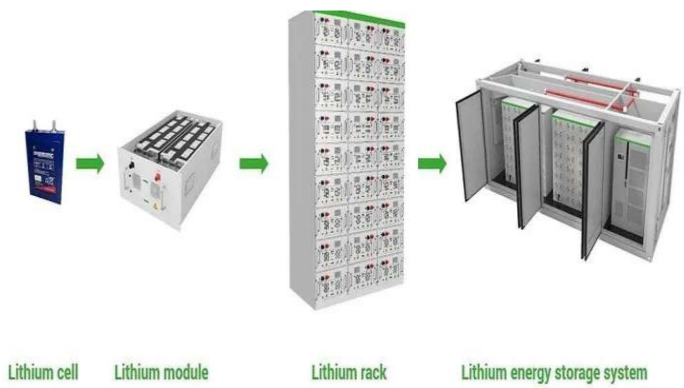
NIVESH आय

Battery Energy Storage System

Industry Report

18th September, 2025

Inside The Report



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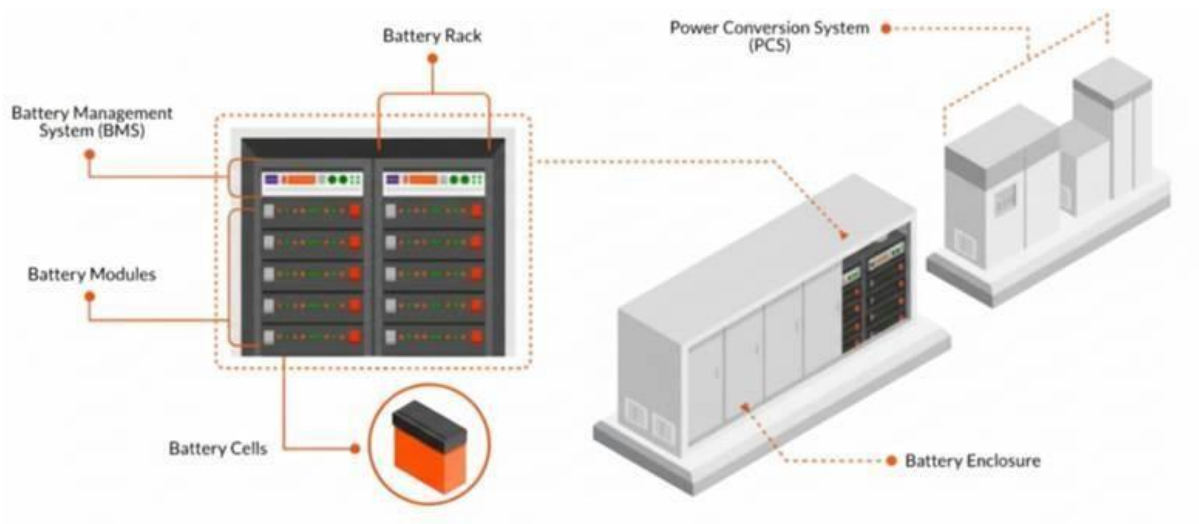
Introduction

Electricity systems are being reshaped by three forces moving in tandem: aggressive decarbonization targets, the rapid build-out of variable renewables, and growing electrification of industry, buildings, and transport. As solar and wind become the marginal source of new generation in many markets, their variability exposes constraints in legacy grids designed around dispatchable thermal assets. Battery Energy Storage Systems (BESS) have moved from pilot projects to grid-critical infrastructure, offering fast, precise flexibility that conventional assets cannot provide. Let's understand what is battery, its keys components, use cases, technology in further section below

"Breaking the battery" – Components, costs and material

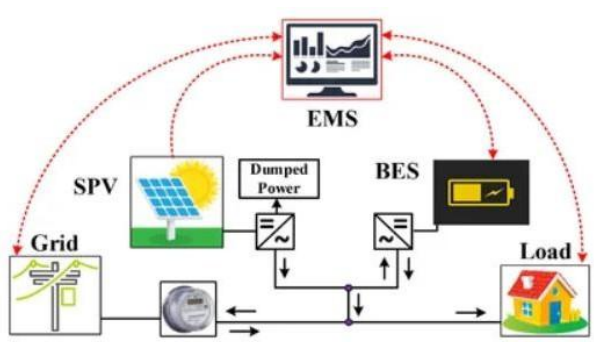


A BESS is more than just a big battery. It includes several major components; each serves a specific function to ensure the system stores and delivers power safely and efficiently:

- **Battery Cells & Racks:**
  - **Battery Cell**
    - **What it is:** The smallest electrochemical unit (usually lithium-ion) where energy is stored/converted.
    - **Output:** Low DC voltage (a few volts) and limited capacity per cell.
  - **Battery Module**
    - **What it is:** A pack of many cells arranged **in series** (to raise voltage) and **in parallel** (to raise capacity), enclosed with basic structural support.
    - **Why it matters:** Modules are the **manageable building blocks** that make assembly, maintenance, and safety control practical.
  - **Battery Rack**

- **What it is:** An assembly of multiple modules wired together to reach the **target system voltage and capacity**; often mounted in cabinets/frames.
- **Why it matters:** Racks are the **deployable units** that determine the BESS's **usable energy (MWh)** and **how long it can supply power** at the required voltage.

- **Power Conversion System (PCS):** This is the **energy conversion hub** of the BESS that connects the DC batteries to the AC grid. Batteries output direct current (DC) power, but the electrical grid and most loads use alternating current (AC). The PCS (also called a bi-directional inverter) converts DC to AC when discharging and AC to DC when charging, allowing energy to flow in both directions. In effect, the PCS gives the BESS its ability to both **charge and discharge**. It also controls parameters like voltage and frequency so that the battery system can seamlessly integrate with the grid or facility. An efficient PCS minimizes conversion losses and reacts quickly to control signals (for example, responding within fractions of a second to supply power for grid stabilization).
- **Battery Management System (BMS):** This is the **brain of the battery pack**. The BMS is an electronic control system that monitors the health and status of the battery cells and modules in real time. It tracks critical parameters such as cell voltage, temperature, state-of-charge (SoC), and state-of-health (SoH) for each battery module. By doing so, the BMS ensures the batteries operate within safe limits and prevents conditions that could damage the cells (over-charge, over-discharge, over-heating, etc.). The BMS can dynamically balance the charge of cells (so no cell overcharges before others), and it can initiate protective actions (like reducing charge current or shutting down the system) if any cell is outside safe conditions. A well-designed BMS is vital for **safety and longevity** of the battery, guarding against issues like thermal runaway (fire risk) by managing temperature and voltage of cells.
- **Energy Management System (EMS):** The EMS is the **master controller** that oversees the operation of the entire BESS. It is essentially software (often running on an industrial computer or controller) that decides when to charge or discharge the battery and by how much. The EMS communicates with the PCS and BMS – and often with external signals like electricity prices, grid demands, or renewable generation data – to optimize the performance of the BESS. For example, in a peak shaving application, the EMS may instruct the BESS to charge when demand is low (or energy is cheap) and discharge during



high demand (when energy is expensive or limited). It coordinates the various components to ensure the BESS provides the intended service (be it backup power, load shifting, frequency regulation, etc.) while also maximizing battery life and economic returns. In summary, the EMS handles the **control and scheduling** of the BESS's energy flow.

- **SCADA System: Supervisory Control and Data Acquisition (SCADA)** is a monitoring and control interface often used in large BESS installations (and other industrial systems). The SCADA system allows human operators and automation systems to supervise the BESS. It provides real-time data visualization, alarms, and controls for the BESS equipment. In some setups, the SCADA system can take on EMS functions or vice-versa – essentially, SCADA is the user interface and integration layer for the BESS, often communicating with remote control centers or utility systems. SCADA logs data on battery performance, temperatures, power output, etc., and can be critical for diagnostics and compliance (for example, recording data for grid operators). While the EMS optimizes operations, SCADA focuses on **monitoring, data logging, and high-level control** of the system by operators.

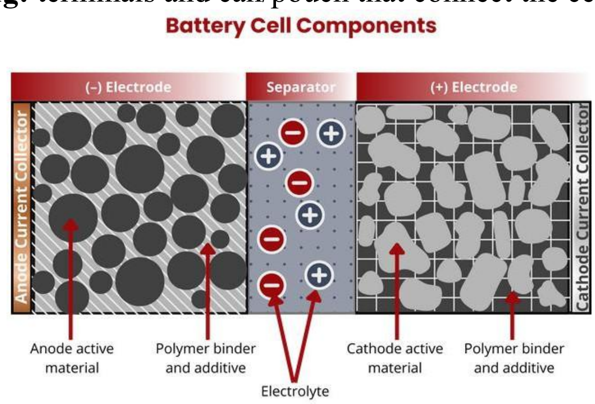
- **Thermal Management System:** Batteries work best within a certain temperature range, so large BESS installations include active cooling (and sometimes heating) systems. **Thermal management** may consist of liquid cooling loops or air conditioning units that circulate coolant/air through the battery racks to remove excess heat. If batteries overheat, their performance and lifespan drop, and safety risks increase; thus, cooling is critical especially for lithium-ion cells. Some BESS designs use *air conditioning or chillers* for containerized systems, while others might use liquid coolant flowing through plates in the racks. Good thermal management keeps all cells at a uniform temperature, preventing hot spots and contributing to safe, reliable operation. (In cold environments, heating may also be applied to keep batteries from getting too cold to charge efficiently.)

- **Fire Protection and Safety Systems:** As with any high-energy electrical system, safety is paramount. Modern BESS containers are equipped with **fire detection and suppression systems** in compliance with safety standards (like NFPA 855 for battery installations). These include smoke and heat detectors, fire extinguishing systems (such as aerosol, gas, or sprinkler systems designed for battery fires), and ventilation systems to evacuate smoke. Additionally, there are electrical safety components: circuit breakers and disconnect switches to isolate the battery in case of faults, and protection relays to prevent over-current or short-circuits. The safety system works together with the BMS; if a dangerous condition is detected (e.g. an overheating cell), the BMS/EMS will trigger alarms or shutdown, and fire suppression can activate to contain any thermal event. Overall, these **safety layers** ensure that the BESS operates safely and can be rapidly shut down or rendered safe during emergencies.

Physical Setup: In practice, a full BESS is often housed in modular units (for example, standard 20 or 40-foot containers). Each container might hold multiple battery racks, the BMS, cooling units (fans or HVAC on the container), fire suppression cylinders, and other auxiliary equipment. The PCS (inverters) might be housed in the same container or a separate power electronics enclosure, often accompanied by a **transformer** to step up the AC voltage to grid level. All these components are integrated so that the BESS can be transported, installed on-site, and connected to the grid or facility with minimal effort (a true plug-and-play solution).

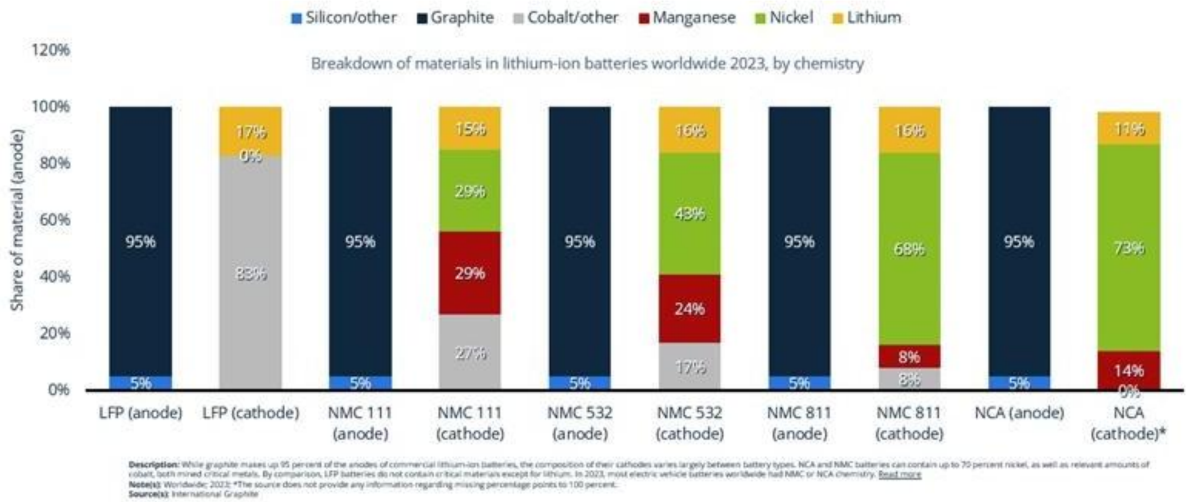
Breaking the cell

- **Cathode (positive, on Al foil):** active material stores/accepts Li^+ during discharge; sets most of the cell's voltage, energy, and safety.
- **Anode (negative, on Cu foil):** usually graphite (often with a small % silicon) hosts Li^+ during charge; forms a protective **SEI** layer in first cycles.
- **Separator:** porous PE/PP film that prevents short circuits but lets Li^+ pass; many cells use multilayer "shutdown" separators for safety.
- **Electrolyte:** lithium salt (commonly **$LiPF_6$**) in organic solvents that conducts Li^+ between electrodes; additives tune SEI and stability.
- **Additives & binders:** carbon black/graphite for conductivity; **PVDF** (or similar) binder holds particles to the foil.
- **Tabs & housing:** terminals and can/pouch that connect the cell and contain the chemistry



(cylindrical, prismatic, or pouch formats).

Battery materials (the “ingredients”)



- **Cathode families (chemistry):**
  - **LFP ($LiFePO_4$):** iron-phosphate
  - **NMC ($LiNiMnCoO_2$):** nickel–manganese–cobalt blends (111/532/811, etc.)
  - **NCA ($LiNiCoAlO_2$):** nickel-rich with a little cobalt and aluminium.
- **Anode:** predominantly **graphite** (>90% of anode material in mainstream cells); small silicon blends boost capacity; **LTO** is a niche fast-charge alternative.
- **Separator:** polyethylene/polypropylene microporous films (often tri-layer) providing mechanical isolation and thermal “shutdown” behavior.
- **Electrolyte:** $LiPF_6$ salt in carbonate solvents (e.g., EC/EMC/DEC); new gels/solid electrolytes are emerging for next-gen cells.
- **Current collectors: Aluminium** for cathode, **copper** for anode—ultra-thin foils that carry electrons.

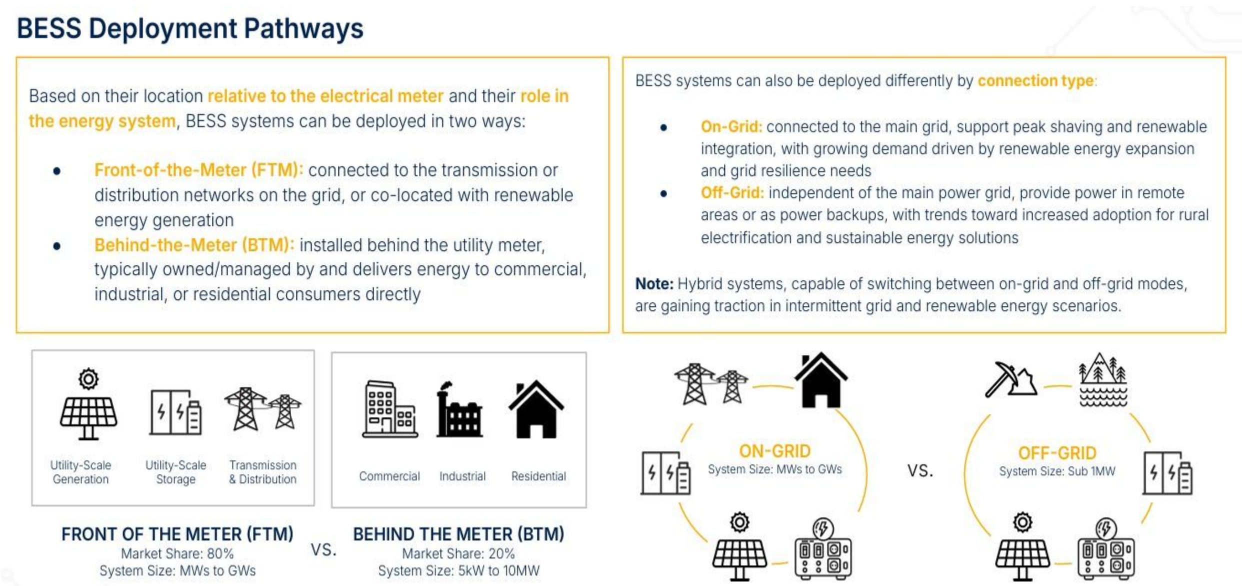
Chemistry (LFP vs NMC/NCA) defines the cathode compound and thus much of the cell’s performance/safety profile, while the anode is typically graphite across all chemistries. The separator and electrolyte enable ion transport and safety, and foils/binders make the electrodes functional and durable.

- **Cost Breakdown of BESS Component:**

Battery Components (as % of Battery Pack)	LFP (%)	NMC (%)
Cell as % of battery pack	~75%	~65%
Battery Management System (BMS)	9–12%	11–13%
Metal components (frames, busbars, structure)	8–11%	11–13%
Electricals (harness, contactors, fuses)	4–6%	7–9%
Other components	2–4%	4–6%
Total Battery Pack	100%	100%

Cell Component	LFP (%)	NMC (%)
Cathode Active Material (CAM)	25–28%	37–40%
Copper + Aluminium Foil (current collectors)	9–11%	3–7%
Graphite (Anode)	10–12%	12–15%
Separator	12–14%	3–5%
Electrolyte	2–5%	2–3%
Others (cell cap, packaging, etc.)	6–9%	6–8%
Total Cell as % of Battery Pack	~75%	~65%

Use and Application of BESS



Source: NREL, Symtech Solar and Cervicorn Consulting

Defining the BESS Landscape: FTM vs. BTM

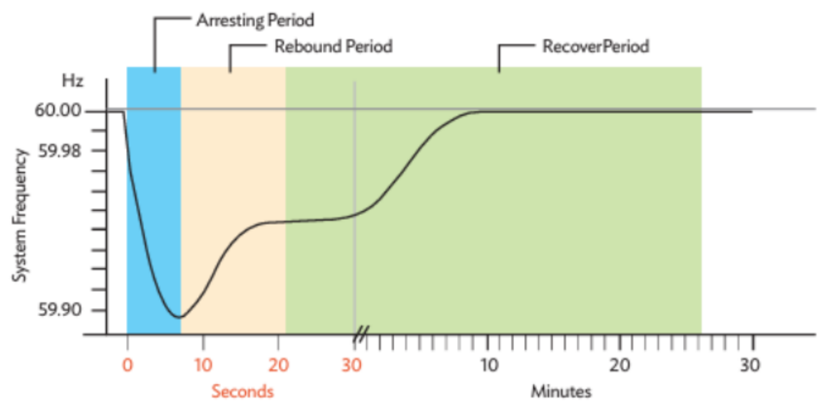
Based on their location relative to the utility electricity meter, BESS deployments are categorized into two distinct segments, each with unique characteristics, applications, and economic drivers, as illustrated in the provided schematic.

Front-of-the-Meter (FTM): FTM systems, also known as utility-scale storage, are connected directly to the transmission or distribution networks on the utility's side of the meter. These are large-scale projects, with capacities ranging from tens of megawatts (MW) to several gigawatts (GW) and are typically owned and operated by utility companies or Independent Power Producers (IPPs). The primary role of FTM BESS is to support the broader power grid. Key application include:

Grid Applications

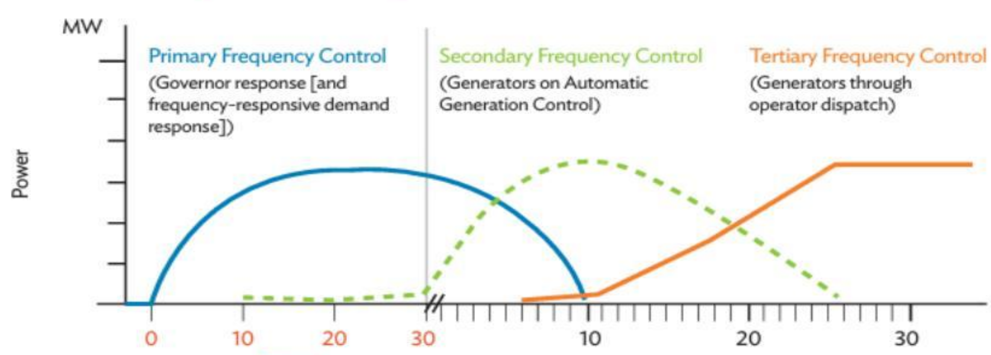
1. **Frequency Regulation**:
   BESS helps in maintaining grid stability by quickly responding to frequency fluctuations. Energy storage systems are used to inject or absorb power into the grid, helping to balance the frequency and ensure continuous supply.
   Example: **Utility-scale BESS installations** can manage these rapid adjustments within milliseconds, making them ideal for stabilizing renewable energy fluctuations.
   Think of the electrical grid's frequency as its **heartbeat**. For the grid to be stable and safe, this heartbeat must be kept at a constant rate (either 50 or 60 Hz, depending on the country).

Figure 3.2: Frequency Containment and Subsequent Restoration*



Hz = hertz.
* Following a contingency such as an outage at a large power station.
Source: Sandia National Laboratories (2013).
Sandia National Laboratories, "DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA," DOE, 2013.

Figure 3.3: Suitability of Batteries for Short Bursts of Power*



MW = megawatt.
*Such as the case in primary and secondary reserve.
Source: Sandia National Laboratories (2013).
Sandia National Laboratories, "DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA," DOE, 2013.

Explanation of above photo:

a. Primary Frequency Control (Blue Line)

- **Timeframe:** Immediate (0 to 30 seconds).
- **Purpose:** This is the grid's instant, emergency first response. Its sole job is to provide a rapid burst of power to "arrest" or stop the system's frequency from falling further, preventing a potential blackout.
- **How it works:** This is an automatic reaction. Batteries are extremely suitable for this task because they can release a large amount of power in less than a second, acting much faster and more precisely than the mechanical governors on traditional power plants.

b. Secondary Frequency Control (Green Dashed Line)

- **Timeframe:** 30 seconds to several minutes.
- **Purpose:** This is the second wave of response that takes over from the primary control. Its goal is not just to stop the frequency drop, but to actively bring the frequency back to its normal target (e.g., 60 Hz).
- **How it works:** This is typically handled by automated signals ("Automatic Generation Control") sent to more flexible power plants, instructing them to ramp up their power output over several minutes.

c. Tertiary Frequency Control (Orange Line)

- **Timeframe:** Several minutes and longer.
- **Purpose:** This is the final, long-term rebalancing. It involves bringing larger, slower power plants online to replace the lost generation and restore the energy reserves that were used during the primary and secondary responses.

How it works: This is a much slower process, often involving manual dispatch by human grid operators.

