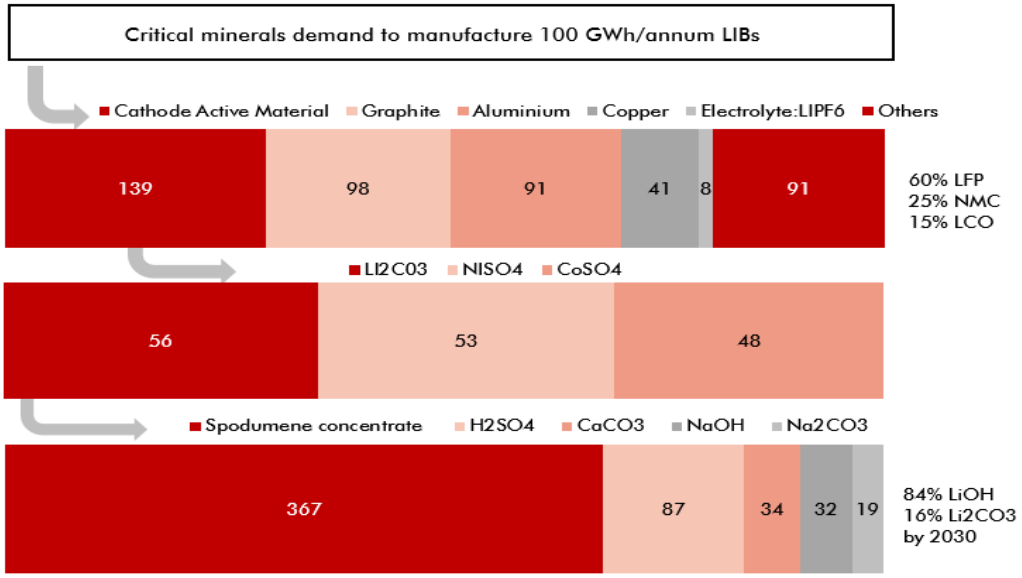
Batteries use a variety of metals, with steel (including stainless steel), aluminium and copper being the main ones. Aluminium is used for foil collectors for cathode while copper is used for anode. HNDL has announced plans to invest Rs8bn for setting up 25KTPA of battery-grade foil capacity. 25 KTPA of battery foil should be able to support 50-60Gwh of battery cell manufacturing. Aluminium is also used in pack jacket. 1Kwh of battery requires 0.5 kg of copper and 0.7 kg of aluminium. Shyam Metallics has also announced plans to manufacture battery-grade aluminium foil. If global battery demand were to grow from 1,000Gwh at present to 3,000Gwh sometime in future, it would require 6% of current global annual copper production and 2% of aluminium consumption. Like most emerging applications, even batteries rely heavily on copper and aluminium. These two metals are likely to benefit the most from battery demand.

Exhibit 72: Battery manufacturing requires various raw materials, ranging from lithium/nickel to coal-based (needle coke, coal tar pitch) to copper and aluminium



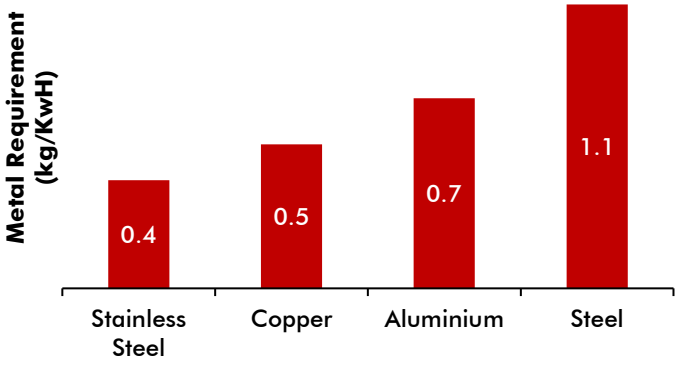
Source: Niti Aayog, Ambit Capital research

Exhibit 73: Raw material requirements for 100Gwh domestic manufacturing capacity, assuming 60% LFP and 25% NFP in cathode active materials (CAM)



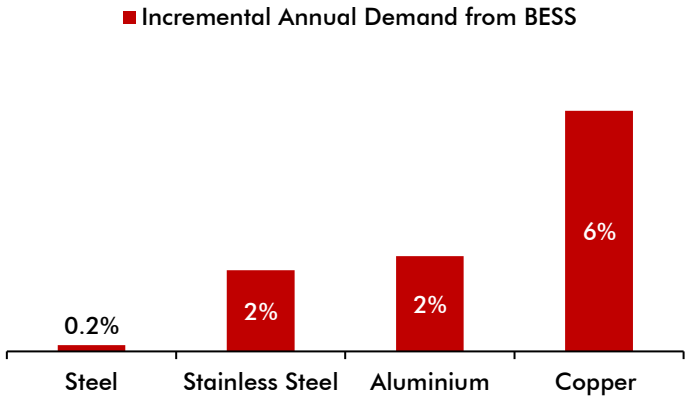
Source: Niti Aayog, Ambit Capital research

Exhibit 74: Batteries require various metals such as steel, copper and aluminum



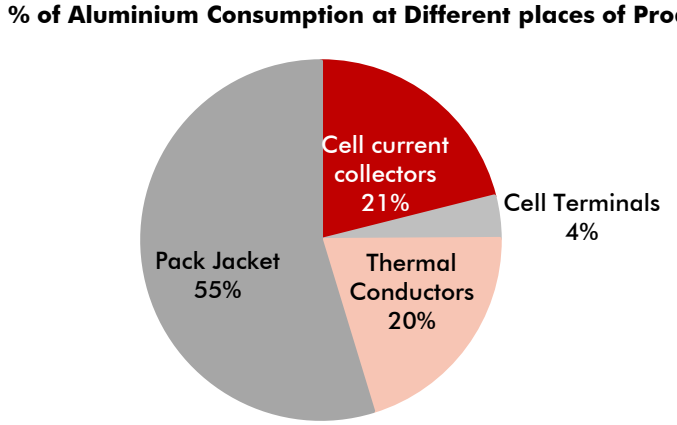
Source: Argonne National Laboratory, Ambit Capital research

Exhibit 75: If we assume 3,000GWh battery production, it would require almost 6% of current global copper demand



Source: Argonne National Laboratory, Ambit Capital research

Exhibit 76: Aluminum consumption in batteries - it is used not only in battery foils but also in pack jacket



Source: Argonne National Laboratory, Ambit Capital research

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