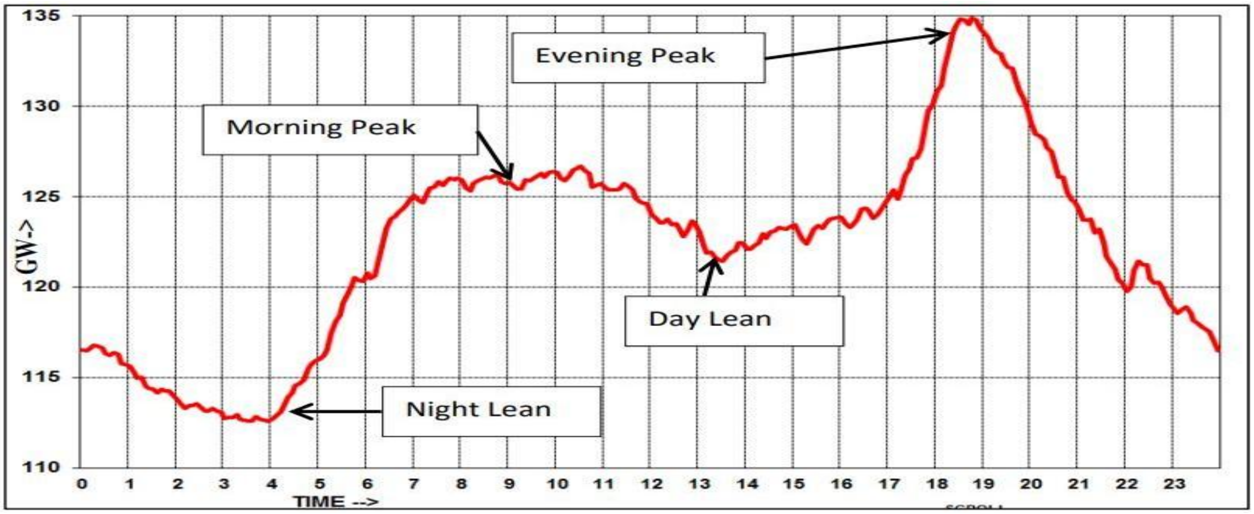
2. **Renewable Energy Integration**:
The Problem with Solar and Wind

- Solar and wind power are unpredictable. This makes it hard to manage the electrical grid.
- Sometimes, the grid can't handle all the renewable energy being produced, forcing operators to waste it (this is called "curtailment").
- Fixing the grid to handle this instability is expensive, and the costs are passed on to customers through higher electricity bills.

A significant portion of this additional demand in the near future is expected to be met through renewable energy sources, particularly solar, marking a substantial shift from previous trends.

However, a key challenge with renewable energy is intermittency, which can lead to grid instability. We will further understand it in more detail: -

Above is the typical chart of the India's load curve (do note these has changes over the period and is all different across season and across month, but this is based on an overall data)

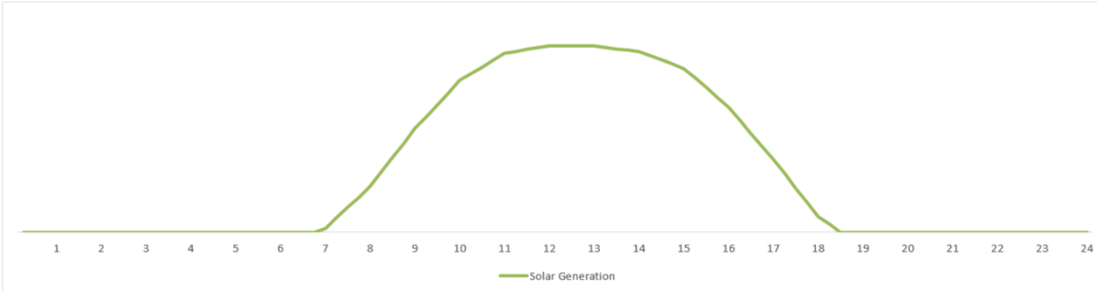


Two important things to keep in mind before we move ahead are:

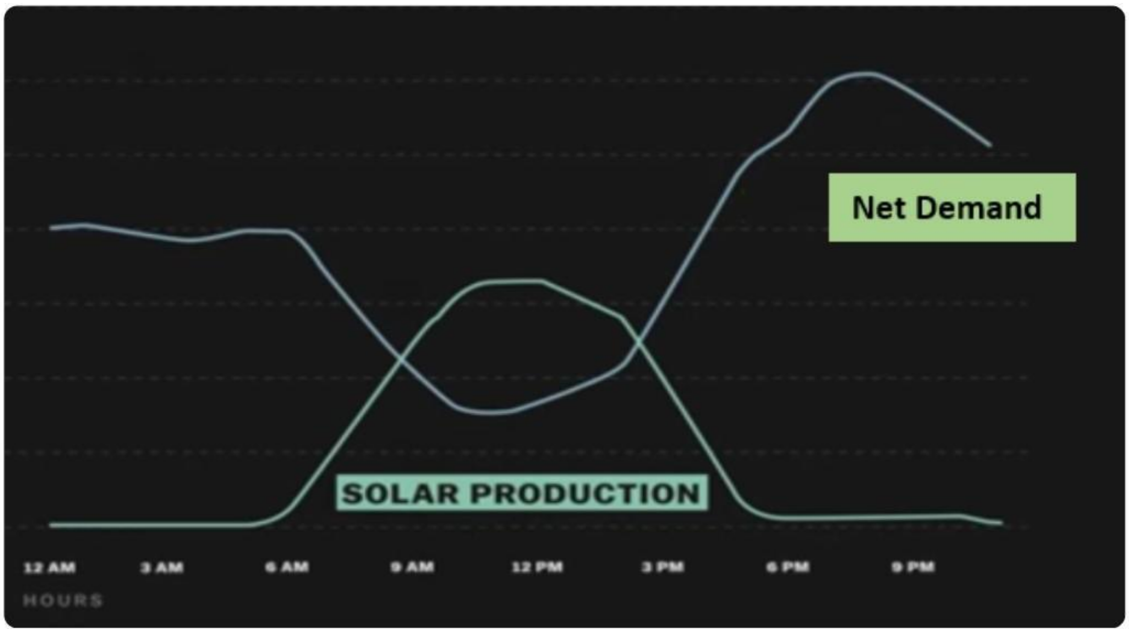
1. The load curve of all energy sources, except solar sources, is relatively flat, meaning their output does not fluctuate significantly throughout the day. While wind energy may exhibit some skewness in the evening, its variability is not as pronounced as that of solar energy.
2. All energy sources, except wind and solar, are dispatchable. This means their output can be controlled by operators, allowing them to regulate how much energy is generated and when it is released.

Now, with India planning significant amount of renewable energy capacity addition, especially solar which is highly intermittent and non-dispatchable, this creates a huge challenge for India's grid as solar energy availability and therefore, solar power production varies with time of the day. It is limited to daytime and peaks around afternoon. However, the load or demand doesn't adjust with the change in solar power production.

Below is the graph of a typical solar load curve.



Now, let's combine the typical solar generation curve and India's typical load curve, to understand, how the curve looks after considering solar generation, below is the graph showing the above-mentioned point-



As solar generation begins to increase after sunrise, the net demand—i.e., the demand that must be met by other power sources—starts to decline. We will refer to this reduced demand as "Net Demand," which is simply the total demand minus solar power production.

Solar power introduces larger ramps in the Net Demand curve. In the morning and early afternoon, as solar generation ramps up, other power sources must ramp down accordingly. Conversely, in the evening, when solar power decreases and overall demand rises, there is a steep ramp-up in the generation required from other sources.

Looking at the Net Demand curve in the image above, one thing becomes evident: India, as a country, must rely on other energy sources—excluding solar—to manage the morning and evening peaks (non-solar hours). However, this presents significant challenges:

1. **Ramp-up and Ramp-down Capabilities**: There is a need for substantial flexibility from other power plants to ramp up or down quickly in response to demand fluctuations.

2. **Economic and Operational Challenges**: Ramping up and down power plants, especially thermal power plants, poses a major challenge due to cost inefficiencies. Thermal plants are most economical and resource-efficient when operated continuously at near-full capacity. Running them at partial loads leads to higher costs and suboptimal utilization of natural resources and machinery, making it difficult to produce power at competitive rates.

   Conversely, in winter and other non-summer months, the peak energy demand typically occurs in the morning, with relatively lower peaks in the evening. This pattern necessitates significant ramping up and down of other energy sources, a trend that is clearly reflected in the load curves.

How Energy Storage Solves This

- Energy storage (like a big battery) acts as a buffer. It saves surplus power when generation is high and releases it when generation is low.
- This allows us to connect more renewable energy to our existing power lines.
- It smooths out the choppy power supply from solar and wind, making the grid more stable and reliable.

Ultimately, this reduces wasted energy and the need for expensive grid upgrades, which helps keep costs down for consumers.

3. **Peak Shaving and Load Leveling:**
BESS is used to reduce the need for peaking power plants that are often expensive and inefficient. By storing energy during low-demand periods, it can be used to meet peak demand, reducing overall grid cost.
Example: In **India**, BESS systems provide a cost-effective alternative to peaking thermal plants, offering savings of **RS. 25/kWh** as opposed to RS. **55/kWh** for thermal power.

What is Peak Shaving?

In simple terms, **peak shaving** is the strategy of reducing electricity consumption during the "peak hours" when demand on the grid is highest.

Why is Peak Shaving Important?

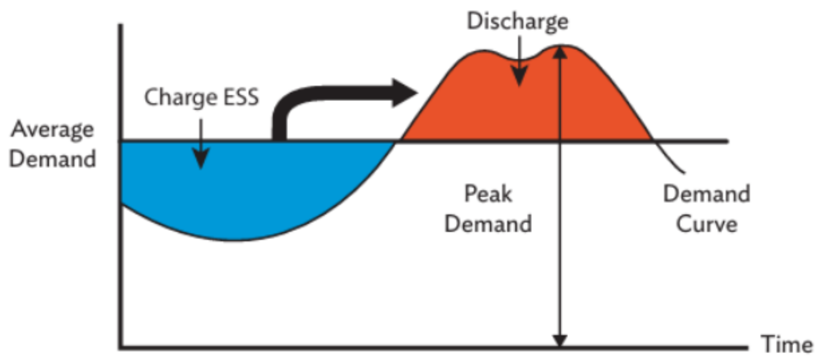
Peak shaving has significant benefits for both the utility companies and the end customers:

a. Benefits for the Grid and Utility Companies:

- **Defers Expensive Upgrades:** Building a grid that can handle the absolute maximum "rush hour" demand is very expensive. By "shaving" the peak, utilities can delay or avoid costly investments in upgrading power lines and building new power plants.

- **Avoids Using "Peaking Plants":** To meet high demand during peak hours, utilities often have to turn on special backup power plants called "peaking generators." These plants are often less efficient and more expensive to run than regular power plants. Peak shaving reduces the need to use them.

Figure 3.7: Use of Energy Storage Systems for Peak Shaving



ESS = energy storage system.
Source: Korea Battery Industry Association 2017 “Energy storage system technology and business model”.

b. Benefits for Customers:

Lowers Electricity Bills: Customers who participate in peak shaving (for example, by using on-site battery storage or reducing their consumption) are often rewarded with lower electricity rates ("tariffs") or direct payments from the utility.

4. **<u>Load levelling</u>**

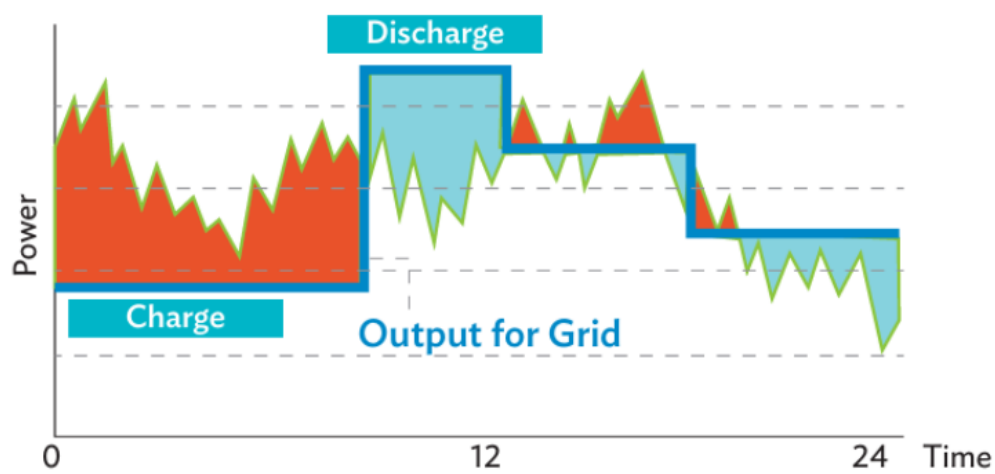
It is the process of shifting electricity use away from busy peak hours to quieter off-peak hours. The goal is to make the demand on the grid more even, or "level," throughout the entire day.

This can be done in two main ways:

Changing User Behavior: Utilities can offer cheaper electricity prices during off-peak times (like late at night). This encourages people to run appliances like washing machines or charge their electric vehicles when demand is low.

Using Technology (like Batteries): A battery system automatically charges using cheap power during off-peak hours. It then powers your home or business during expensive peak hours. This achieves load leveling for the grid without you having to change your habits at all.

Figure 3.8 Use of Energy Storage Systems for Load Leveling



5. **Energy Arbitrage:**
   Energy arbitrage involves buying electricity when prices are low (typically during off-peak hours) and selling it when prices are high (during peak demand). This process helps utilities and large industrial players optimize energy costs.

6. **Microgrids:**
   Microgrids are localized grids that can operate independently of the main grid. They often rely on BESS to store energy from **renewables** and provide backup power during grid outages. Microgrids are particularly useful in remote areas where extending the grid is expensive.

Behind-the-Meter (BTM): BTM systems are installed on the customer's side of the utility meter, serving the energy needs of a specific home or business directly. These systems are typically much smaller than FTM installations, ranging from a few kilowatts (kW) for residential applications to several megawatts for large industrial facilities. The primary goal of BTM BESS is to provide direct economic and operational benefits to the end-user. The BTM market is further segmented:

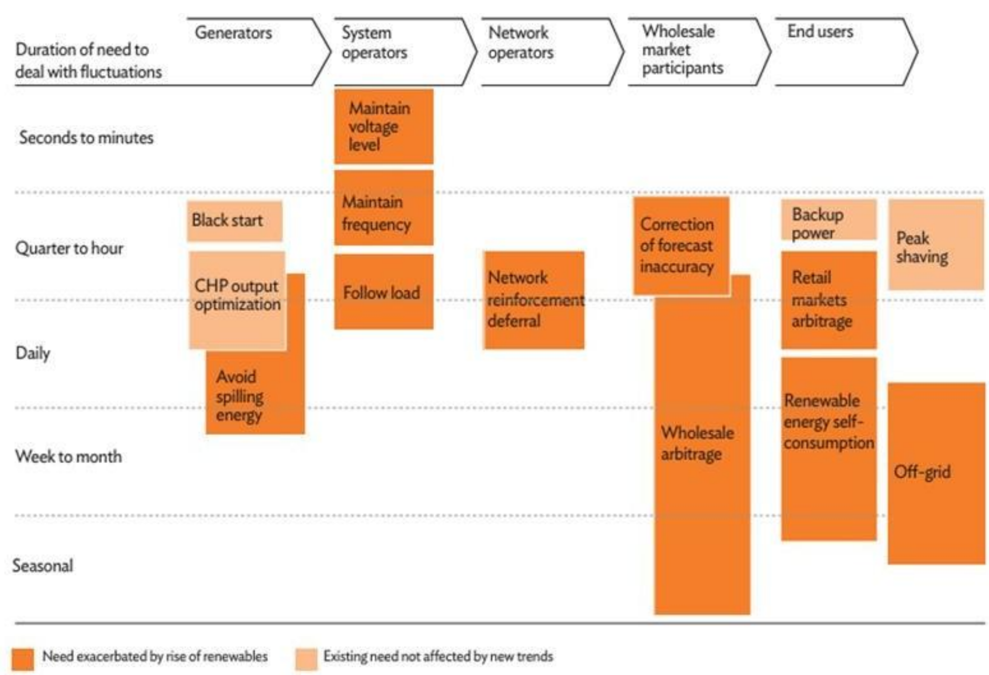
Commercial and Industrial (C&I) Applications

- **Capacity Firming:**
  In industrial settings, BESS helps to firm up renewable energy supply, making it more reliable. This is critical for industries aiming to shift to renewable energy without risking downtime or disruptions.
  Example: **JSW Energy** and **ArcelorMittal** have adopted **energy storage systems** to stabilize their renewable energy supply.

- **Diesel Abatement**:
  Many industrial and commercial establishments rely on **diesel generators** for backup power during grid outages. By using BESS, these entities can reduce their dependence on expensive and polluting diesel, leading to significant cost savings and environmental benefits.
  BESS provides a more economical and environmentally friendly alternative to diesel generators for backup power during grid outages. The cost of running a BESS coupled with renewables is estimated at around RS. 20/kWh, significantly lower than the RS. 30-35/kWh for diesel generation.
- **Power Quality Improvement**:
  BESS improves **power quality** by providing voltage support, reactive power, and compensating for harmonics, thereby reducing downtime for sensitive equipment.
- **Backup Power**:
  For industries facing frequent power cuts, BESS can serve as a reliable backup source, ensuring continuity in operations and preventing loss of productivity.

While FTM projects represent the backbone of grid-level decarbonization, BTM solutions empower consumers and businesses, creating a more distributed and resilient energy ecosystem.

<u>Grid storage needs along the value chain</u>



Source: ROLAND BERGER GMBH (2017). R. Berger, "Business models in energy storage – Energy Storage can bring utilities back into the game," May.

Battery Chemistries

What is exactly this battery chemistry?

Battery chemistry = the specific electrochemical recipe that makes a battery work — i.e., which materials are used for the cathode, anode, and electrolyte, and the reactions between them. Changing the chemistry changes the cell's voltage, energy density, cycle life, safety, cost, and temperature behavior. The performance of the battery mainly depends on these chemistries and particular use cases.

Performance Metrics for Key Battery Chemistries	Lithium Ion								Sodium ion	Lithium Metal	Solid State	Lithium Sulfur
Cathode Anode	High Voltage LCO Gr	NMC Gr	NCA Gr	LFP Gr	LMFP Gr	LMO Gr	High Voltage LNMO Gr	High Ni Majority Silicon	NaMOx Hard Carbon	High Ni Lithium Metal	High Ni Lithium Metal	Sulfur Lithium Metal
Gravimetric Energy Density Wh/kg (cell level)	180-200	250-300	250-280	160-205	190-230	100-150	150-165	325-350	130-160	400-450	300-450	300-500
Volumetric Energy Density Wh/L (cell level)	400-700	650-800	600-750	250-400	400-580	300-400	400-650	750-1000 +	150-300	700-1000	700-900	450-650
Cycle Life (C/2+ rate) (>80%)	750	1500	1000	3000	2000	500	750	500	6000	400	500	300
Calender aging (Qual)	Avg	Avg	Avg	Good	Avg	Low	Poor	Low	Avg	Avg	-	Avg
Self Discharge (%/Month)	1.00%	0.25%	2.50%	0.50%	1.00%	2.00%	-	5.00%	0.20%	-	-	1.00%
Charge Rate Capability (Qual)	Avg	Avg	Avg	Avg	Avg	Avg	Avg	Good	Avg	Low	Low	Avg
Discharge Rate Capability (Qual)	Good	Avg	Avg	Avg	Avg	Good	Avg	Good	**Avg	Avg	Avg	Avg
Safety (Active Materials)	Avg	Low	Low	Avg	Avg	Avg	Low	Low	Good	Poor	**Poor	**Avg
Possible Form Factors and Challenges	No Issue	No Issue	No Issue	No Issue	No Issue	No Issue	No Issue	*High Swelling*	No Issue	handling issues	Manufacturing Challenges	No Issue
Nominal Voltage (V) Voltage Range (V)	3.6 (3.0 - 4.5)	3.7 (2.5 - 4.3)	3.6 (3.0-4.3)	3.2 (2.5 - 3.65)	3.7 (2.75 - 4.0)	3.8 (3 - 4.3)	4.7 (3.0 - 5.0)	3.5 (2.5 - 4.2)	3.1-3.7 (1.5 - 4.2)	3.7 (2.5 - 4.2)	3.7 (2.5 - 4.2)	2.1 (1.5 - 3)
Cathode Specific Capacity (mAh/g)	274	215	200	170	160	148	147	215	170	215	215	1675
High Temperature Operation (60C+)(Qual)	Low	Avg	Low	Good	Good	Low	Low	Avg	Good	Low	**Low	Good
Low Temperature Operation (10C-)(Qual)	Poor	Good	Good	Poor	Avg	Avg	Avg	Good	Poor	Low	**Low	Poor
Recycle Value (Li, Co, Ni, Cu) for Cost/Effort	Good	Avg	Avg	Low	Low	Low	Avg	Avg	Poor	**Avg	**Avg	Low

Best 5
Good 4
Avg 3
Low 2
Poor 1

What is the different type of chemistries and their key characteristics?

Source: Volta battery report

Understanding the above table through qualitative inputs

Chemistry (Cathode – Anode)	Pros	Trade-offs	Best-fit uses
LFP – Graphite	Very safe, long life, low cost, tolerant to abuse	Lower energy density than Ni-rich; larger packs for same kWh	**BESS (1–4h) dominant**, buses, mid-range EVs
NMC (622/811) – Graphite/Si-graphite	High energy → long EV range; mature supply chain	Pricier (Ni/Co), tighter thermal safety envelope	**EVs needing range**, some high-power packs
NCA – Graphite/Si-graphite	Very high energy/power	Cost & safety management similar to NMC	**Premium EVs**, high-specific-energy packs
LMO-blend – Graphite	Good power, decent cost	Shorter life vs LFP/NMC alone	Some EV hybrids, power-tools; limited BESS
LFP/NMC – LTO *(LTO anode family)*	Ultra-long life, fast charge, very safe	Low energy density, higher $/kWh	**Heavy cycling BESS**, rail, buses, UPS
Sodium-ion (layered/prussian) – Hard carbon	Lower cost materials, good low-temp, safer	Lower energy density than Li-ion today	**Cost-sensitive BESS**, entry EV/2-wheelers
NaS (sodium–sulfur, high-temp)	Multi-hour, low fade, small footprint	300–350 °C ops, thermal safety engineering	**Longer-duration BESS (6–8h)**, remote
Na-NiCl$_2$ (Zebra, high-temp)	Stable chemistry, tolerant storage	High-temp ops, efficiency penalty	Select stationary/industrial
VRFB (vanadium flow)	Unlimited cycle life style, deep DoD, no fire risk	Lower efficiency; lower energy density; capex	**Long-duration BESS (6–12h+)**, heavy cycling
Zn–Br (flow)	Scalable energy, tolerant to hot climates	Bromine handling, efficiency	**Longer-duration BESS**, hot sites
Aqueous Zn-ion (Zn–MnO$_2$, etc.)	Very safe, simple logistics	Energy density & maturity still improving	**Stationary BESS (2–6h)** pilots/early
Iron–air	Very low $/kWh-energy potential	Low power density; early-stage	**Multi-day storage** (24–100h), future
Solid-state Li-metal	Step-change energy & safety potential	Scaling, durability, cost still in work	**Future EVs**, later BESS niches

Key take aways:

Lithium-ion batteries (both LFP and NMC types) provide the highest energy density and efficiency, which is why they dominate today's 1–4-hour storage projects. LFP in particular stands out for its combination of long cycle life, safety, and rapidly dropping cost, making it the leading choice for new BESS deployments.

Lead-acid is cheap but too short-lived and bulky for most new installations, though it remains in low-cost backup roles. Sodium-sulfur offers a compelling high-temperature solution for long-duration needs and has proven reliability in decades of service, but its niche nature and heat requirements limit widespread adoption.

Flow batteries like VRFB excel at unlimited cycling and long discharge durations; while they lag in efficiency and energy density, their ability to last 20+ years with minimal fade gives them an attractive levelized cost for multi-hour storage.

Each chemistry thus has "sweet spots": for example, Li-ion for fast, energy-dense storage up to a few hours, and flow or high-temp batteries for very long-duration or extremely high cycle applications.

It's also important to consider **depth of discharge and operational strategies**. Li-ion batteries often are operated between 10%–90% state of charge to extend life (especially NMC batteries) – this effectively reduces usable energy but improves cycle count. By contrast, flow batteries and NaS can be regularly cycled at 0–100% without harming longevity. This functional difference can influence project sizing (one might oversize a Li-ion bank to reduce the DOD per cycle, whereas an equivalently rated flow battery could use its entire capacity each time). In terms of **response time**, all the listed chemistries respond quickly (sub-second to seconds). Li-ion and capacitive systems are fastest (millisecond-scale), but even large flow batteries can ramp output in a few hundred milliseconds, suitable for grid frequency regulation.

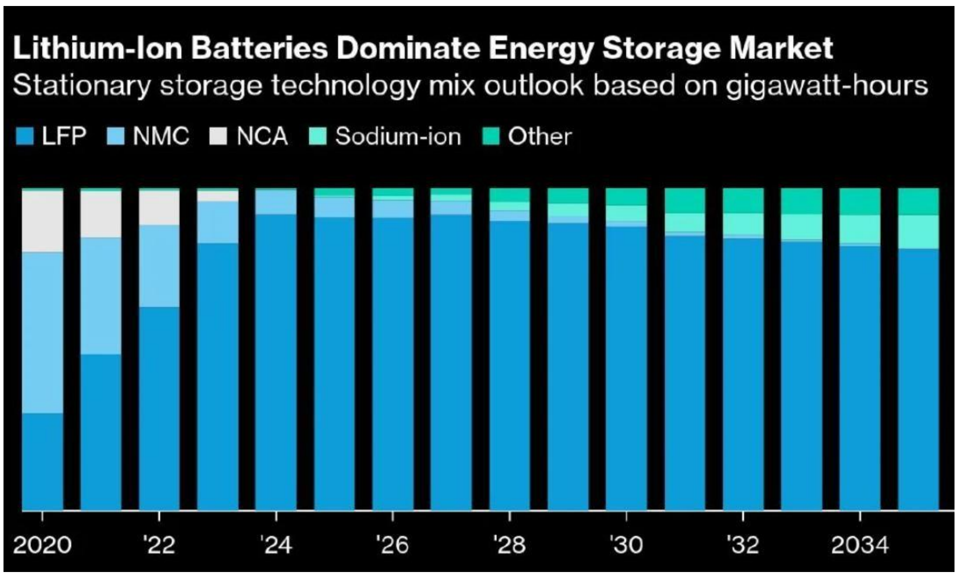
Which is the chemistry that that currently dominates for storage applications?

The global chemistry mix for battery storage has undergone a clear shift in the past decade and is expected to continue evolving as new technologies mature. **Lithium-ion batteries have established a near-monopoly in recent years,** lithium iron phosphate (LFP) batteries, accounted for about 85-90% of the total battery storage market in 2024, up from about 65% in 2022. Within the Li-ion segment, there has been a notable internal shift: **LFP chemistry's market share has surged relative to NMC/NCA**. BloombergNEF notes that LFP's combination of lower cost and longer life has made it the preferred chemistry for energy storage, and predicts LFP will remain the dominant stationary battery chemistry through at least 2035. This is enabled by enormous scaling of LFP production (especially by Chinese firms) and even traditional nickel-based cell producers converting some lines to LFP to supply storage projects. As a result, NMC/NCA chemistries – while still common in EVs and some high-density applications – have been losing ground in stationary storage.

Lead-acid batteries, once significant in off-grid and remote storage, have seen their share of new deployments shrink drastically. Most new BESS installations now favor Li-ion unless there is a special reason to use lead-acid (such as extreme low-cost requirement and infrequent cycling). Likewise, high-temperature NaS batteries, which saw notable deployment in the 2000s (hundreds of MWh in Japan), have not grown at the same pace – their share globally is quite small compared to Li-ion. They remain in use in certain Japanese projects and a handful of installations elsewhere, but no major boom is evident as Li-ion undercut NaS on cost for <8h applications.

The area with potential change is **long-duration storage (>8–10 hours)**. There is increasing recognition by grid planners that while Li-ion excels up to a few hours, other technologies may fill the >10h gap more economically Governments and utilities in the U.S., Europe, and Asia are funding demonstrations of alternatives, and setting targets for long-duration capacity (for example, California aims for 1 GW of long-duration storage by 2026, and at least 10% of 50 GW by 2045, to come from 8+ hour technologies). As such, **flow batteries, metal-air batteries, thermal and gravity storage, and other novel systems to gain market share in the late 2020s and 2030s** in the long-duration niche. BloombergNEF's 2024 Long-Duration Energy Storage report highlights that in markets outside China (where Li-ion is cheapest), several long-duration techs are *already reaching lower capex per kWh than Li-ion for >8h durations* (e.g. compressed air, advanced thermal storage). In China, Li-ion is so inexpensive that alternatives still struggle to compete on cost, but even there sodium-ion and flow batteries are being actively developed to meet policy goals for diversified supply.

Overall, we can expect lithium-ion to continue leading the BESS market in the near and midterm but with a **broadening of the technology mix** on the horizon. Policy support for long-duration storage and supply chain diversification (e.g., avoiding overreliance on lithium) are key drivers encouraging alternative chemistries

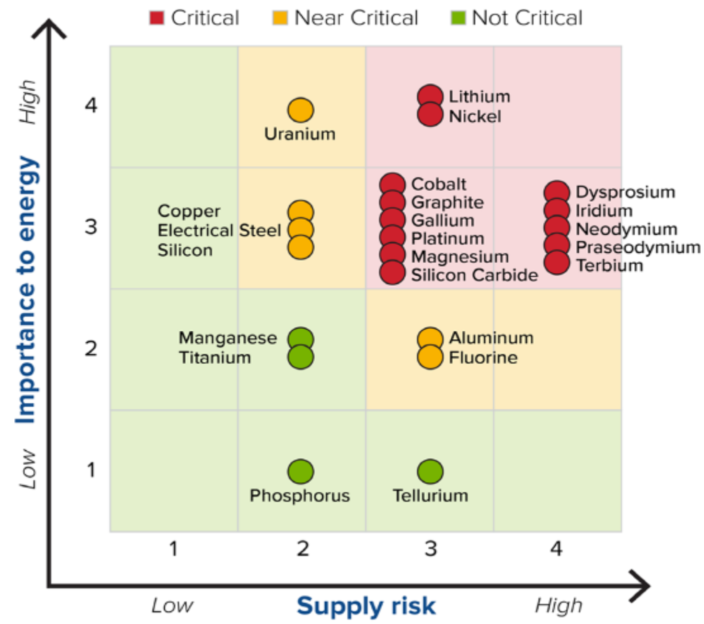


Source: Bloomberg

Upcoming future technologies/non lithium technologies –

But before understanding the future/non-lithium technologies, let's understand why do we even need alternatives, if lithium ion has already become techno-commercially viable at wide scale?

We need alternatives to lithium-ion because the supply chain, costs, sustainability profile, and application fit all have limits. Lithium reserves and processing are highly concentrated—~90% of mining in Australia/Chile/China, ~60% of processing in China and ~30% in Chile—with graphite processing also centred in China, creating exposure to geopolitical shocks and natural-disaster disruptions. Also in the next few years, the demand for LIBs is expected to outpace supply, according to McKinsey, the global demand for Li-ion cells will grow 6X from 2022 (~700 GWh) to 2030 (~4700 GWh) and then there is a broader/natural attribute to innovation and higher efficiency technology. Below image very well summarizes the supply risk (we will talk about more of this is supply chain analysis) of lithium



DOE 2025-2035 Criticality Matrix

Below is the list of few promising non-lithium technologies:
There are a lot of batteries technologies being developed around the world across similar and new chemistries as well as across storage duration, after evaluating various of these technologies such as Sodium ion, Solid state, Zinc Ion batteries, Flow batteries, etc. We decided to focus on sodium ion batteries as it was the ahead of most in the technological as well as commercial curve and is considered as a serious replacement to LFPs in 2-4h energy storage markets, (biggest markets). Below is the detail of the sodium ion batteries.

Sodium Ion battery

SIBs operate on similar principles as LIBs but utilise sodium ions as the charge carriers as compared to lithium ions. The two metals used for these batteries, lithium and sodium, are both Alkali metals and thus share similar chemical characteristics. Other key battery components, such as the anode, electrolyte, and current collector, can also differ. The component-wise materials used in LIBs and SIBs are described in the table below

Component	Lithium-ion Batteries	Sodium-ion Batteries
Anode	Graphite, Si-graphite, Lithium Titanite Oxide (LTO)	Hard carbon / expanded graphite / tin or antimony alloyed with sodium metal
Separator	Polymer	Polymer
Electrolyte	Organic carbonates: Lithium salt and sodium salt, solid electrolyte	Organic carbonates: Sodium salt
Cathode	Lithium Cobalt Oxide (LCO) Nickel Manganese Cobalt (NMC), Nickel Cobalt Aluminium (NCA), Lithium Iron Phosphate (LFP) and modified LFP as Lithium Manganese Iron Phosphate (LMFP)	Prussian Blue and analogues, Layered Transition Metal Oxides, Polyanion (Combinations of sodium, iron, manganese, phosphorus, sulfur, vanadium, nickel, and carbon)
Collector	Aluminium	Aluminium

The basics characteristics of sodium ion vs LIBs is mentioned above.
The two biggest advantages of sodium ion is listed below: -

1. **Cost:** SIBs are cost-competitive and may become even cheaper than LIBs in the long term since sodium compounds are cheaper than lithium equivalents. Additionally, SIBs do not use copper current collectors like LIBs and instead use cheaper aluminium current collectors. SIB chemistries also do not require cobalt, which is scarce and expensive. Although today's SIB costs ($125/kWh) are not yet competitive with LFP, ($50 – 70/kWh), projections and various studies shows that once SIBs achieve widespread production and benefit from economies of scale, their overall costs could be 15%-20% lower than LFP LIBs.

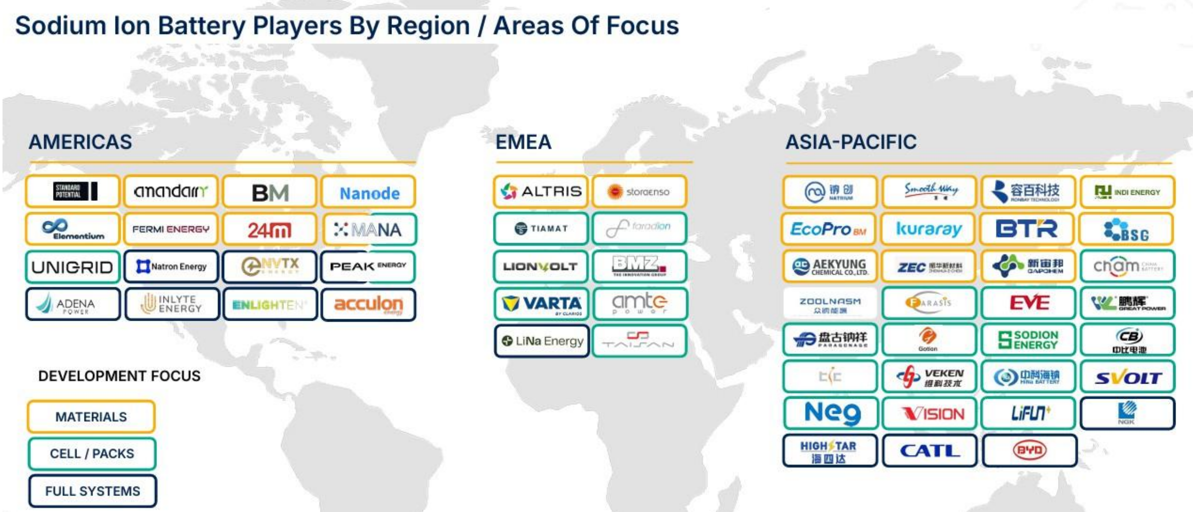
2. **Supply chain decentralization**: Sodium is abundantly available, and present in almost all countries. The processes for synthesising sodium compounds used in batteries leverage seawater and limestone and are well established. Additionally, SIBs use hard carbon instead of graphite (whose manufacturing is concentrated in China) as the anode material. Thus, a number of countries can realistically aim to develop manufacturing capabilities**.**

Risk area	Lithium-ion batteries	Sodium-ion batteries
Technology	Well established technology	Nascent stage with further R&D required
Supply chain	Volatile and geopolitically concentrated supply chain	Underdeveloped supply chain, but potential to be distributed worldwide
Raw material availability	Reliant on critical minerals	Significantly less reliant on critical minerals
Manufacturing	Established manufacturing capacity and processes	Limited manufacturing capacity, but similar process to LIBs
Cost	Higher cost at cell level but lower cost at pack level	Lower cost at cell level but higher cost at pack level with potential for reduction through economies of scale
Sustainability	Uses cobalt, which is associated with environmental and human rights concerns	Does not rely on cobalt, mitigating sustainability concerns

SIBs also have some challenges/constraints such as Even with rapid progress, SIB **gravimetric/volumetric energy density** typically trails LFP, so containers are larger/heavier for the same MWh and Hard-carbon (HC) anodes suffer **low initial Coulombic efficiency (ICE)** and SEI instability vs. Li-ion, so you lose usable energy in formation and early cycles.

Must see, covers everything about sodium ion battery:
https://www.youtube.com/wah?v=RQE56ksVBB4

Players in the sodium ion battery value chain:



<u>Major chemistries across storage durations</u>

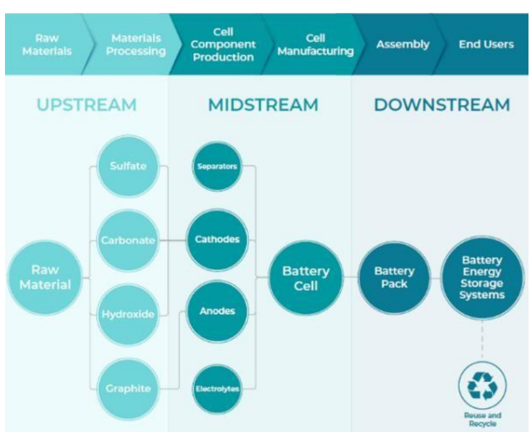
	Storage duration				
	4h or less	4h to 8h	Days	Weeks	Seasonal
Lithium-ion	Suitable	Suitable	Unsuitable	Unsuitable	Unsuitable
Sodium-ion	Suitable	Suitable	Unsuitable	Unsuitable	Unsuitable
Redox flow	Marginal	Suitable	Suitable	Unsuitable	Unsuitable
Iron air	Unsuitable	Unsuitable	Marginal	Suitable	Unsuitable

Suitable   Marginal   Unsuitable

Global battery supply chain

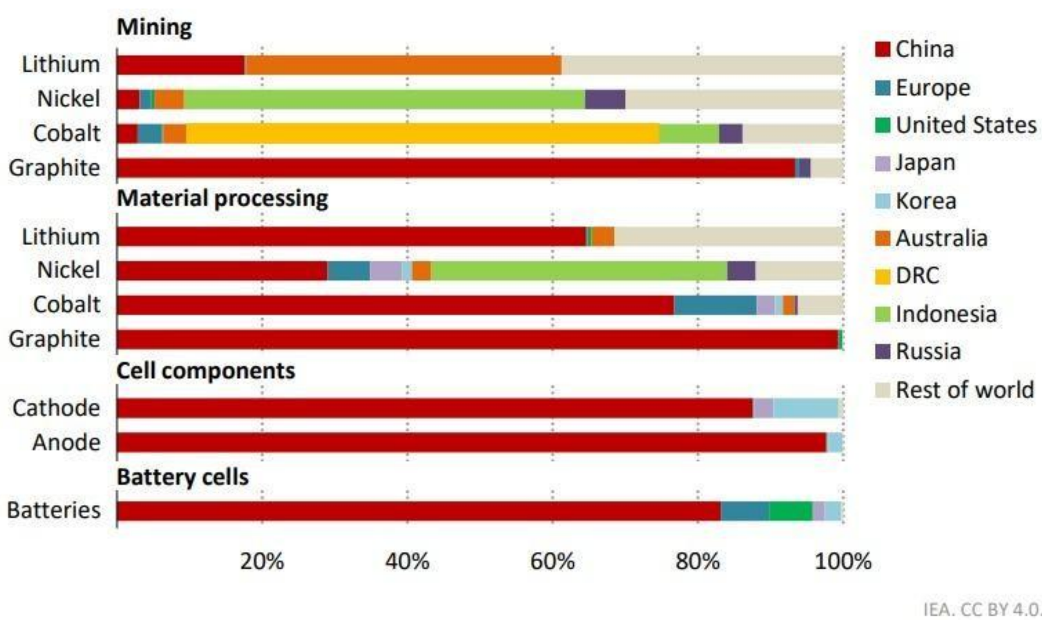
BESS supply-chain roadmap

Understanding the process in brief



1. **Raw materials (mining):** the ores and concentrates: lithium, cobalt, nickel, graphite, manganese — plus copper, phosphate and other inputs (aluminium, iron, rare earths). These are the physical feedstocks pulled from mines and brines.
2. **Material processing & active materials:** ores → battery-grade chemicals (e.g., lithium carbonate/lithium hydroxide, nickel sulphate, cobalt sulphate) → *precursors* → final cathode/anode powders (CAM & AAM, e.g., NMC/LFP powders, spherical graphite). This is the chemical heart of the chain.
3. **Cell manufacturing:** electrode coating, cell assembly, formation and testing in gigafactories that turn active materials + components into battery cells (pouch, prismatic, cylindrical). This is the capital-intensive factory step.
4. **Battery pack assembly**: cells → modules → packs include mechanical frames, busbars, safety hardware and the Battery Management System (BMS) and cooling; delivers a tested pack ready for integration.

Understanding the supply chain in detail



China dominates across the entire downstream battery supply chain

1. **Raw Materials for Batteries:** Batteries, especially lithium-ion, rely on several critical raw minerals: Lithium, Cobalt, Nickel, Graphite, Manganese, and others like Phosphate (for LFP cathodes) and Copper (for electrical components). This section provides an overview of each key material – their role in batteries, major source countries

   Lithium:

- What & where: Lithium is the key metal in all Li-ion chemistry; it comes from brine and hard rock deposits.
- 2024 picture (production): Global mine output **≈** 240,000 t (Li). Australia ≈ 88,000 t (~37%)**,** Chile ≈ 49,000 t (~20%)**,** China ≈ 41,000 t (~17%)**.**
- Reserves: Chile holds the largest reserves **(**~9.3 million t**),** followed by Australia **(**~7.0 million t).
- Demand gap & outlook: Demand must scale rapidly -2024 output (~240 kt) is far below projected needs (IEA/industry scenarios show demand could exceed ~3,000,000 t by 2030**)**

Cobalt:

- Role: Key cathode metal (NMC, NCA) boosting energy density & stability; mostly a byproduct of copper/nickel mining**.**
- 2024 mines output: Global ≈ 290,000 t**;** DRC ≈ 220,000 t (~75%), making it overwhelmingly dominant. Indonesia is a distant second.
- Reserves: DRC holds >50% of global reserves (~6 Mt of 11 Mt)**.**
- Refining: China produces ~70–80% of refined cobalt, despite minimal domestic ore; most DRC output flows to Chinese refineries.
- Trends: Cobalt use in batteries has risen fast **(**EVs ≈43% of demand in 2024**),** but intensity per kWh is falling as chemistries shift to lower-Co options (e.g. LFP, high-nickel).

Nickel:

- Role**:** Essential for high-energy cathodes (NMC, NCA); requires high-purity Class 1 nickel for batteries.
- 2024 mines output**:** Global ≈ 3.7 Mt; Indonesia **≈** 2.2 Mt (~55–60%), far ahead of others. Philippines (~11%), Russia (~6%), Australia/Canada/New Caledonia smaller shares.
- Reserves: Indonesia (~55 Mt) and Australia (~24 Mt) hold the largest global reserves.
- Processing: Indonesia is expanding refining (HPAL/MHP) and rising fast in battery-grade sulfate; China remains the largest producer today.
- Trends & risks: ~14% of nickel demand now goes into batteries (vs 5% in 2015)

Manganese:

- Role: Present in all NMC cathodes; future high-Mn cathodes could raise demand. Most mined Mn goes to steel, but battery-grade Mn sulfate is a niche product.
- 2024 mines output: Global ≈ 20 Mt; South Africa ≈ 7.4 Mt (~37%), Gabon ≈ 4.6 Mt (~23%). Other suppliers: Australia, China, Brazil.
- Reserves: Global ≈ 1.7 billion t; South Africa ≈ 560 Mt (largest share).

- Trends & risks: Manganese itself is abundant (not usually "critical"), but high-purity Mn sulfate for batteries could be a supply pinch point if demand surges. Supply is Africa-heavy but diversified enough to mitigate extreme bottleneck risk.

Phosphate:

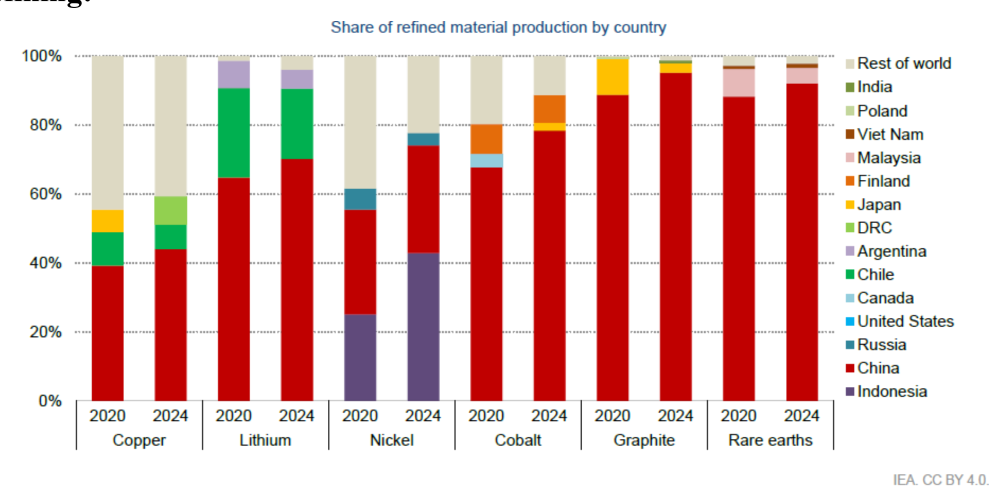
- Role: Core to LFP cathodes (lithium iron phosphate), now widely used in EVs & stationary storage for low cost and cobalt/nickel-free chemistry.
- Reserves: Global phosphate rock ≈ 70% in Morocco; others include China, Egypt, Algeria.
- Production (2024): China is the largest producer of phosphate rock and a leading supplier of purified phosphoric acid (PPA) for LFP.
- Demand context: Most phosphates go to fertilisers; battery demand is still a small share.

2. **<u>Material processing & active materials:</u>** This stage converts raw ores into battery-ready inputs and manufactures the key components that go into cells.

It includes:
Refining & chemicals: ores → battery-grade salts (e.g., lithium carbonate/hydroxide, nickel & cobalt sulfates, purified phosphoric acid).
Active materials: production of cathode powders (CAM) and anode materials (AAM, mainly spherical/synthetic graphite).

Other components: electrolytes, separators, current collectors that complete the cell stack.
Geography: The stage is highly concentrated in a few countries, with China dominating refining and active-material production across lithium, cobalt, nickel, graphite, and phosphates — giving it a pivotal role in the midstream supply chain

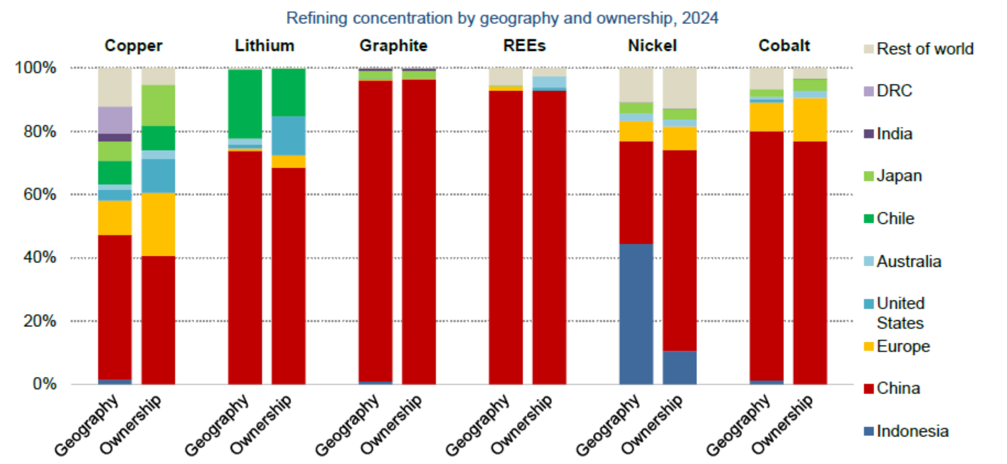
Refining:



Notes: DRC = Democratic Republic of the Congo. Graphite is based on battery-grade spherical and synthetic graphite. Rare earths are magnet rare earths only.

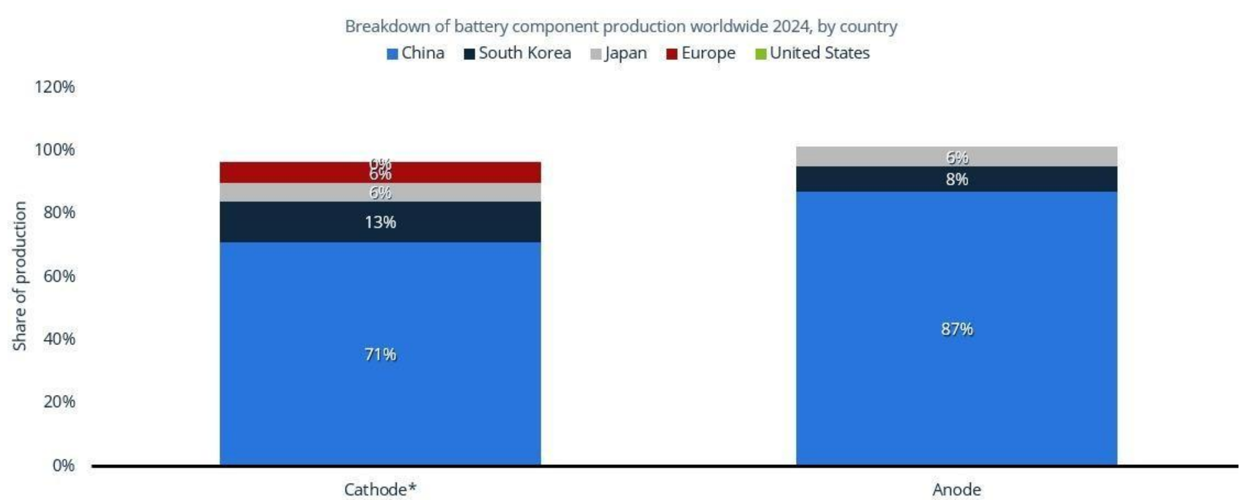
- Role**:** Converts mined ores into battery-grade chemicals (Li carbonate/hydroxide, Co & Ni sulfates, purified phosphates, spherical graphite).

- Concentration: Refining is more concentrated than mining. China dominates: ~60% of lithium, ~80% of cobalt, >80% of battery-grade graphite, plus large shares of nickel refining. Indonesia also hosts ~65% of nickel refining for batteries.
- Outlook: By 2030, China's share of processed materials is still projected >50%, despite diversification.
- Risks: Heavy reliance on one country creates strategic vulnerability — trade restrictions or supply shocks in China would affect the whole battery industry.
- Players: Key Chinese refiners: Ganfeng, Tianqi (Li), Huayou, Jinchuan (Co); Tsingshan, Huayue (Ni in Indonesia). Outside China, new Li refining is being developed in Australia, Europe, and North America, but remains small.



IEA. CC BY 4.0.

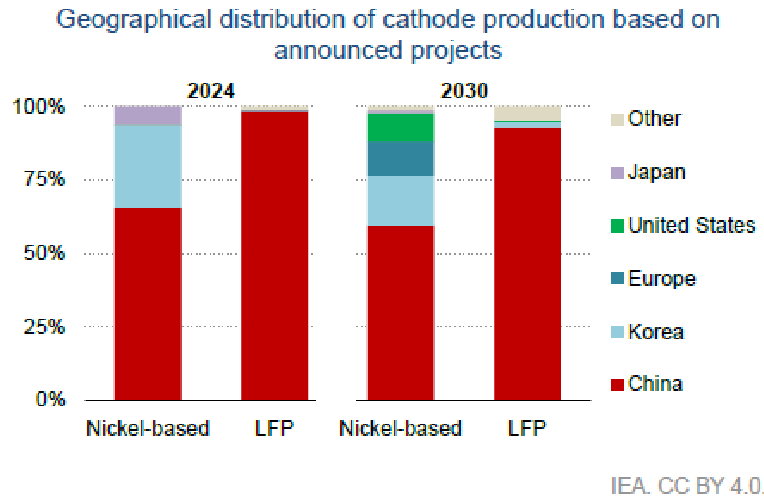
Active materials:



Description: China accounted for between 70 and 87 percent of global production of battery materials in 2024, depending on the component. Overall, Southeast Asia produced 90 percent of battery cathodes worldwide and almost the totality of anodes, separators, and electrolytes for batteries. Read more
Note(s): Worldwide; 2024; *The source does not include information on missing values to 100 percent, but other countries likely account for the remaining production.
Source(s): Fraunhofer

Cathode Active Material (CAM) Production:

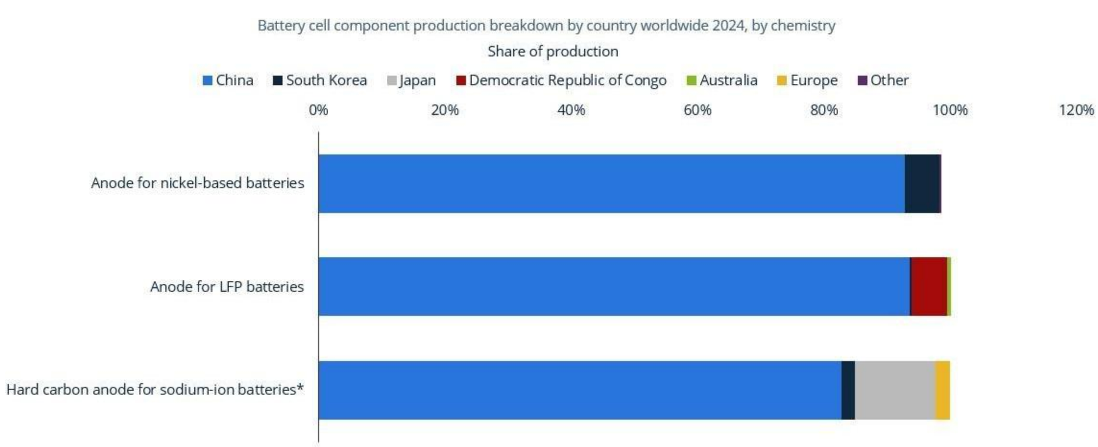
- Role: Converts refined metals into finished cathode powders (NMC, NCA, LFP), a high-tech, precision step critical for performance.



Source: IEA analysis based on BloombergNEF (2024).

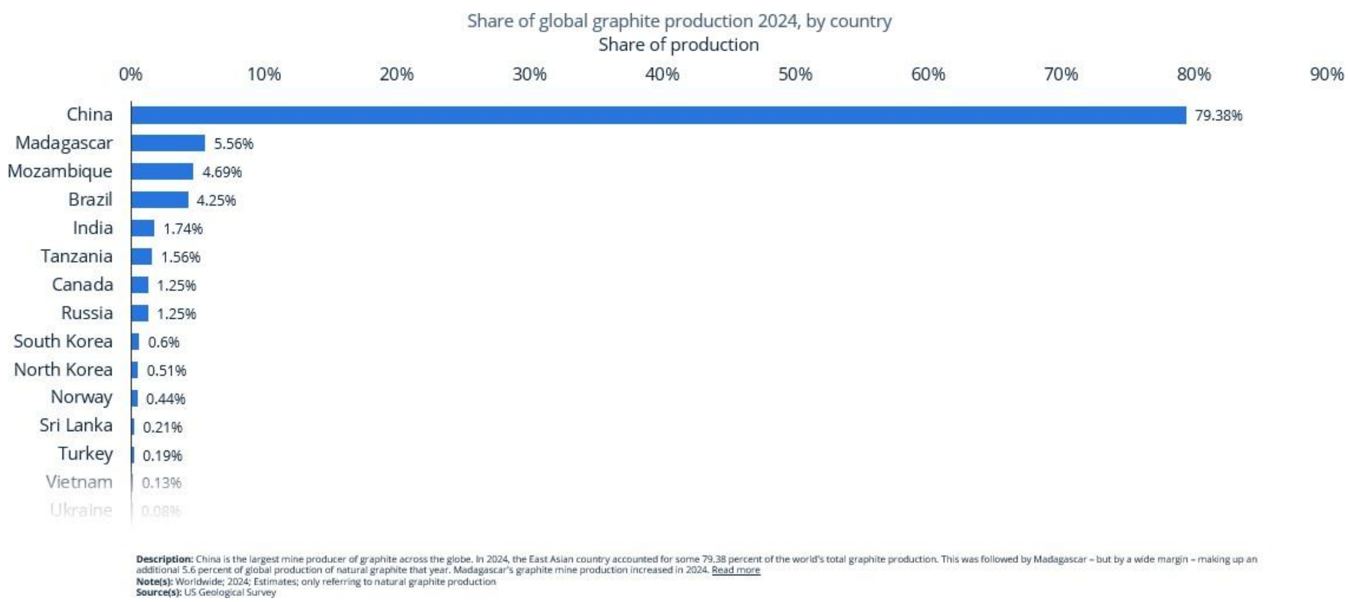
- 2024 geography: Asia, ≈90% of global cathode output. China dominates (70–87% depending on chemistry), especially LFP (pioneered in China) and most NMC.
- Others: South Korea (~28% of nickel-based CAM), with players like Ecopro, L&F; Japan (Sumitomo Metal Mining) also important for NMC/NCA.
- Rest of world: Europe/North America still small (firms like Umicore, BASF building capacity).
- Companies**:** Major CAM producers — Ningbo Shanshan, CNGR, GEM (China); POSCO Chemical (Korea); Umicore (Belgium).
- Risk**:** Nearly all CAM manufacturing is in East Asia, so supply to global gigafactories is exposed to export or disruption risks.

Anode Material (AAM) Production:



Description: In 2024, between 65 and 100 percent of the production of the components of the most common battery types in the world, namely nickel-based lithium-ion batteries, lithium iron phosphate (LFP) batteries, and sodium-ion batteries, was based in China, depending on the technology chemistry. Overall, manufacturing activities of battery anodes and cathodes were concentrated in the Asia-Pacific region. Alongside China, 28 percent of the nickel-based cathode production was in South Korea, [...] Read more
Note(s): Worldwide; 2024; Source does not provide reasons for missing values to 100 percent. LFP refers to lithium iron phosphate batteries. *Also includes some soft carbon anode capacity.
Source(s): IEA

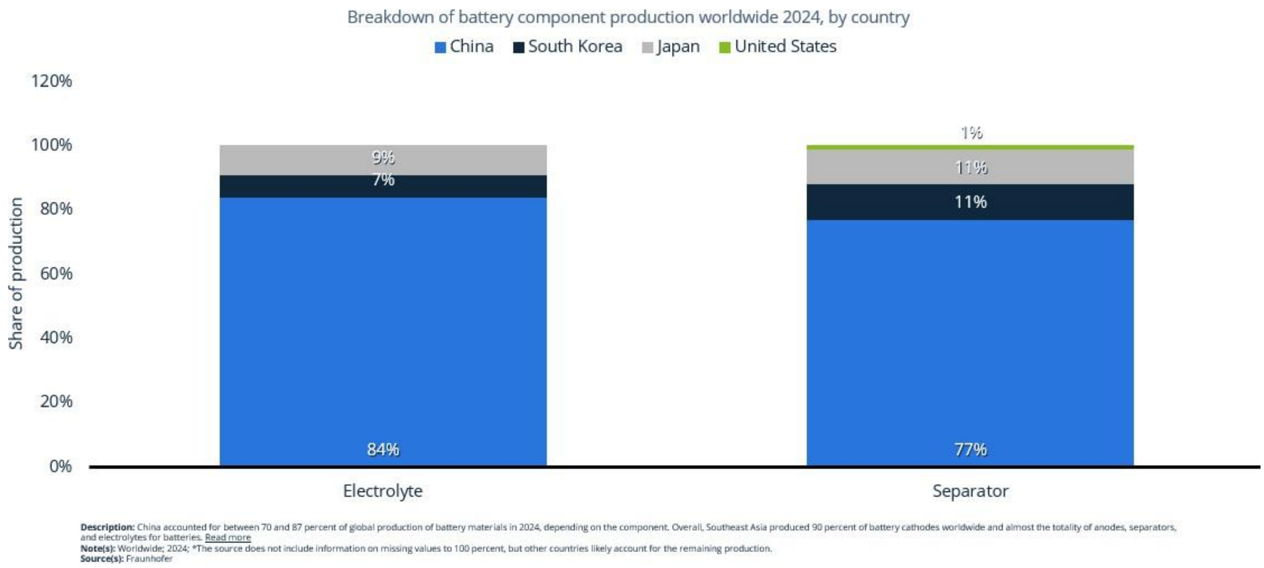
- Role: Anodes are ~95% graphite today (natural + synthetic), sometimes blended with small silicon.
- 2024 geography: China produces virtually all battery-grade anodes, covering almost the entire global supply of coated spherical graphite.



- Companies: Key players — BTR, Shanshan, Danao Technology (China); small output from Japan (Mitsubishi Chemical) and others.
- Risks: Supply is geographically concentrated in China; IEA flags this as a critical vulnerability. In late 2023, China imposed export license requirements on graphite, underscoring its leverage.

Other Battery Components:

- Role**:** Separators & electrolytes are core cell components (safety & ion transport), though less visible than electrodes.
- 2024 geography: East Asia dominates; China produces nearly all separators & electrolytes, with Japan & Korea as secondary players.
- Separators: China holds a huge share in both wet & dry process separators. Major firms: Asahi Kasei, Toray (Japan); Shanghai Energy (China).
- Electrolytes: China also leads in lithium salts & solvent-based electrolytes. Key companies: Shenzhen Capchem, Guotai Huarong.



- Theme**:** Just like electrodes, concentration in East Asia (esp. China) is near total — reinforcing midstream supply chain risk.

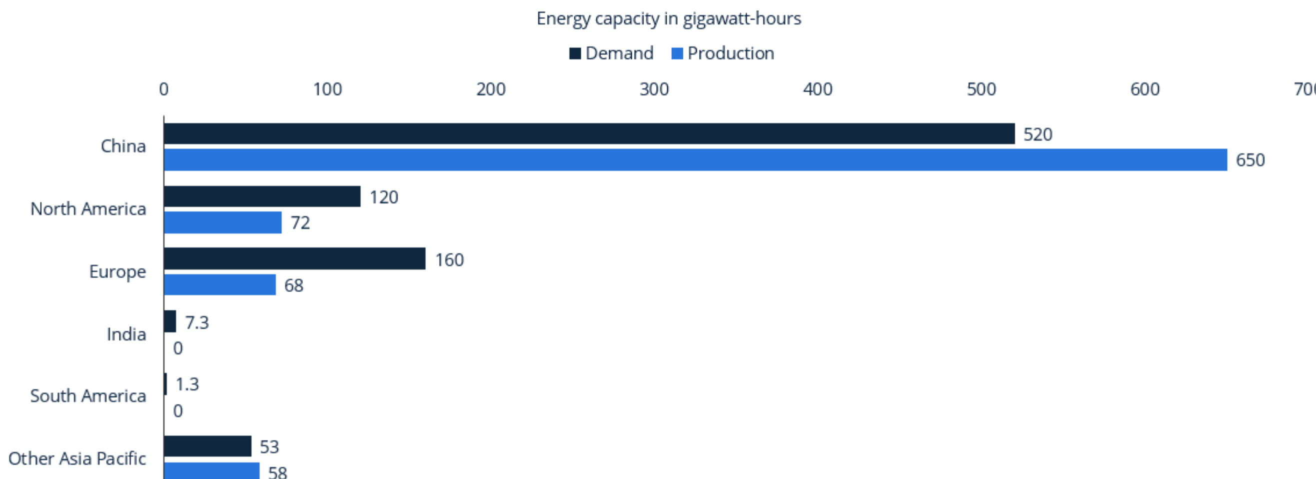
Major Country & Company Profiles:

- **China:** The clear hub in integrated chemical supply chains, low-cost energy, and huge domestic EV/BESS demand. This has enabled China to capture 70–90%+ of cathode, anode, separator & electrolyte production. Leading firms: CATL-linked Ningbo Shanshan, CNGR, GEM (cathodes); BTR, Shanshan (anodes); Capchem (electrolytes).
- **South Korea & Japan:** Important for high-nickel cathodes and advanced materials. Korea accounts for ~28% of nickel-based CAM (2024), led by Ecopro, L&F, POSCO Chemical. Japanese companies (Sumitomo Metal Mining, Mitsubishi Chemical) supply cathodes and some synthetic anodes. Both countries' firms supply European gigafactories.
- **Indonesia:** Expanded nickel refining, backed by Chinese investment (e.g. Tsingshan, Huayue) — an example of vertical integration moving midstream closer to raw sources. Supplies ~60% of global battery-grade nickel sulfate.

3. **<u>Battery Cell Manufacturing:</u>** Battery cell manufacturing is the stage where **cathodes, anodes, separators, and electrolytes are integrated into finished cells** (cylindrical, prismatic, pouch).

***Geographic Distribution of Battery Cell Manufacturing*:**

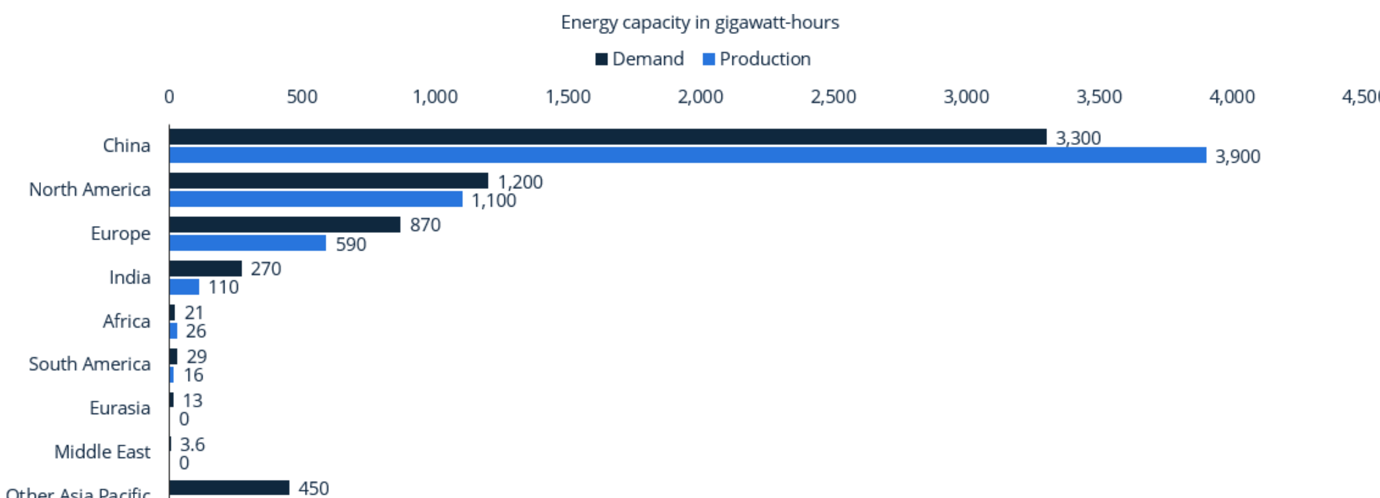
Battery cell manufacturing capacity is **heavily concentrated in China**, which has expanded faster than any other region.



Production and demand capacity of battery cells worldwide 2023, by country

Description: China by far accounted for the largest production and demand of battery cells in the world in 2023. Asia Pacific was the only region in the world where battery cell production exceeded demand, with a supply surplus of over 100 gigawatt-hours in China. Read more
Note(s): Worldwide; 2023
Source(s): IEA

- **China:** Accounted for ~**83% of global cell capacity in 2023**, up from ~75% in 2020, showing that China is adding new gigafactories at a pace unmatched globally. Future Demand:



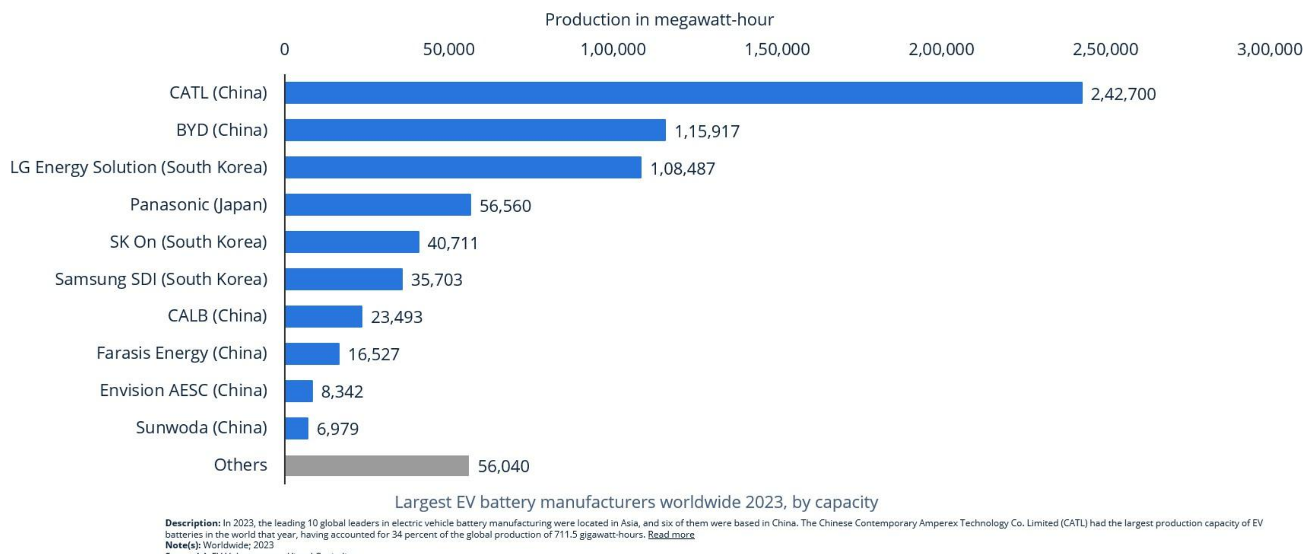
Production and demand capacity of battery cells worldwide 2035, by country

Description: According to a recent forecast, the battery cell production in the world will surpass six terawatt-hours by 2035, of which over 70 percent in Asia Pacific. China alone will account for over 60 percent of the global battery production that year and over 50 percent of the demand. Read more
Note(s): Worldwide; 2024; Forecast according to current policy settings.
Source(s): IEA

- **Europe & United States:** Together hold only ~13% (Europe ≈8%, US ≈5%) despite strong investment pipelines. Current output is still modest compared with China.

- **Japan & South Korea:** Once pioneers in Li-ion technology, they now account for only a few per cent of capacity. However, Korean firms (LG, SK, Samsung SDI) are highly active abroad — in 2023, they ran ~350 GWh of capacity outside Korea, including plants in Poland, Hungary, and the US. Korean-led plants make up most of Europe's output (LG Poland alone ≈50% of Europe's battery capacity).
- **Foreign plants:** Panasonic (Japan) operates in the US, while CATL (China) has built in Germany and is expanding in Hungary — though these remain smaller than domestic operations.
- **Exports:** Asia, particularly China, not only produces for its domestic EV market but also for export. In 2023, China exported ≈870,000 EV battery units, largely to Europe.

Top Battery Manufacturers:

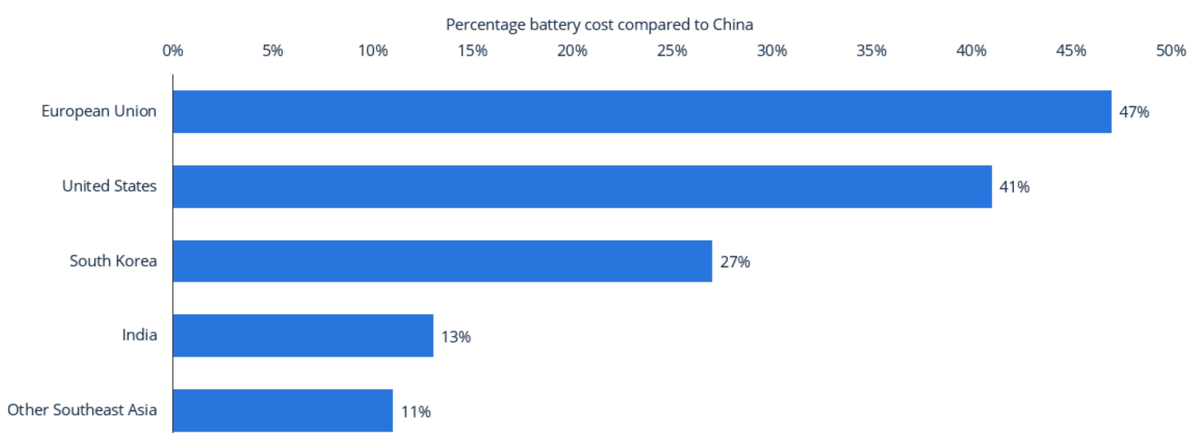


- **Overall:** The EV battery market is dominated by a small set of specialised cell-makers headquartered in Asia.
- **Global total (context):** 2023 global EV battery production ≈ 711.5 GWh (used as the base for market shares).
- **CATL (China):** #1 globally. Accounted for ~34% of global EV battery output in 2023 (of the 711.5 GWh). CATL supplies many Chinese OEMs and has OEM relationships (and some direct supply links with overseas OEMs).
- **BYD (China):** #2–#3 globally. Around ~16% market share in 2023; BYD manufactures cells for its own vehicles (vertically integrated) and is expanding to supply others.
- **LG Energy Solution (South Korea):** top Korean firm, ~14% market share (2023); a major supplier to western OEMs.
- **Panasonic (Japan):** long-time Tesla partner, ~7–8% share in 2023.

- **SK On & Samsung SDI (South Korea):** significant players, each roughly mid-single-digit % shares (~5% order of magnitude each in 2023).
- **Other notable players:** Chinese firms such as CALB, Gotion High-Tech, Farasis, and Japanese/Korean players, including NEC/Envision AESC — each holding small single-digit shares.
- **Regional concentration (top 10):** All top 10 EV cell producers in 2023 were based in Asia (six in China, plus Japan/Korea entries), underscoring the regional concentration of capacity.
- **OEM relationships & in-house production:** Many automakers use strategic partnerships / JVs with these battery firms (Tesla–Panasonic historically; GM–LG/Ultium; VW–Northvolt; Stellantis–ACC, etc.). A few OEMs (notably Tesla and BYD) are increasing in-house cell production, but independent battery manufacturers still supply most cells as of the mid-2020s.

Regional expansion & policies:

- Europe is building multiple gigafactories (Northvolt in Sweden, ACC in France, VW in Germany, and CATL's German plant) to reduce reliance on imports.
- The United States is scaling rapidly under the Inflation Reduction Act (IRA) with more than a dozen major projects announced, including LG and SK plants in the US and Tesla's expansion in Texas.
- China's share of global cell capacity may fall from ~83% in 2023 to ~67% by 2030 as Western capacity comes online, but the market will remain highly concentrated.
- Scaling outside Asia remains difficult — IEA notes that new gigafactories are capital-intensive and slow to build, and equipment and material bottlenecks add to delays.
- China retains a cost advantage: battery production costs in the US/EU are significantly higher than in China, due to cheaper input materials and economies of scale in China. Below data shows China = 100, EU/US ≈140, Rest of Asia ≈110 (indexed).



Percentage levelized cost of battery production compared to China 2023, by country

Description: The levelized cost of battery production in the European Union and the United States was up to over 40 percent higher than in China in 2023. By comparison, battery production costs in the rest of Southeast Asia were considerably lower, although still 10 percent higher than in China. Read more
Note(s): Worldwide; 2023; Cost refers to last step of manufacturing, assuming imports of batteries from China. It excludes financial credits for batteries.
Source(s): IEA

4. **Battery Pack Assembly & Integration:** Once cells are produced, they must be integrated into battery packs or modules with the appropriate management systems, cooling, and enclosures for use in end applications.

Process Overview — Battery Pack Assembly

What it is: Battery pack assembly involves grouping individual cells (sometimes first into modules, then into larger packs), and integrating battery management systems (BMS), thermal/cooling components, and protective enclosures. This produces the final pack that is used in EVs or stationary storage systems.
Where it happens: Unlike cells (which are globally traded), pack assembly is often carried out near the end-use market or directly by the end-user's company.
Examples:
EV manufacturers (e.g., Tesla, BYD, VW) typically assemble packs in their own vehicle factories to integrate directly into the chassis.
Stationary storage system integrators assemble packs or racks in regional facilities or on-site for grid or residential applications.
Electric Vehicle Pack Assembly:

Automakers assemble packs near their factories: EV pack assembly usually happens at or near vehicle plants, since packs must be integrated directly into the chassis. This contrasts with cell production, which is more globally concentrated.
Tesla: Sources cells from Panasonic, CATL, LG, BYD, but assembles them into proprietary battery packs (with BMS/cooling) in its Gigafactories in the US and China.
Volkswagen (VW): Initially sourced modules/packs from LG and other suppliers, but is now building its own pack capacity in Germany and Europe through PowerCo and in-house facilities.
BYD (China): Is vertically integrated, producing both cells and packs (including its Blade Battery system). BYD supplies not only its own vehicles but also sells complete battery systems to external OEMs.
General Motors (GM): Through its Ultium Cells JV with LG Energy Solution, manufactures cells and ready-to-install modules/packs for GM's EV lineup in the US.
Geographic spread: Pack assembly more closely mirrors automotive manufacturing geographies — with significant operations in China, Europe, the US, Japan, and Korea. This makes pack assembly less dominated by China compared to cells, though CATL and BYD export turnkey battery systems abroad

Stationary Storage (Grid BESS) Integration:

Distinct sub-industry: Grid-scale BESS integration involves taking battery modules (often similar to EV cells) and combining them with inverters, control systems, and containerised housings to deliver complete storage systems.

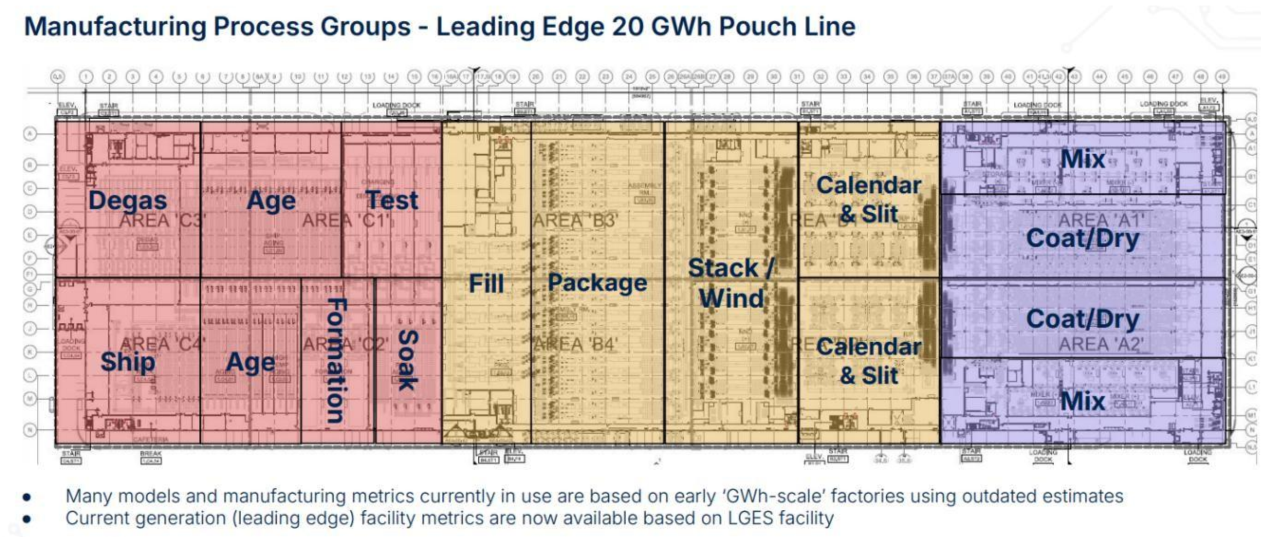
Key players: Major integrators include Fluence (AES–Siemens JV), Tesla Energy (Megapack systems), Wärtsilä, as well as storage divisions of leading cell makers like LG Energy Solution, Samsung SDI, BYD, and CATL.
China's dominance: By 2024, China had ~215.5 GWh of cumulative BESS installed capacity — about 65% of the global total — reflecting rapid domestic deployment by firms like CATL and BYD.
Other markets: The United States, United Kingdom, and Australia are the next largest stationary storage markets, supplied by a mix of international integrators such as Tesla, Fluence, and Wärtsilä.
Integration model: BESS units are typically factory-assembled into containerized systems and then shipped to project sites for installation**.**

Conclusion:

- The BESS supply chain shows both bottlenecks and opportunities: high concentration in a few countries poses risks, yet soaring demand from EVs and stationary storage creates vast growth potential.
- Opportunities span the value chain: from mining projects in stable regions, to new refining/processing capacity outside China, to battery recycling ventures (expected to supply ~10% of mineral demand by 2030), and cell manufacturing plants scaling in the US/EU.
- Bottlenecks such as cobalt supply, graphite processing, or separator production highlight where investment can yield strong returns — e.g. regional processing capacity has guaranteed demand under policy-driven diversification.
- Geopolitical alignment and policy incentives are crucial: IRA in the US, EU's Critical Raw Materials Act, and mineral partnerships aim to de-risk supply and support local projects, though costs remain higher in the West.
- On the demand side, EVs and renewables guarantee robust growth. Battery demand is projected at 3–4 TWh by 2030 (≈5–6× 2020 levels), underpinned by decarbonization policies. The main uncertainty is supply and cost volatility.

Outlook: The supply chain is shifting from a China-dominated model (~83% of cell capacity today) to a more distributed, innovative ecosystem by the 2030s. Investors & Entrepreneurs with a full-chain perspective — from mines to markets — will be best positioned to capture upside.

Manufacturing Process



<u>Process in detail:</u>

Process Flow (Right → Left)

1. <u>Mix</u>

What happens in the Mix step

1. **Start with powders**

- Cathode side: active material (like NMC or LFP) + carbon black (helps conduct electricity) + binder (glue).
- Anode side: usually graphite + binder.

2. **Add <u>a</u> liquid (solvent)**

- Cathode: toxic but powerful solvent called **NMP (N-Methyl-2-pyrrolidone)**.
- Anode: usually just pure water.

3. **Mix everything together** in a big industrial mixer → it becomes a slurry (like a thick paste or cake batter).

Why it's so critical

- The slurry has to be **perfectly uniform** → no lumps, no clumps.
- It needs the right **thickness (viscosity)**:
    - Too thick = can't coat evenly.
    - Too thin = runs everywhere.
- ***If mixing is poor, those defects cannot be fixed later — they travel all the way into the final battery.***

2. <u>Coat/Dry</u>

- The slurry is **coated onto thin foils** (aluminium for cathode, copper for anode).
- Then foils pass through **long drying ovens** to evaporate solvents.

3. Calender & Slit

- Dried electrode sheets are **pressed** with rollers (calendering) to set thickness & density.
- Then they are **slit** into narrower rolls (daughter coils) for use in cells.

4. Stack / Wind

What happens here

- By this stage, you already have electrode rolls (anode on copper foil, cathode on aluminium foil) and the separator film.
- Now you must assemble them into the "cell core."

Two main methods:

1. **Stacking** (used for **pouch** and **prismatic** cells):
   - Electrodes and separators are cut into sheets.
   - Then they are stacked like a sandwich: anode → separator → cathode → separator … repeated many times.
   - Makes a flat "stack" that fits into a pouch or box.
2. **Winding** (used for **cylindrical** and some pouch cells):
   - Electrodes and separator are wound together tightly in a spiral, like rolling up a Swiss roll cake.
   - This is why a cylindrical cell looks like a jelly roll when cut open.

Why it matters

- This step builds the **active "engine" of the battery**.
- Precision is critical:
  - Electrodes and separator must be aligned perfectly.
  - If edges are misaligned → risk of short circuit.
  - Consistent stacking/winding ensures uniform performance.

5. Fill / Package

What happens here

- To make it work, you must add the **electrolyte** → a special liquid that lets lithium ions move back and forth between anode and cathode.
- The electrolyte is injected into the cell in a very precise amount (too little = poor performance, too much = leakage or swelling).

- The cell is left for some time so the liquid can soak in and wet all the porous electrodes and separator.
- Finally, the pouch/can is **sealed air-tight** (often under vacuum to remove trapped air bubbles).

Why it matters

- The electrolyte is **the blood of the battery** — without it, ions cannot move.
- Any **moisture contamination** here is dangerous → it reacts with electrolyte to form gases or even acid.

6. **Formation**

What is Formation?

- The Formation step is when the cell is charged and discharged for the first time, very slowly and carefully.
- This is not just testing — it actually creates a critical internal layer inside the cell.

What forms inside

- On the anode surface (usually graphite), the electrolyte reacts during the first charge.
- This reaction creates a thin, stable film called the **SEI (Solid Electrolyte Interphase)**.
- The SEI is like a protective skin:
  - It lets lithium ions pass through (so the battery works).
  - But it blocks electrons and further reactions (so the electrolyte doesn't keep breaking down).

Without SEI → the battery would keep consuming electrolyte, produce gas, lose capacity fast, and might even fail dangerously.

Why it takes time

- Formation is done slowly (can take 10–20+ hours for one cycle).
- If you rush, the SEI forms unevenly → leading to bad performance, swelling, or short life.

7. **Soak (Red)**

- After **electrolyte filling** and **formation charging**, the battery needs time for the liquid electrolyte to **fully spread and penetrate** all the tiny pores inside the electrodes and separator.

8. **Age**

What is Aging?

- After formation (the first careful charging/discharging), the battery isn't yet stable.
- The cells are placed in storage racks at a controlled temperature (not too hot, not too cold).

- They stay there for days or even weeks.

Why do we do it?

1. **Stabilization:**
    - The SEI protective layer formed during formation needs time to “settle” and become uniform.
2. **Screening weak cells:**
    - Some cells will lose energy (self-discharge) faster than others.Aging allows these bad cells to be identified before shipping.
3. **Safety & reliability:**
    - If a cell has tiny internal defects (like micro-shorts), they usually show up during this period.

9. De-gas

- Any gases formed during formation/aging are **removed** from pouch cells.

10. Test

- Final quality checks: capacity, resistance, voltage. Cells are graded into performance bands.

11. Ship

- Good cells are packed and shipped to customers.

Key Takeaways from the Layout

- **Color coding**:
    - Purple → *Electrode making* (Mix, Coat/Dry).
    - Yellow → *Cell assembly* (Calender, Slit, Stack/Wind, Fill, Package).
    - Red → *Formation & finishing* (Soak, Age, Degas, Test, Ship).
- **Linear flow**: Materials move **from right to left in a straight line**, improving efficiency.
- **Scale**: This is a **20 GWh factory**, so every section is massive, with dedicated areas for each stage.
- **Modern design**: Earlier factories (<10 GWh) used angular/ad-hoc layouts. Here, everything is modular and aligned, reducing wasted movement.

Why battery manufacturing has high scrap rates and how reducing scrap is critical to stay competitive, especially against China’s leaders like CATL

Scrap Rates Over Years of Operation

- At the start of production (SoP), scrap rates are extremely high.

- Over time, as factories learn and optimize, scrap rates drop:

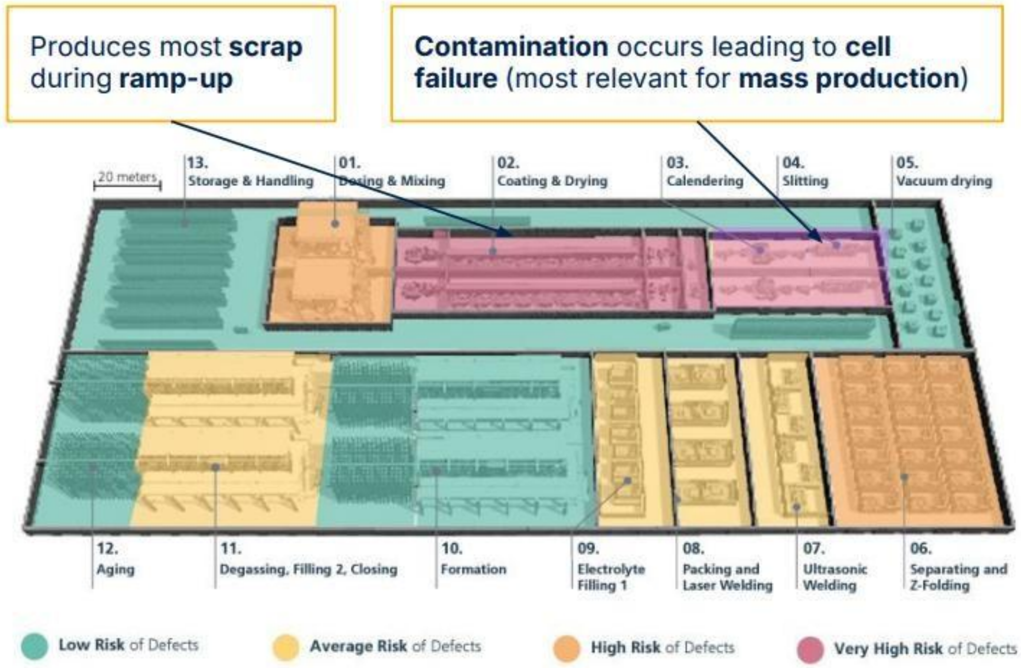


Figure 6 Layout of a typical, modular battery cell production line (7-10 GWh/a) and their risk level for defects. A battery cell factory has multiple of such modules/lines.

  - Year 1: ~28%
  - Year 2: ~18%
  - Year 3: ~15%
  - Year 4: ~10%
  - Year 5: ~9%
- Even after years, factories still have some scrap — not zero.

<u>Electrode manufacturing is the hardest part of battery cell production:</u>

Every step in battery production presents challenges, but some, like **coating, drying, and slitting** carry a significantly higher risk of defects. The heat map illustrates these critical areas, highlighting their likelihood of defects.

Machinery Suppliers Ecosystem

A concentrated cohort of ***Chinese and South Korean suppliers has achieved overwhelming dominance, driven by scale, cost-efficiency, and deep integration*** with their domestic battery champions. Western equipment manufacturers, while possessing strong capabilities in specific niche areas, currently lack the scale and comprehensive "turnkey" offerings of their Asian counterparts.

The turnkey approach is a hallmark of the leading Chinese suppliers. Industry giants such as **LEAD Intelligent Equipment** and **Yinghe Technology** have developed the capability to design, manufacture, and integrate all the machinery required for a complete cell production line, from mixing to final testing. This offering is particularly attractive to new market entrants or companies with limited in-house engineering depth, as it significantly de-risks the complex task of machinery integration and can accelerate the timeline from factory construction to first production.

LEAD Intelligent Equipment- Strategic Partnership with CATL**:** LEAD has a deep, multifaceted partnership with CATL, the world's largest battery manufacturer. In 2020, CATL placed a massive CNY 3.23 billion (approx. USD 450 million) order for lithium battery production equipment with LEAD. This relationship was further solidified in late 2024 with a strategic cooperation agreement that makes LEAD the priority supplier for CATL's core cell production equipment. This partnership is crucial for CATL's continuous and rapid global expansion. **Proven Global Scale:** Beyond specific contracts, LEAD has a proven track record of enabling large-scale production globally, having provided customers with more than 120 complete production lines, accounting for over two terawatt-hours (TWh) of battery capacity.

Yinghe Technology- Powering Volkswagen's Gigafactory Expansion: Yinghe Technology formed a strategic partnership with Volkswagen to supply the core equipment for its 20GWh gigafactory in Salzgitter, Germany. Yinghe is providing the first production line, including machinery for coating, laser cutting, and laminating, directly assisting VW in building its own battery supply chain in Europe. Yinghe signed a deal to supply LG Chem (now LG Energy Solution) with 19 high-precision automatic coilers (winders) for its plant in Nanjing, China. The company has received orders from and lists CATL, BYD, Gotion Hi-Tech, EVE Energy, and CALB among its key customers. This includes a major 1.44-billion-yuan contract to provide automated production equipment to CATL, directly supporting its massive production scaling.

The Vertical Integration Anomaly: The Case of BYD

BYD stands as a significant anomaly in the battery manufacturing landscape, pursuing a strategy of deep vertical integration that extends to the production equipment itself. Unlike its competitors who primarily source machinery from third-party suppliers, BYD, through its battery division FinDreams Battery, develops and manufactures a substantial portion of its own production equipment in-house.

This strategy was instrumental in the development and successful scaling of its proprietary Blade Battery technology. The Blade Battery's unique cell-to-pack design, which uses long, blade-like cells arranged directly in an array within the battery pack, required novel manufacturing processes and machinery that were not available on the open market.[11] By developing this equipment internally at its state-of-the-art Chongqing factory, BYD created a formidable competitive moat. This in-house capability protects its core manufacturing intellectual property.

South Korean Equipment Ecosystem – Key Points

- Tight integration: South Korea's battery giants (LG Energy Solution, Samsung SDI, SK On) work very closely with domestic equipment suppliers (PNT, CIS, KGA, Wonik, DA Technology, etc.).
- Co-development model: Instead of a simple buyer–seller relationship, these companies run joint R&D projects, creating custom equipment designed specifically for each battery maker's needs.

US & European Equipment Ecosystem – Key Points

- Specialist focus: Western firms (e.g., Dürr, GROB, Comau, Delta ModTech) are niche leaders in coating, automation, and robotics. Unlike Chinese or Korean rivals, they don't usually supply entire turnkey lines — they specialize in certain high-tech steps.

Dry Electrode Processing (DEP)

Normal (wet coating) uses slurry + solvents (like NMP) + big ovens to dry electrodes. Dry coating (DEP) skips all of that. Instead, you take a powder mix (active material + binder like PTFE + conductive additive) and press it directly onto the foil using pressure and heat.
It Could cut **manufacturing costs by 17–30%**. Factory size shrinks → electrode line could be **¼ the size of today's wet line**.

Who is working on it?

- Tesla → bought Maxwell Technologies (2019) for its dry coating patents, now trying to scale it for its 4680 cells.
- Dürr (Germany) + LiCAP (USA) → partnered to develop *Activated Dry Electrode®*, with a pilot line for Porsche (2026).

- LEAD Intelligent (China) → claims its version cuts energy use by 35% and costs by 20%.

The tech works in labs and small pilot lines, but no one has proven it yet at gigafactory scale (GWh-level). Scaling is very hard → the process must be reliable, super uniform, and high-speed.

Strategic dilemma:

- **Safe path:** Wet coating (proven but costly).
- **Risky path:** Dry coating (high risk, but big rewards if it works).

Whoever masters DEP first could **leapfrog competitors** and build much cheaper factories.

Conclusion

The global battery equipment supply chain is split across distinct models: Korea has built a tightly integrated ecosystem where suppliers co-develop bespoke machinery with LGES, Samsung SDI, and SK On; China dominates with turnkey, cost-competitive solutions; while in the U.S., most joint ventures with Korean battery makers source heavily from Korea, given the lack of full-line American suppliers. U.S. and European firms, though technologically advanced in niches like coating or automation, do not yet provide complete end-to-end lines.

The BESS Decade: Sizing a 2,000+ GWh opportunity across four key markets by 2030

The global Battery Energy Storage System (BESS) market is at a critical inflection point, poised for a near tenfold expansion in cumulative capacity by 2030. This surge is driven by the non-negotiable need for grid stability in an era of accelerating renewable energy penetration, supportive government policies, and rapidly improving project economics. The total cumulative BESS capacity across these regions is forecast to surge from approximately 380 GWh at the end of 2024 to over 2,100 GWh by 2030, representing a monumental investment cycle in grid modernization.

Front-of-the-Meter (FTM), or utility-scale, applications will remain the dominant driver of this growth, projected to account for approximately 85% of the total market by 2030. The Behind-the-Meter (BTM) segment, while smaller in absolute GWh, will exhibit strong growth, particularly in mature markets where it offers consumers a compelling value proposition through electricity bill savings and enhanced power reliability.

Regionally, China and the US will cement their positions as the two largest markets, collectively representing over 70% of the total installed base by 2030, propelled by aggressive national policies and massive renewable build-outs. China's growth is a function of state-mandated industrial policy, creating unparalleled scale for its domestic champions. The US market is being supercharged by the landmark Inflation Reduction Act (IRA), which has fundamentally de-risked standalone storage investments. Europe will be defined by its mature and rapidly growing BTM segment, the most developed in the world, even as its FTM market accelerates to address grid-level challenges. ***India represents the highest-growth opportunity, albeit from a nascent base***, with its trajectory heavily dependent on successfully navigating significant project execution risks.

The emergence of geopolitical considerations, particularly US policies regarding Chinese-made components, is set to bifurcate the global supply chain, creating distinct risks and opportunities for market participants.

Region	Total 2024 Capacity (GWh)	Total 2030E Capacity (GWh)	FTM 2030E (GWh)	BTM 2030E (GWh)	CAGR (2024-2030)
US	83	450	405	45	32.50%
China	141	720	684	36	31.20%
Europe	61.1	400	220	180	36.80%
India	0.4	200	192	8	181.73%
Total	**285.5**	**1,730**	**1,461**	**269**	**35.00%**

The Global BESS Imperative: A Grid in Transition

The global energy system is undergoing its most profound transformation in a century. The rapid shift towards decarbonization, driven by climate imperatives and the compelling economics of renewable energy, is fundamentally reshaping electricity grids. This transition introduces a critical challenge: managing the inherent intermittency of solar and wind power. Battery Energy Storage Systems have emerged as the key technology to solve this challenge, enabling the transition from a fossil-fuel-based, dispatchable generation system to a clean, resilient, and flexible grid.

Regional Market Analysis: Four Distinct Paths to Scale

While the global drivers for BESS are universal, the market's evolution is highly regional. The United States, China, Europe, and India each present a unique landscape shaped by distinct policy frameworks, market structures, and competitive dynamics. Understanding these regional nuances is critical for identifying the most attractive investment opportunities and risks.

A. United States: IRA Supercharges a Maturing Market

The US BESS market is characterized by its rapidly growing utility-scale segment, a vibrant residential market in key states, and the transformative impact of the Inflation Reduction Act (IRA), which has fundamentally altered the investment landscape.

U.S. Market Segment	2024 Capacity (GWh)	2030E Capacity (GWh)	2030E Market Share
Front-of-the-Meter (FTM)	76.5	405	90.00%
Behind-the-Meter (BTM) - Residential	5	30	6.70%
Behind-the-Meter (BTM) - C&I	1.5	15	3.30%
Total	**83**	**450**	**100.00%**

Catalysts & Headwinds
The trajectory of the US BESS market will be shaped by the interplay of powerful tailwinds and significant, structural challenges.

Catalyst - The Inflation Reduction Act (IRA): The IRA is the single most important policy driver for the US BESS market. Its introduction of an Investment Tax Credit (ITC), ranging from 30% to 70%, for *standalone* energy storage projects is a game-changer. Previously, storage assets had to be co-located with a solar facility to qualify for federal tax credits. This decoupling dramatically improves project economics, particularly for FTM BESS, and has unlocked a massive wave of investment.

Headwind - Foreign Entity of Concern (FEOC) Rules: A major emerging risk is the implementation of FEOC rules tied to the IRA. Starting in 2026, projects that utilize a significant percentage of battery components or critical minerals from entities based in China and other designated countries will be ineligible for the IRA's tax credits.[41] Given that approximately three-quarters of US lithium-ion battery imports currently originate from China, this policy poses a severe near-term supply chain challenge. It is intended to spur the development of a domestic US manufacturing base but could lead to higher project costs and potential supply constraints in the interim.

The interaction between the IRA incentives and the FEOC deadlines creates a complex market dynamic. The rules include a "safe harbor" provision for projects that begin construction before the end of 2025, allowing them to utilize existing supply chains and still qualify for tax credits.[41] This is driving a significant pull-forward of demand, with developers rushing to sign supply contracts and commence construction to lock in the benefits of the ITC with lower-cost Chinese hardware. This dynamic likely contributed to the 2 GW of projects that were delayed from late 2024 into 2025, as developers work to meet these critical deadlines.[29] The result could be a surge in deployments in 2025, followed by a potential "air pocket" or slowdown in 2026-2027 as the industry transitions to new, higher-cost, FEOC-compliant supply chains. ***This presents a near-term positive for Chinese suppliers with existing contracts but creates a powerful, policy-driven long-term opportunity for manufacturers in the US and allied nations.***

> This is due to the reliance of the battery energy storage system (BESS) market on imported products from China, with "nearly all" battery cells used in US utility-scale projects in 2024 coming from there.
>
> Depending on the severity of potential tariff increases, the cost of utility-scale BESS could rise between 12% and 50% across three tariff scenarios modelled by Wood Mackenzie analysts.
>
> Wood Mackenzie vice-chairman of power and renewables Chris Seiple said that while US battery cell manufacturing capacity is expanding, this is not happening fast enough "to meet even a small fraction of battery projects in the US."
>
> "In 2025, we estimate there is sufficient domestic manufacturing capacity to only meet about 6% of demand and, by 2030, domestic manufacturing could potentially meet 40% of demand," Seiple said.

(Source:https://www.energy-storage.news/us-import-tariff-analysis-extent-of-challenge-us-battery-storage-industry/)

B. China: Policy-Driven Dominance from Cell to System

China's BESS market is defined by its staggering scale, breakneck pace of deployment, and the central role of government policy in driving both domestic demand and the global competitiveness of its manufacturers. The market is overwhelmingly dominated by FTM applications, a direct result of top-down industrial and energy strategy.

China Market Segment	2024 Capacity (GWh)	2030E Capacity (GWh)	2030E Market Share
Front-of-the-Meter (FTM)	134	684	95.00%
Behind-the-Meter (BTM) - C&I	7	36	5.00%
Behind-the-Meter (BTM) – Residential	<0.1	<0.1	0.00%
Total	**141**	**720**	**100.00%**

Catalysts & Headwinds
China's BESS market is propelled by an unparalleled alignment of policy, industrial capacity, and strategic ambition.

Central and Provincial Mandates: The primary market driver is top-down government policy. Unlike market-driven economies, China's BESS deployment is largely a function of mandates. The requirement for new large-scale renewable energy projects to be paired with energy storage creates a massive and predictable demand pipeline for FTM BESS, de-risking investment in manufacturing capacity.

From 2022 to mid-2025, China's BESS demand was heavily driven by storage pairing mandates, with estimates suggesting 50–75% of installations tied to these rules. With the mandates lifted for new projects after June 2025, this built-in demand source shrinks, forcing developers to adjust—either adding storage voluntarily if the economics work, pursuing standalone storage or offtake agreements, or reducing storage ratios. A short-term spike in deployments is expected as developers rush to secure approvals under existing rules before they expire, but growth may slow afterward unless new mechanisms such as subsidies, cost improvements, or market reforms take hold. The policy risk now shifts from whether mandates exist to how incentives and market structures—like wholesale pricing, ancillary service credits, and grid dispatch rules—make storage profitable and truly valuable in the post-mandate era.

Even with the mandates lifted, there is still policy ambition: China's Special Action Plan for New Energy Storage (2025-2027) targets aggressive growth, planning, standardization, efficiency improvements and broader market participation of storage. That means even without mandates, demand is likely to remain strong due to other drivers (curtailment, grid stability, renewables integration) and perhaps new rules for compensation for grid services.

Catalyst - Supply Chain Dominance & Cost Leadership: China has established a dominant position across the entire battery value chain, from the processing of critical minerals to the manufacturing of cells, packs, and integrated BESS solutions. This vertical integration, combined with immense manufacturing scale and fierce domestic competition, has resulted in the world's lowest BESS system prices, making large-scale deployment highly economical.

Headwind - Profitability and Utilization: A significant challenge for the market is the economic viability of the deployed assets. Many mandated renewable-paired storage systems suffer from low utilization rates, as their operation is not always optimized for market-based revenue streams. While policies are evolving to create more robust business models through participation in ancillary service and capacity markets, there remains a risk of underutilized or stranded assets if market reforms do not keep pace with deployment mandates.

The structure of China's BESS market reveals that its rapid expansion is a function of a strategic industrial policy as much as it is an energy policy. The government's mandates serve a dual purpose. First, they provide a domestic solution to the immense challenge of integrating hundreds of gigawatts of new wind and solar power onto the national grid. Second, and perhaps more strategically, these mandates create a vast, protected domestic market that allows national champion manufacturers like CATL, BYD, and Sungrow to achieve unparalleled economies of scale. This scale provides them with a formidable and sustainable cost advantage in global markets, enabling them to dominate exports to regions like Europe and the Middle East, where geopolitical barriers to entry are lower than in the United States. In effect, China's domestic energy policy is subsidizing the global expansion of its industrial base.

C. Europe: A Fragmented Market Accelerating on Energy Security

The European BESS market is the most mature in the world in terms of its BTM segment, particularly residential storage. However, the market is now undergoing a structural shift towards larger, FTM installations as the continent grapples with the energy security and grid stability challenges highlighted by the war in Ukraine and its ambitious REPowerEU targets.

Europe Market Segment	2024 Capacity (GWh)	2030E Capacity (GWh)	2030E Market Share
Front-of-the-Meter (FTM)	30.5	220	55.00%
Behind-the-Meter (BTM) - Residential	24	130	32.50%
Behind-the-Meter (BTM) - C&I	6.6	50	12.50%
Total	**61.1**	**400**	**100.00%**

Catalysts & Headwinds

Europe's BESS market is being propelled by geopolitical imperatives and strong consumer demand, but its full potential is constrained by regulatory complexity.

Catalyst - REPowerEU & Energy Security: Russia's invasion of Ukraine served as a major catalyst, fundamentally shifting Europe's energy strategy towards accelerating the deployment of domestic renewable resources to reduce dependence on imported fossil fuels. The REPowerEU plan and the updated Renewable Energy Directive, which targets at least a 42.5% renewable share by 2030, create an urgent and large-scale need for BESS as a key enabling technology.

Catalyst - Mature BTM Market: Europe possesses the world's most developed BTM storage market, particularly in Germany and Italy. Europe’s BTM storage market is the most advanced, led by Germany and Italy, primarily due to high retail electricity prices, early subsidies, and the shift from feed-in tariffs to self-consumption, which made pairing solar with batteries highly attractive. In contrast, the U.S. has lower retail tariffs and generous net-metering, so batteries are less economic and adoption has mostly been driven by resilience needs in places like California and Texas. Across Asia, household storage has lagged because of low or subsidized power prices and a policy focus on utility-scale projects; the key exceptions are Japan, where post-Fukushima incentives supported resilience, and Australia, where high tariffs and strong solar uptake created European-style consumer economics.

The European market is currently undergoing a pivotal structural shift. The initial boom in BESS deployments was led by the BTM segment, a direct consumer reaction to the extreme energy price volatility of 2022-2023. As those prices have stabilized and direct subsidies have been phased out in key markets, the growth rate in the residential segment is normalizing. Concurrently, the grid-level imperative of integrating massive new renewable capacity is forcing utilities and grid operators to accelerate the procurement of large-scale FTM projects. The data for 2024, which showed FTM additions surpassing BTM additions in GWh terms for the first time, confirms this inflection point. This trend is expected to continue, fundamentally reshaping the composition of the European BESS market through 2030.

D. India: The High-Growth Wildcard

India represents one of the most significant long-term growth opportunities for BESS globally. The market is currently nascent but is poised for exponential growth, driven by ambitious government targets for renewable energy. However, this immense potential is tempered by considerable project execution risks that could moderate the pace of deployment.

India Market Segment	2024 Capacity (GWh)	2030E Capacity (GWh)	2030E Market Share
Front-of-the-Meter (FTM)	0.42	192	96.00%
Behind-the-Meter (BTM) - C&I	0.02	7	3.50%
Behind-the-Meter (BTM) - Residential	<0.01	1	0.50%
Total	**0.44**	**200**	**100.00%**

Catalysts & Headwinds
India's BESS ambitions are backed by strong political will and clear policy, but the market's success hinges on overcoming significant implementation challenges.

Catalyst - Ambitious National Targets & Policy Support: The primary catalyst is India's national target to install 500 GW of non-fossil fuel capacity by 2030. This goal is backed by a suite of concrete policies, including a substantial Viability Gap Funding (VGF) scheme designed to support 43.2 GWh (13.2 + 30 = 43.2 GWh) of BESS projects, a Production-Linked Incentive (PLI) scheme to foster domestic battery manufacturing, and mandatory Energy Storage Obligations (ESOs) for utilities.

The **10% storage mandate** and the **Energy Storage Obligation (ESO)** are two different but complementary policies. The 10% mandate is a **project-level rule** that applies only to specific renewable energy tenders floated by agencies like SECI, NTPC, or state governments. Under this, developers bidding for a solar or wind project must include storage equal to around 10% of the project's rated capacity, usually with a fixed duration requirement. For example, a 500 MW solar tender would need to be paired with about 50 MW of storage. This ensures that every new project coming through such tenders directly contributes to storage deployment, creating immediate and predictable demand at the project level.

In contrast, the ESO is a **system-level requirement** imposed on utilities, open-access consumers, and captive power users, similar to Renewable Purchase Obligations. Instead of being tied to a single project, it mandates that these entities must meet a rising share of their **total annual electricity consumption** through renewable energy stored in batteries or other storage systems. The targets start at 1% in FY2025–26 and increase gradually to 4% by FY2029–30. Compliance can be achieved by building storage, signing PPAs with developers, or buying from aggregators, and is monitored annually by regulators.

Catalyst - Favorable Economics for RTC Power: The market is rapidly shifting towards tenders for Round-the-Clock (RTC) renewable power, which inherently require energy storage. These hybrid projects are becoming increasingly cost-competitive with new-build thermal power plants, creating a strong, market-based demand signal for BESS.

What "RTC Renewable Power" means

- Round-the-Clock (RTC) power refers to electricity supply that is firm, reliable, and available 24×7 (or close to it), similar to what coal, gas, or nuclear plants provide.
- Traditional solar or wind on their own are variable and intermittent, so they can't deliver RTC by themselves.
- By combining solar + wind + battery storage (BESS) — and sometimes even pumped hydro — developers can offer a firm RTC product that competes directly with thermal plants.

Why RTC is important in India (and similar markets)

- India's grid is still heavily coal-dependent. As renewable penetration grows, variability creates stress for DISCOMs and the grid.
- Regulators and procurers (SECI, NTPC, state DISCOMs) increasingly need firmed renewable power to replace retiring or expensive coal.
- RTC projects solve two problems at once: they add clean power *and* provide firm supply.

How storage enables RTC

- Solar + wind complementarity: solar peaks in the day, wind often peaks at night/monsoon.
- Batteries fill the gaps: charging when solar/wind oversupply, discharging when demand is high or renewables are low.
- This mix allows a project to guarantee, say, 80–90% annual availability, close to thermal benchmarks.

Headwind - Project Execution Risk: The single greatest risk facing the Indian BESS market is execution. There is a significant and persistent gap between the volume of capacity that has been auctioned and the volume that has been commissioned. As of mid-2025, despite a pipeline of 12.8 GWh in auctioned capacity, only about 219 MWh was operational. This is largely due to long delays in the signing of Power Purchase Agreements (PPAs) and challenges in securing affordable project financing, which could severely impede the pace of actual deployment.

The Indian BESS market is best described as a "tender-driven" market confronting a critical execution gap. Unlike markets propelled by organic consumer economics or broad industrial policy, India's growth is almost entirely dependent on the successful execution of government-led tenders for utility-scale projects. The significant discrepancy between auctioned and commissioned capacity highlights a key structural issue: offtakers, typically state-owned distribution utilities, often delay the signing of PPAs in the hope of securing even lower tariffs in subsequent auction rounds, a rational behavior given the rapid global decline in battery prices.[80] This creates a high-risk, uncertain environment for project developers and makes the achievement of the 2030 forecast highly contingent on streamlining these critical post-auction administrative and financial processes. The effectiveness of the VGF scheme in de-risking these projects will be a key indicator of the government's ability to close this execution gap and unlock the market's vast potential.

Comparative Analysis & Strategic Outlook

Cross-Market Scorecard

Synthesizing the regional analyses provides a comparative framework for strategic decision-making. China and the US are clearly established as the gigawatt-hour volume leaders, while India offers the highest growth potential. Europe stands out for its uniquely developed BTM segment.

Metric	United States	China	Europe	India
Market Size (2030E GWh)	450 (Rank 2)	720 (Rank 1)	400 (Rank 3)	200 (Rank 4)
CAGR (2024-2030E)	32.50%	31.20%	36.80%	181.73%
FTM Dominance (% of 2030E)	90% (High)	95% (Very High)	55% (Moderate)	95% (Very High)
BTM Development (% of 2030E)	10% (Developing)	5% (Nascent)	45% (Mature)	5% (Nascent)
Policy Support Level	High (IRA)	Very High (Mandates)	Medium-High (Targets)	High (VGF, ESOs)
Execution / Policy Risk	Medium (FEOC, Queues)	Low (Policy-driven)	Low-Medium (Fragmentation)	High (PPA Delays)

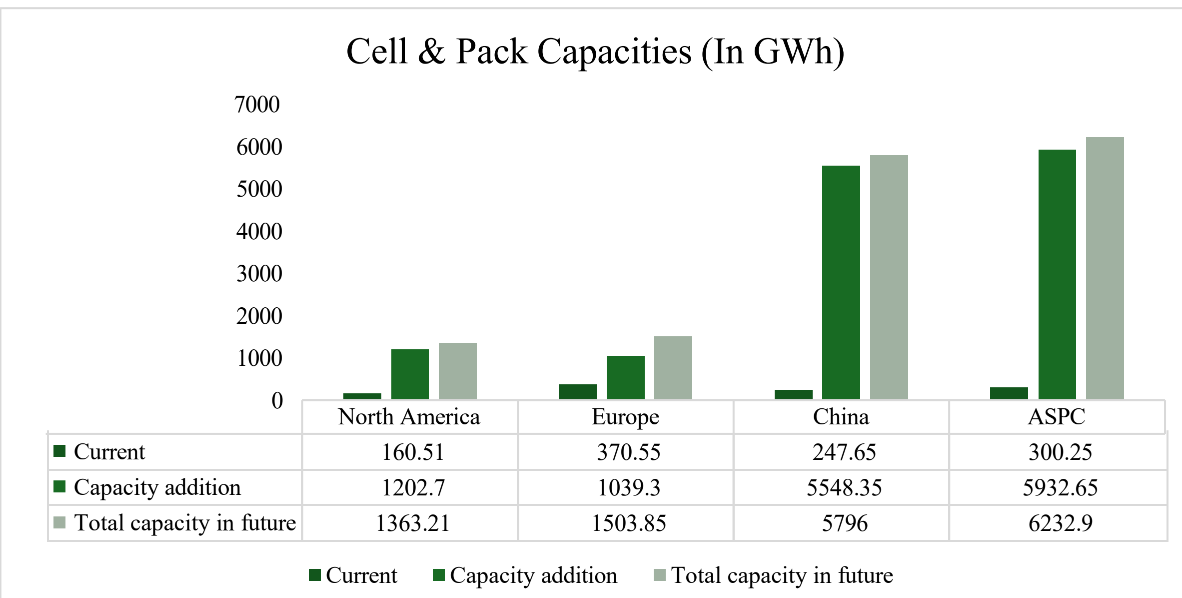
Dominant Themes and Investment Thesis

Across these diverse markets, several key strategic themes emerge that should guide investment decisions in the BESS sector through 2030.

- **FTM is the Volume Play:** The sheer scale of utility-level projects means that FTM applications will drive the majority of GWh deployment and, consequently, the bulk of capital investment globally. Success in this segment is less about direct consumer marketing and more about the ability to navigate complex regulatory and policy landscapes, manage large-scale project execution, and secure long-term, bankable offtake agreements with utilities and grid operators.

- **BTM is the Value Play:** While smaller in absolute GWh terms, BTM markets—particularly the mature residential segment in Europe and the growing residential market in the US—offer potentially higher-margin opportunities. Value is captured not just from hardware sales but from a suite of services including financing, installation, and software-based optimization through Virtual Power Plants (VPPs). Success in BTM requires a focus on efficient customer acquisition, brand building, and developing sophisticated software platforms that maximize value for the end-user.
- **The Rise of Geopolitical Supply Chains:** The implementation of the US FEOC policy is a pivotal moment for the global BESS industry. It is forcing the creation of a bifurcated supply chain: one centered on China's dominant, low-cost manufacturing ecosystem, and another focused on developing domestic manufacturing capabilities in the United States and allied nations. This creates a significant, policy-driven investment opportunity for non-Chinese battery manufacturers and companies across the supply chain that are positioning to serve FEOC-compliant markets, even if it comes at a near-term cost premium.
- **Execution is the Key Variable:** In high-growth, emerging markets like India, the primary differentiator will be execution. The market is defined by a large gap between ambitious targets and on-the-ground reality. Companies that can successfully navigate bureaucratic hurdles, secure financing, and bring tendered projects to commercial operation in a timely manner will capture significant market share and establish a powerful first-mover advantage.

<u>Global cell manufacturing capacity as per announced plans of various companies:</u>



	North America	Europe	China	ASPC
Current	160.51	370.55	247.65	300.25
Capacity addition	1202.7	1039.3	5548.35	5932.65
Total capacity in future	1363.21	1503.85	5796	6232.9

Indian players in BESS Value Chain

(Source: Industry Report, Avner)

Below is the summary of the key cell plans announced:

Company	Location	Announced / Updated Timelines	Capacity (GWh)	Capex (₹ Cr)	Tie-ups / Tech Partners	Chemistry	Current Status
Ola Electric	Tamil Nadu	5 GWh Phase-1 by FY26 (commercial production Q1-FY26); Long-term 20 GWh	5 (Phase-1), 20 (planned)	≈1,200 (raised); part of ACC-PLI ₹18,100 Cr scheme	In-house R&D; ACC-PLI awardee	NMC (4680 cylindrical)	Trial production done; ramping for commercial output FY26
Exide Energy Solutions	Bengaluru, Karnataka	6 GWh Phase-1 by end-FY26; 12 GWh later	6 (Phase-1), 12 (planned)	≈5,000 (Phase-1)	SVOLT (cell tech)	NMC, LFP	Plant under construction; commissioning expected 2025; commercial ops FY26
Amara Raja Energy & Mobility	Divitipalli, Telangana	2 GWh Phase-1 by end-FY26; 16 GWh long term	2 (Phase-1), 16 (planned) + 5 GWh pack	≈9,500 (over 10 years)	Gotion-InoBat (LFP licensing)	LFP, NMC (initial focus LFP)	Pack line operational; pilot cell line building; commercial cell output FY26
TDSG (Toshiba–Denso–Suzuki JV)	Hansalpur, Gujarat	Electrode production started 2025; hybrid EV cell output started	~5 (≈30 million cells/year)	≈4,267 cumulative	Toshiba, Denso, Suzuki	LTO	Electrode localisation >80%; supplying hybrid EV programs
Tata Agratas Energy	Sanand, Gujarat	20 GWh Phase-1 by 2027; site scalable to 40 GWh	20 (Phase-1), 40 (planned)	≈13,000+ (estimated)	Tata Group (in-house); tech licensing from global suppliers	LFP, NMC (planned)	Construction ongoing; C-sample cells expected end-2026
Reliance New Energy	Jamnagar, Gujarat	5 GWh under ACC-PLI; delayed; new timeline under discussion	5 (initial)	Not disclosed (PLI scheme funded)	Faradion (sodium-ion), Lithium Werks (LFP tech)	LFP, Sodium-ion (future)	Delayed; seeking extension under PLI; project under construction
Rajesh Exports / ACC Energy Storage	Dharwad, Karnataka	5 GWh under ACC-PLI; delayed; revised schedule pending	5 (initial)	Not disclosed (PLI scheme funded)	Not public	Likely LFP	Delayed; seeking extension under PLI
GODI India	Hyderabad, Telangana	Small-scale cell production ongoing; gigafactory planned	<0.1 (pilot), 2.5–10 planned	≈8,000 (target, long term)	CECRI, Graphite India (investor)	NMC, LFP, Sodium-ion (R&D	Small-scale commercial cells; planning large-scale facility
Log9 Materials	Bengaluru, Karnataka	Currently <0.1 GWh; plans 1 GWh by FY27	0.05 now; 1 planned	Not disclosed	Musashi (EV powertrains)	LTO, TiB-based, Zinc, others	Commercial small-scale cells; scaling up
Waaree	Gujarat	Announced - 3.5 Gwh	Announced - 3.5 Gwh	Not disclosed	Not disclosed	Not disclosed	Expected to start in 2026

India Tenders Data

Below is the summary of the energy storage tenders in India from 2018 to H125:

Stage	Number of Tenders	RE Capacity	ESS Capacity	PSP Capacity	BESS Capacity
		GW	GWh	GWh	GWh
NIT	5	1.21	10.06		10.06
RfS	29	11.26	55.05	35.25	21.00
Bidding Closed	3	1.20	2.90		2.90
Cancelled	29	11.43	38.72	31.63	7.22
Awarded	21	8.77	14.75		14.75
Under Construction	24	11.79	48.54	39.45	9.59
Operational	7	0.16	0.50	0.00	0.50
Total	**118**	**46**	**171**	**106**	**66**

Understanding the Chinese market and global peers

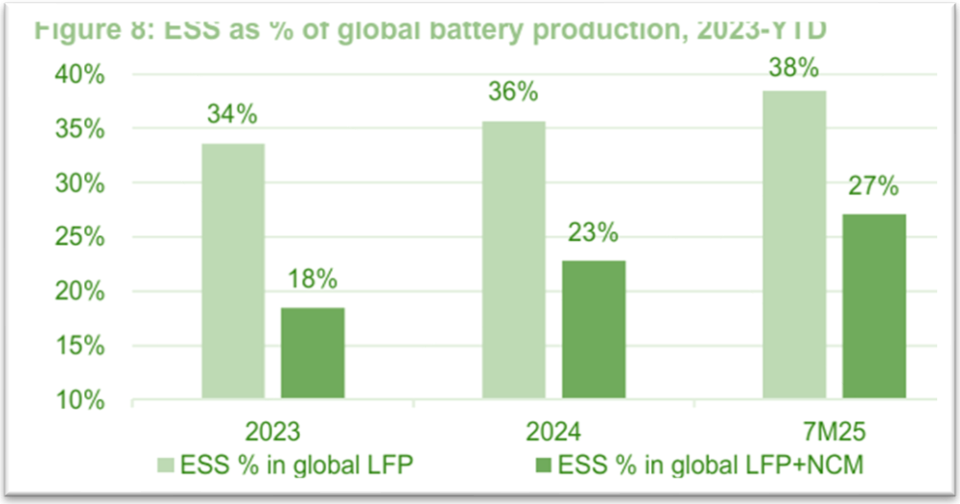
ESS Battery trend

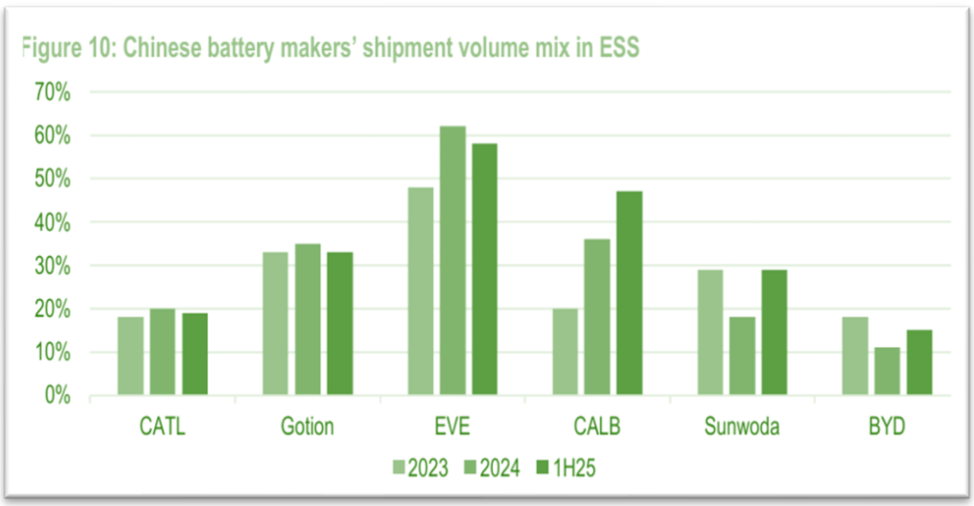
Category	2024 (GWh)	7M25 (GWh)	Y/Y (%)	Mix (%)	1Q25 (GWh)	Q/Q (%)	Y/Y (%)	2Q25 (GWh)	Q/Q (%)	Y/Y (%)
Global ESS battery shipments	**330.3**	**313.2**	**111%**	**100%**	**99.6**	**-18%**	**142%**	**157.5**	**58%**	**99%**
KR/JP battery players	9.2	7.2	52%	2%	2.6	-11%	41%	3.3	30%	53%
CH battery players	321	305.9	113%	98%	97	-18%	146%	154.2	59%	101%
Global ESS battery shipments by end-demand region	**330.3**	**313.2**	**111%**	**100%**	**99.6**	**-18%**	**142%**	**157.5**	**58%**	**99%**
China domestic demand	155.2	112.6	50%	37%	38.3	-24%	49%	57.2	49%	40%
Ex-China demand	175.1	200.6	173%	64%	61.3	-13%	188%	100.3	64%	163%
China exports (direct exports + exports by ESS customers)	165.8	193.3	181%	62%	58.8	-11%	202%	97	65%	170%
JP/KR players	9.2	7.2	52%	2%	2.6	-11%	41%	3.3	30%	53%
Chinese player shipments by end-demand application	**321**	**305.9**	**113%**	**100%**	**97**	**-18%**	**146%**	**154.2**	**59%**	**101%**
Utility-scale	254.9	245.1	122%	80%	79.6	-18%	160%	121.5	53%	108%
Commercial & Industrial (C&I)	27	27.2	103%	9%	9.3	2%	263%	12.9	39%	49%
Telecom base station	10.3	5.5	1%	2%	2.2	-34%	-11%	2.5	15%	159%
Residential	24.6	25.9	111%	8%	4.9	-34%	66%	16.3	232%	159%
Portable	2.7	1.5	-4%	1%	0.6	-11%	-2%	0.6	-2%	-6%
UPS	1.5	0.8	-1%	0%	0.4	-13%	105%	0.3	-18%	-22%
Chinese player shipments by end-markets	**321**	**305.9**	**113%**	**100%**	**97**	**-18%**	**146%**	**154.2**	**59%**	**101%**
China	155.2	112.6	50%	37%	38.3	-24%	49%	57.2	49%	40%
US	58.8	77.2	226%	25%	25.4	4%	212%	35.8	41%	206%
EU	43.5	50.2	151%	16%	12	-23%	245%	28.5	137%	169%
RoW	63.6	65.9	163%	22%	21.3	-23%	245%	32.7	53%	139%

Observation from the above table:

In 7M 2025, global ESS shipments grew strongly to 313 GWh (+111% YoY), with Chinese players maintaining dominance at nearly 98% share while KR/JP suppliers, though growing, remain marginal. Demand has shifted sharply overseas as ex-China markets now outpace domestic installations, with the U.S. and EU emerging as the largest growth engines. Utility-scale projects still lead volumes, but the surge in C&I (+263% YoY) and residential (+111% YoY) signals a structural broadening of the market beyond traditional grid-scale deployments. Overall, the data highlights China's continued leadership, accelerating global adoption, and the rapid rise of new applications driving the next leg of ESS growth.

ESS as a % of global battery sales by chemistry and players





As seen above, CATL and BYD is still getting major revenues from EVs battery.

Below is the data of company wise shipments

Company	2023	2024	YoY growth	H1 2024	H2 2024	H1 2025	YoY %	Q1 2024	Q2 2024	Q3 2024	Q4 2024	Q1 2025	Q2 2025
CATL	69	93	34.78%	46	48	52	13.04%	19	25	27	22	22	30
Gotion	15	22	46.67%	10	12	13	30.00%	5	6	6	6	8	7
EVE	26	50	92.31%	21	30	29	38.10%	7	14	15	15	13	16
CALB	8	25	212.50%	8	17	21	162.50%	0	0	0	0	0	0
Farasis	0	0		0	0	0		0	0	0	0	0	0
Sunwoda	5	5	0.00%	1	4	5	400.00%	0	0	0	0	0	0
Hithium	18	34	88.89%										

Although, on a smaller base, tier 2 players are showing significant improvement in the scale.

ESS Shipment mix

Company	2023	2024	H1 2024	H2 2024	H1 2025	Q1 2024	Q2 2024	Q3 2024	Q4 2024	Q1 2025	Q2 2025
CATL	18%	20%	22%	18%	19%	20%	23%	21%	15%	18%	20%
Gotion	33%	35%	37%	33%	33%	42%	40%	38%	30%	44%	32%
EVE	48%	62%	62%	65%	58%	54%	67%	68%	63%	57%	59%
CALB	20%	36%	32%	38%	47%						
Farasis	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Sunwoda	29%	18%	12%	21%	29%						
Hithium	100%	100%									
REPT						59%					

Targets

	2024 shipments	2025 target	y/y	1H25 shipments	1H25 run-rate (on original targets)
EV+ESS shipments (Gwh)					
Gotion	68	100 - ESS 30Gwh - EV 70Gwh	47%	40	40%
EVE	81	130Gwh - ESS 80Gwh - EV 50Gwh	60%	50	38%
CALB	70	120Gwh Vs. previous 110 Gwh	71%	45	41%
Farasis	14	15-18 Vs. previous 20-25	43-79%	6	24% - 25%
Sunwoda	37	35-40 - ESS 10Gwh - EV 25-30Gwh	-5% ~8%	23	58%-66%

Understanding numbers

Average selling price for battery

ASP (Rmb/Wh) - BESS + EV									
Company	2021	2022	2023	2024	1H23	2H23	1H24	2H24	1H25
CATL	0.79	0.97	0.89	0.65	0.96	0.81	0.69	0.63	0.58
Gotion	0.62	0.77	0.67	0.53	0.73	0.65	0.59	0.49	0.46
EVE	0.83	0.87	0.74	0.47	0.89	0.65	0.49	0.44	0.46
CALB	0.65	0.89	0.68	0.4	0.77	0.61	0.5	0.34	0.36
Farasis	0.64	0.96	0.96	0.81	1.02	0.93	0.89	0.7	0.68
Sunwoda	0.84	0.85	0.75	0.67			0.82	0.6	0.53
Hithium		0.8	0.56	0.38					
REPT	0.56	1.18	0.58	0.34	0.72	0.49	0.56	0.26	0.48
Svolt	0.88	1.04	0.87	0.62					

The sole reason why CATL is able to command a premium, is its superior tech.

Energy storage system ASP prices (RMB/Wh) – China players

Companies	2021	2022	2023	2024	1H23	2H23	1H24	2H24	1H25
CATL	0.82	0.96	0.87	0.61	0.87	0.86	0.63	0.6	0.54
Gotion	0.31	0.78	0.46	0.36	0.72	0.3	0.43	0.29	0.34
EVE		0.94	0.62	0.38	0.79	0.54	0.37	0.34	0.36
CALB	0.67	0.75	0.59	0.18	0.64	0.57	0.34	0.32	0.27

Gross margins

GP (Rmb/Wh) - BESS + EV									
Company	2021	2022	2023	2024	1H23	2H23	1H24	2H24	1H25
CATL	0.16	0.14	0.16	0.16	0.17	0.15	0.16	0.16	0.13
Gotion	0.1	0.12	0.1	0.09	0.09	0.1	0.09	0.09	0.07
EVE	0.12	0.12	0.11	0.07	0.13	0.1	0.06	0.07	0.07
CALB - new acct	0.05	0.09	0.09	0.06	0.07	0.1	0.08	0.05	0.06
Farasis	-0.14	0.03	0.03	0.11					
Sunwoda	-0.24	-0.13	-0.08	0.07			0.1	0.05	0.06
Hithium		0.1	0.07	0.07					
REPT	-0.1	0.1	0.02	0.02	0.03	0.00	0.03	0.01	0.02

GP margin (Rmb/Wh) - BESS + EV									
Company	2021	2022	2023	2024	1H23	2H23	1H24	2H24	1H25
CATL	20.3%	14.4%	18.0%	24.6%	17.7%	18.5%	23.2%	25.4%	22.4%
Gotion	16.1%	15.6%	14.9%	17.0%	12.3%	15.4%	15.3%	18.4%	15.2%
EVE	14.5%	13.8%	14.9%	14.9%	14.6%	15.4%	12.2%	15.9%	15.2%
CALB - new acct	7.7%	10.1%	13.2%	15.0%	9.1%	16.4%	16.0%	14.7%	16.7%
Farasis	-21.9%	3.1%	3.1%	13.6%	0.0%	0.0%	0.0%	0.0%	0.0%
Sunwoda	-28.6%	-15.3%	-10.7%	10.4%			12.2%	8.3%	11.3%
Hithium		12.5%	12.5%	18.4%					
REPT	-17.9%	8.5%	3.4%	5.9%	4.2%	0.4%	5.4%	3.8%	4.2%

Table 12: Battery makers' EV/ESS battery GPM

	2024	1H25
EV battery		
CATL	23.9%	22.4%
EVE	14.2%	17.6%
Gotion	15.1%	14.2%
Sunwoda	8.8%	9.8%
Farasis	11.2%	n/a
ESS battery		
CATL	26.8%	25.5%
EVE	14.7%	12.0%
Gotion	21.8%	19.3%
Sunwoda	20.4%	20.3%
Farasis	n/a	n/a

Source: Company reports, J.P. Morgan. Note: CALB restated its financials and reclassified the government grants in AR. *2024, 1H25 GPM are reported numbers post accounting changes–with warranty provisions include in COGS.

Conclusion from the above three table:

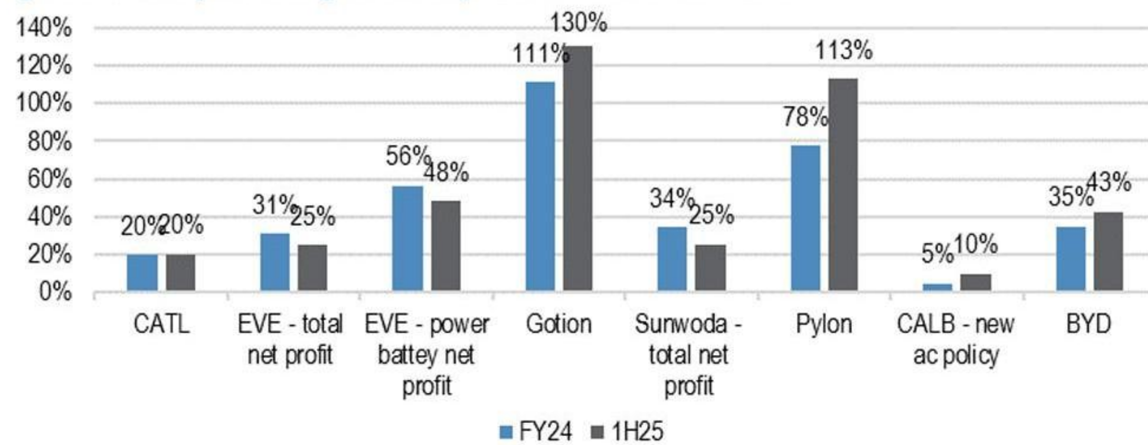
Even with a falling ASP, companies were maintain a close range of similar GP, leading to increasing in margins over the years, (passing on lower benefits to the end client), however if u look at recent numbers (H2 25), the things have changed leading to fall in absolute GP/wh as well as margins, a part of this reduction was due to international markets currency appreciation and reduction in export rebates.

NP margin - BESS + EV (RMB/Wh) - With subsidy									
Company		**2022**	**2023**	**2024**	**1H23**	**2H23**	**1H24**	**2H24**	**1H25**
CATL		11.34%	12.36%	16.92%	12.50%	13.58%	15.94%	15.87%	18.97%
Gotion		1.30%	2.99%	3.77%	1.37%	4.62%	1.69%	6.12%	2.17%
EVE – power battery		6.90%	6.76%	6.38%	7.87%	6.15%	6.12%	6.82%	4.35%
CALB (new acct policy)		3.37%	1.47%	2.50%	2.60%	37.70%	4.00%	2.94%	0.00%
Farasis		-8.33%	-12.50%	-2.47%	-11.76%	-11.83%	-2.25%	-4.29%	-4.41%
Sunwoda – power battery		-8.24%	-12.00%	-10.45%			-12.20%	-8.33%	-5.66%
Hithium		-51.25%	-19.64%	2.63%					
Rept		-2.54%	-13.79%	-8.82%	-13.89%	-14.29%	-7.14%	-11.54%	-0.42%

NP margin - BESS + EV (RMB/Wh) - W/O subsidy

Company		2022	2023	2024	1H23	2H23	1H24	2H24	1H25
CATL		10.31%	11.24%	13.85%	10.42%	12.35%	14.49%	14.29%	17.24%
Gotion		-2.60%	0.30%	-0.75%	0.27%	0.31%	0.34%	1.22%	-0.02%
EVE – power battery		4.60%	4.05%	4.26%	3.37%	3.08%	4.08%	4.55%	2.17%
CALB (new acct policy)		3.37%	1.47%	2.50%	1.30%	1.64%	2.00%	2.94%	2.78%
Farasis		-9.38%	-5.21%	-3.70%	-12.75%	-10.75%	-2.25%	-4.29%	-4.41%
Sunwoda – power battery		-8.24%	-13.33%	-8.96%			-12.20%	-10.00%	-11.32%
Hithium		-52.50%	-21.43%	-2.63%					
Rept		-3.39%	-13.79%	-8.82%	-13.89%	-14.29%	-7.14%	-11.54%	-0.42%

Figure 19: Battery makers' govt subsidy as % of NP in 1H25 vs. FY24



It's clearly visible that subsidy is driving profit margin for most of the tier 2 players

Cashflow analysis

Table 20: CH battery makers' free cashflow analysis

Cash flow analysis																			
		OPCF						Capex						FCF					
		1Q24	2Q24	3Q24	4Q24	1Q25	2Q25	1Q24	2Q24	3Q24	4Q24	1Q25	2Q25	1Q24	2Q24	3Q24	4Q24	1Q25	2Q25
EV battery	Unit																		

Table 21: KR/JP battery makers' free cashflow analysis

Cash flow analysis																			
		OPCF						Capex						FCF					
		1Q24	2Q24	3Q24	4Q24	1Q25	2Q25	1Q24	2Q24	3Q24	4Q24	1Q25	2Q25	1Q24	2Q24	3Q24	4Q24	1Q25	2Q25
EV battery	Unit																		
LG Energy Solution	Rmb mn	2,869	4,412	2,971	16,330	5,821	16,330	(18,569)	(14,924)	(14,544)	(17,357)	(16,354)	(14,822)	(15,700)	(10,512)	(11,573)	(1,027)	(24)	4,522
Samsung SDI		(1,933)	(1,408)	588	1,928	863	1,928	(4,378)	(10,641)	(6,611)	(11,260)	(4,378)	(5,159)	(6,310)	(12,049)	(6,023)	(9,332)	1,034	1,931
SK Innovation		(5,632)	15,676	2,360	(727)	(4,285)	(727)	(8,502)	(21,867)	(16,022)	(6,559)	(10,057)	(4,663)	(14,134)	(6,191)	(13,662)	(7,286)	(12,790)	3,523
Panasonic		11,577	8,281	10,099	13,009	10,586	13,009	(5,868)	(5,988)	(6,829)	(8,404)	(9,168)	(8,848)	5,709	2,293	3,270	4,605	14,782	4,909

Source: Company, Bloomberg Finance L.P., J.P. Morgan.

In China, CATL remains a standout with consistently strong OPCF and positive FCF every quarter despite heavy capex, while CALB, Sunwoda, Gotion and Great Power are FCF-negative on sustained build-outs.

Capital Structure

Gearing analysis

Net debt (cash)/ Equity	1Q22	2Q22	3Q22	4Q22	1Q23	2Q23	3Q23	4Q23	1Q24	2Q24	3Q24	4Q24	1Q25	2Q25
EV battery														
CATL	54%	37%	27%	37%	4%	5%	-16%	-18%	-36%	-23%	-35%	-33%	-44%	-43%
EVE	53%	78%	101%	60%	51%	56%	44%	38%	41%	40%	39%	37%	42%	49%
Gotion	47%	76%	46%	62%	78%	85%	92%	111%	123%	137%	133%	125%	123%	136%
Farasis	15%	57%	36%	12%	11%	-8%	-4%	54%	18%	89%	8%	46%	20%	68%
Sunwoda	45%	79%	44%	52%	25%	32%	17%	32%	22%	44%	30%	61%	39%	79%
Great Power	65%	75%	40%	61%	63%	43%	26%	47%	44%	61%	63%	95%	80%	95%
CALB			11%		38%		43%		55%		67%		79%	
Rept			-2%		29%		6%		12%		55%		54%	

Gearing analysis

Net debt (cash)/ Equity	1Q22	2Q22	3Q22	4Q22	1Q23	2Q23	3Q23	4Q23	1Q24	2Q24	3Q24	4Q24	1Q25	2Q25
EV battery														
LG Energy Solution	-15%	-4%	9%	11%	16%	19%	23%	24%	28%	34%	40%	37%	44%	54%
Samsung SDI	14%	14%	7%	6%	14%	13%	16%	13%	18%	29%	35%	42%	44%	39%
SK Innovation	57%	52%	63%	69%	69%	64%	58%	56%	64%	61%	66%	78%	97%	105%
Panasonic	-6%	26%	26%	21%	18%	17%	19%	17%	14%	12%	13%	11%	10%	13%

CATL is the clear outlier, moving from moderate leverage in 2022 to a sustained net-cash position through 2Q25 (≈−40% ND/E), while most China peers (Gotion, Sunwoda, CALB, Great Power, Farasis, EVE) have levered up steadily, many now at 60–135% net debt/equity. **Funding intensity and refinancing risk have shifted up** for everyone except CATL (and to a lesser extent Panasonic).

ROE comparison

	2022	2023	2024	1H25
CATL	25%	24%	25%	24%
EVE	15%	12%	11%	10%
Gotion	1%	4%	5%	5%
Farasis	-9%	-17%	-3%	-3%
Sunwoda	6%	5%	6%	6%
Great Power	19%	1%	-5%	-7%
CALB	2%	1%	2%	2%
Rept	-6%	-13%	-11%	-7%
LG Energy Solution	6%	6%	-5%	-3%
Samsung SDI	12%	11%	3%	-2%
SK Innovation	8%	1%	-10%	-7%
Panasonic	9%	8%	11%	8%

As can be concluded from the above data, given CATL's superior margins, cash generations, CATL would be an Outlier in ROE as well. The other players in industry are operating at a very unsustainable terms despite getting subsidies.

R&D a major expense item across major Chinese players

Expensed R&D investment (Rmb mn)							
	CATL	BYD	EVE	Gotion	Sunwoda	Farasis	CALB
2018	1,991	4,989	315	347	1,060	113	
2019	2,992	5,629	459	437	1,523	271	136
2020	3,569	7,465	684	499	1,806	372	202
2021	7,691	7,991	1,310	644	2,327	542	285
2022	15,510	18,654	2,153	1,793	2,742	598	665
2023	18,356	39,575	2,732	2,061	2,711	749	992
2024	18,607	53,195	2,942	2,148	3,330	582	1418
1H25	10,095	29,596	1,261	1,046	1,924	298	860

Capitalized R&D investment (Rmb mn)							
	CATL	BYD	EVE	Gotion	Sunwoda	Farasis	CALB
2018	-	3,547	80	146	-	-	
2019	-	2,792	18	151	-	-	288
2020	-	1,091	39	197	-	-	288
2021	-	2,636	69	522	-	-	270
2022	-	1,569	108	622	-	-	370
2023	-	343	139	707	-	-	73
2024	-	966	117	781	-	-	73
1H25	-	1,284	178	336	-	-	n/a

% of R&D being expensed							
	CATL	BYD	EVE	Gotion	Sunwoda	Farasis	CALB
2018	100%	58%	80%	70%	100%	100%	
2019	100%	67%	96%	74%	100%	100%	32%
2020	100%	87%	95%	72%	100%	100%	41%
2021	100%	75%	95%	55%	100%	100%	51%
2022	100%	92%	95%	74%	100%	100%	64%
2023	100%	99%	95%	74%	100%	100%	93%
2024	100%	98%	96%	73%	100%	100%	95%
1H25	100%	96%	88%	76%	100%	100%	n/a

Total Expensed + Capitalized R&D as % of revenue							
	CATL	BYD	EVE	Gotion	Sunwoda	Farasis	CALB
2018	7%	7%	9%	10%	5%	5%	
2019	7%	7%	7%	12%	6%	11%	24%
2020	7%	6%	9%	10%	6%	33%	17%
2021	6%	5%	8%	11%	6%	15%	8%
2022	5%	5%	6%	10%	5%	5%	5%
2023	5%	7%	6%	9%	6%	5%	4%
2024	5%	7%	6%	8%	6%	5%	5%
1H25	6%	8%	5%	7%	7%	7%	n/a

Source: Bloomberg Finance L.P., company data, J.P. Morgan.

R&D expense, is a major expense of about 6-10% of the sales across all players.

Understanding capacity, capacity utilization, addition

	2019	2020	2021	2022	2023	2024	2025E	2026E	2027E
Annual designed capacity									
CATL	53	69	170	390	552	676	895	1,095	1,295
BYD	34	53	80	110	250	350	450	550	650
CALB	3	4	12	30	70	90	130	190	250
SVOLT	-	2	7	22	30	50	70	85	100
EVE	11	13	15	33	75	90	140	190	250
Gotion	12	28	30	50	80	100	125	175	250
Sunwoda	-	3	9	26	35	45	75	95	105
Farasis	3	10	15	23	28	28	43	58	68
REPT	6	14	18	26	35	74	90	120	150
Lishen	4	4	5	8	10	18	20	20	20
BAK	13	3	4	7	9	10	15	15	15
A123 (Wanxiang)	3	1	2	8	20	40	60	60	60
Hthium (Haichen)	3	4	4	5	30	50	75	100	125
Great Power	-	7	13	21	30	34	39	42	42
Geely	-	-	-	-	2	10	20	20	20
Yinpai (under Aion)	-	-	-	-	1	9	13	27	36
Greater Bay	-	-	-	2	5	10	16	20	20
Ganfeng				14	16	16	20	33	38
AESC Envision	5	5	6	16	29	74	82	131	145
Others	105	40	60	65	263	263	263	263	263
China total designed capacity	**249**	**260**	**450**	**855**	**1,570**	**2,037**	**2,640**	**3,289**	**3,902**
YoY	**28%**	**4%**	**73%**	**90%**	**84%**	**30%**	**30%**	**25%**	**19%**
Of which: capacity in China	246	257	446	849	1,555	2,015	2,588	3,133	3,650
Of which: capacity outside China	3	3	4	6	15	22	52	156	252
China effective capacity (considering OEE)	**187**	**196**	**347**	**665**	**1,198**	**1,576**	**2,356**	**2,933**	**3,478**
YoY	**30%**	**5%**	**78%**	**91%**	**80%**	**29%**	**30%**	**24%**	**19%**
China power battery production	**95**	**100**	**257**	**653**	**891**	**1,172**	**1,744**	**2,069**	**2,359**
YoY	**25%**	**5%**	**158%**	**154%**	**37%**	**32%**	**49%**	**19%**	**14%**
Industry capacity utilization	**38%**	**38%**	**57%**	**76%**	**57%**	**58%**	**66%**	**63%**	**60%**
China power battery shipment	**85**	**82**	**224**	**578**	**814**	**1,112**	**1,683**	**2,000**	**2,281**
YoY	**26%**	**-4%**	**172%**	**158%**	**41%**	**37%**	**51%**	**19%**	**14%**
Industry sales to capacity	**34%**	**32%**	**50%**	**68%**	**52%**	**55%**	**64%**	**61%**	**58%**
Capacity from top players (on designed capacity)	**113**	**167**	**369**	**730**	**1,185**	**1,537**	**2,093**	**2,658**	**3,243**
	84%	60%	70%	89%	75%	76%	83%	78%	73%
New capacity addition based on effective capacity	55	11	190	405	715	467	603	649	613
	18%	*-80%*	*1651%*	*113%*	*77%*	*-35%*	*29%*	*8%*	*-6%*

Figure 25: China EV and ESS battery industry capacity utilization rate (based on designed capacity)

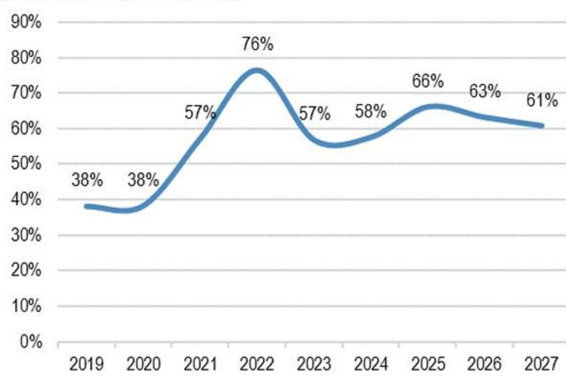
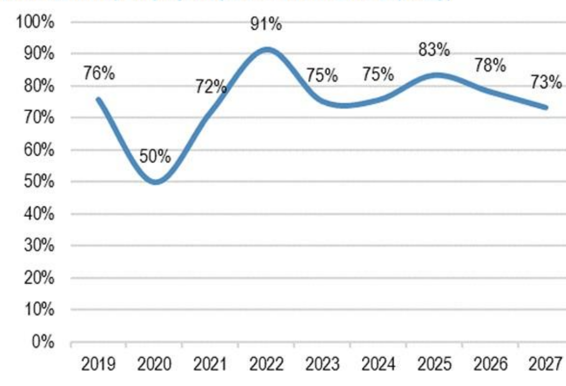


Figure 26: China EV and ESS battery industry capacity utilization rates from Top 10 players (based on effective capacity)



China's cell capacity is still racing ahead of demand: designed capacity doubles from ~2.0 TWh (2024) to ~3.9 TWh (2027E), while production/shipments rise much slower (~1.17 → 2.36 TWh), keeping industry utilization stuck near the low-60s% on a designed basis after a brief 2025 uptick. The top-10 remain far healthier (≈75–90% on effective capacity), showing a clear flight-to-quality as the long tail sits idle. New capacity additions have already decelerated sharply (post-2023 growth slows and even turns negative on some comparisons), signaling that capex peaked and is normalizing. Capacity is also migrating outside China (still small but rising), tracking IRA/EU localization. Bottom line: the market stays oversupplied through 2027, with volume growth absorbed mainly by tier-1 leaders; expect consolidation/deferrals among mid-tiers, continued pricing pressure, and bankability to matter more than nameplate size.

Key financials of key Chinese players

Revenue	2016	2017	2018	2019	2020	2021	2022	2023	2024
CATL	14581	19257	31092	50367	56861	148980	384272	469073	423555
YoY growth %		***32%***	***61%***	***62%***	***13%***	***162%***	***158%***	***22%***	***-10%***
Eve energy	1,581	2,872	4,569	7,053	9,223	19,367	42,403	57,077	56,879
YoY growth %		***82%***	***59%***	***54%***	***31%***	***110%***	***119%***	***35%***	***-0.35%***
Sunwoda electric	7891	13525	21355	21355	33552	42813	60926	55999	65544
YoY growth %		***71%***	***58%***	***0%***	***57%***	***28%***	***42%***	***-8%***	***17.05%***
CALB				1907	3193	7806	24246	31597	32469
YoY growth %					***67.40%***	***144.48%***	***210.63%***	***30.32%***	***2.76%***
Gotion energy	4663	4659	5383	5455	7598	11868	26924	36978	41408
YoY growth %		***-0.08%***	***15.55%***	***1.33%***	***39.30%***	***56.19%***	***126.86%***	***37.34%***	***11.98%***
Global EV shipments					165	341	550	774	950
Global ESS Shipments					26	66	126	213	330

If we look at the pace at which the Chinese players have scaled, its just impressive, the global EV battery industry almost grew 6X and that of ESS at 13X, similar is the rate at which these players grew (combined capacity) at a such a high base. From here, combined (ESS+BESS) industry expected to grow 3x from here.

Gross Profit	2016	2017	2018	2019	2020	2021	2022	2023	2024
CATL	6143	6749	9427	13792	15080	38857	78256	89769	100955
Eve energy	518	827	1049	1978	2618	4178	6914	9004	9765
Sunwoda electric	1158	1885	3062	3062	4667	6288	8432	7158	9596
CALB				-41	491	585	2184	3097	4984
Gotion energy	2180	1809	1562	1419	1764	2209	4791	5587	7195

Net Profit	2016	2017	2018	2019	2020	2021	2022	2023	2024
CATL	2795	3734	3556	5016	6309	18250	35891	51622	59371
Eve energy	247	388	599	1674	1867	3329	4100	4739	4768
Sunwoda electric	441	524	737	737	906	1049	1249	1259	1718
CALB				-131	6	160	823	344	692
Gotion energy	1010	807	609	56	169	116	363	1098	1412

Conclusion

Like every other industry, China story here is also that of scale supported by government subsidies. Right now, according to us, China's battery industry is at a critical juncture—capacity continues to outpace demand, pushing utilization into the low 60%, ASPs are falling, and margins are increasingly under pressure. Tier-2 players remain subsidy-dependent and highly leveraged, while CATL stands out as the only player consistently generating strong cash flows, maintaining a net-cash balance sheet, and sustaining premium margins through superior technology and global reach. The structural oversupply, coupled with the shift in demand to overseas markets like the U.S. and EU, signals that consolidation and pricing pressure will dominate the Chinese market through the rest of the decade.

One company that completely stand out and defy Chinese norms of scale, low margins, low return ratios and low-capacity utilisation is CATL, Let's just briefly understand the success behind CATL,

Founding and Early Strategy: CATL was founded in 2011 by Robin Zeng (an experienced battery entrepreneur) and immediately benefited from Zeng's prior success with ATL (a leading smartphone-battery company he started in 1999). The company was based in Ningde (Fujian), where local government support (land, subsidies, etc.) and in 2016, inclusion on the national "white list" of approved battery suppliers protected it from early foreign competition. Leveraging these advantages and a strategy of aggressive scale-up, CATL became the world's largest battery maker by 2017, overtaking Panasonic. In that period it won early deals with major automakers (e.g. VW, BMW, Daimler) even as it was still relatively unknown. In short, CATL entered the auto- battery market before most rivals, with advanced backing and a government-aligned strategy.

Technology Leadership: CATL uses its immense profits to fund a world-leading R&D program, resulting in a fortress of over 43,000 patents. CATL aggressively developed a broad technology portfolio. It invested early in both high-energy chemistries and novel pack designs. For example, CATL pioneered Cell to-Pack (CTP) and Cell-to-Chassis (CTC) integration: CTP boosts pack energy density from ~55% to 72%, enabling its NMC "Qilin" battery to reach ~255 Wh/kg (and ~160 Wh/kg for LFP), while CTC (integrating cells into the vehicle structure) can extend range beyond 1,000 km. In materials, CATL shifted earlier than most peers from LFP (lithium iron phosphate) to high-nickel NMC chemistries, roughly doubling energy density. It also funds next-generation research (solid-state and semi-solid "condensed state" batteries with target energy densities up to 500 Wh/kg). These innovations – from ultra-fast charging (the Shenxing "SuperCharge" LFP cell) to ultra-long cycle life (deployed 12,000-cycle batteries in a 100 MWh storage project) – keep CATL ahead on both performance and safety. In contrast, most rivals have narrower tech focuses (e.g. CALB's late pivot from LFP to NMC, Sunwoda and EVE with only modest LFP/NMC efforts) and have not matched CATL's R&D breadth.

Vertical Integration and Cost Structure: CATL built an end-to-end supply chain to cut costs and secure inputs. It invested heavily upstream (own cathode/anode materials, mining stakes, lithium projects) so it "effectively" sources its own raw materials. For instance, CATL's 2025 reports highlight a self-owned lithium project in Yichun, and expanding cathode/powder plants to localize supply. This vertical integration – from "dirt in the ground" raw materials to recycling – insulates CATL from price swings and supplier risk. Smaller players tend to lack this scale: e.g. EVE and Sunwoda still rely on external suppliers and have seen costs eat into margins. CATL's massive scale also drives down unit costs; by 2017 it had already cut costs below Korean/ Japanese competitors through high-volume production.

Customer Mix and Market Position: CATL secured a diversified global customer base. It supplies almost every major EV OEM: Tesla (in China), Volkswagen, BMW, Ford, Daimler, GM, and many others. It also serves China's domestic NEV players and public transit (buses, trucks), and has a rapidly growing ESS portfolio (grid/storage customers like Duke Energy in the US). By 2022 it was "supplying almost every electric carmaker" in the world – an extraordinary breadth.

This contrasts with most Chinese competitors, who sell mainly to domestic OEMs or a few niche customers. For example, Sunwoda's EV cell sales are heavily concentrated (40% to Li Auto alone), and CALB's customers are mostly Chinese (GAC, Xpeng, etc. after its 2018 turnaround). CATL's broad client base gives it stable, high-volume demand and stronger negotiating power. It even extends to higher-margin niches: CATL pioneered vehicle-to-grid ESS projects (100 MWh in Jinjiang with 12,000-cycle LFP cells) and battery swapping systems, further diversifying revenue.

The most important is the operating leverage it gets at the size its operating compared to its peers (almost 6x), with higher utilization rates.

While state support opened the door for an entire generation of Chinese battery makers, CATL was the only one to build a sustainable, profitable, and self-funding engine for growth. Its competitors fell into a vicious cycle: competing on price led to weak margins, which resulted in negative cash flow and a reliance on debt. This financial fragility starved them of the capital needed for the scale and R&D to truly challenge the leader.

CATL, conversely, created a virtuous cycle. A strategy focused on quality and benchmark customers allowed for premium pricing. This, combined with extreme manufacturing efficiency, generated industry-leading profits and massive free cash flow. These cash flows were then reinvested into next-generation technology and even greater scale, restarting and accelerating the flywheel. This is the fundamental reason why CATL succeeded not just in scaling, but in scaling with a level of profitability and resilience that has left its rivals far behind.

Before concluding, let's look at the key policies that drove the battery market in China:

2009 – First NEV Subsidy Program. China launched its first national subsidies for new-energy vehicles (NEVs), committing ¥10 billion over 2009–2012 for EV R&D and purchases by public fleets. This pilot (in select cities) kick-started demand for batteries by buying electric buses and taxis, seeding China's EV and battery industries.

2015 – Undoubtedly the most important regulation in China's battery history, The battery "White List" Regulations. On Mar 24, 2015 MIIT issued the "Regulations on the Standards of Automotive Power Battery Industry", creating a government-approved whitelist of battery makers. Only firms meeting national standards could register and supply EV batteries. This design (effective May 2015) shut out foreign suppliers: Samsung SDI, LG Chem, Panasonic, etc., all failed to make the list and halted China projects. Domestic champions (CATL, BYD, etc.) dominated the whitelist. By 2018 China's total installed EV battery capacity reached 56.9 GWh (+57% YoY); CATL alone had 23.4 GWh (41% share) and BYD 11.4 GWh (20%), the top three Chinese firms totaling ~67% of the market. In sum, the whitelist regulations spurred rapid domestic scale-up and "monopolized" China's EV battery market, leading to a 4-5X growth in production capacity from 2015 to 2019.

2016–2019 – Whitelist Enforcement for EV Subsidies. Building on the 2015 rules, China conditioned EV purchase subsidies on using batteries from approved domestic firms. From Jan 2016 to Jun 2019 only EVs with batteries made by MIIT-whitelisted companies could qualify for central subsidies. This local-content mandate sharply boosted Chinese suppliers: the share of battery models on sale in China supplied by Chinese firms rose from ~70% in 2016 to nearly 90% by 2019 (and fell once the policy lapsed). In practice, the policy redirected billions in consumer rebates to Chinese battery makers, accelerating their learning and scale.

2019 – White List Abolition. On June 21, 2019 MIIT scrapped the battery whitelist requirement . The four existing "catalogs" of compliant companies were revoked and the NEV subsidy rules began allowing foreign-made batteries again. This liberalization opened China's battery market to global players; within months, LG and Samsung announced new Chinese factories. However, by then domestic firms already had head start in scale and technology

2022 – 14th Five-Year Plan for Energy Storage. In March 2022 the NDRC and NEA issued an Implementation Plan for New Energy Storage (2021–25) . It explicitly targeted battery energy storage: provinces were urged to install storage, and a target was set of 30 GW of new (non-hydro) storage by 2025. The plan emphasizes market-based investment, grid integration, and technology R&D. By early 2022 over 20 provinces had storage plans totaling >40 GW. The strategy also mandated a 30% reduction in per-kWh storage costs by 2025, aiming to make battery storage commercially viable.

2022 – Supply-Chain Stabilization Notice. On Nov. 10, 2022 MIIT and the State Admin. for Market Regulation issued a Notice on the coordinated and stable development of the lithium-ion battery industry supply chain. This guidance addressed raw-material shortages and overcapacity, calling for rationalizing production capacity and quality control. It signaled Beijing's intent to rebalance the booming battery sector (e.g. by cutting low-end output) and ensure steady materials supply for EV and grid batteries.

2024 – New Battery Industry Standards (Draft). In May 2024 MIIT released draft revisions to the Lithium Battery Industry Specification Conditions (2024 Edition). Unlike the old mandatory whitelist, these new guidelines are non-binding but set higher benchmarks. They implement a "one reduction, one increase" plan: reducing redundant production capacity and raising technology/R&D requirements. For example, firms must use ≥3% revenue on R&D and demonstrate ≥50% capacity utilization before new project approval. The draft explicitly aims to curb overcapacity and push smaller, inefficient plants out of business, promoting "high-quality" growth in batteries.

2025 – New Energy Storage 2025–27 Plan. In late 2024 (announced Sept 2025) the NDRC/NEA issued a "Special Action Plan for Large-Scale Construction of New Energy Storage (2025-2027)" . It set a national target of 180 GW of new energy storage by 2027 (mostly batteries), nearly doubling the 95 GW of storage in place by mid-2025. The plan is backed by ~¥250 billion in investment and shifts from earlier mandates toward market mechanisms. It promotes storage deployment on power plants and grids, participation in ancillary services markets, and further cost declines. Notably, this plan follows the scrapping of a 2022 storage mandate (which had forced co-located batteries with new wind/solar projects). In short, the 2025–27 plan charts a new, market-oriented path to massively scale China's battery storage fleet.

Conclusion from CATL's case study and China policies

One thing which is very clear is that government will have to play a very important to role in setting up supply chain in India by incentivizing both the manufactures and consumers. Already, India is following the steps of China by introducing various similar schemes like FAME, PLI, VGF, ESO, etc. Also, like the game changing whitelist Indian government is most probably enact similar laws for battery cell in India like they did it for solar supporting local players and protecting them against foreign competition. From the case study of CATL, the player with the first mover advantage, backed by strong R&D inhouse, ability to adapt and scale as quickly as possible would the winner in the Indian BESS story.

Valuation Perspective

Global Players involved in BESS ecosystem:

Particulars	Market cap	Capacity	Mcap/capacity	ROE %	ROCE %	GP %	EBITDA %	PAT %
CATL	21,00,000	676	3,107	22.80%	12.90%	24.40%	24.00%	14%
Gotion Hi Tech	98,000	100	980	4.70%	1.60%	18.00%	10.30%	3.40%
CALB	53,000	90	589	1.70%	1.30%	15.90%	12.40%	2.10%
EVE	1,81,000	90	2,011	11.30%	7.80%	17.40%	12.60%	8.40%
FARASIS	31,000	28	1,107	NA	NA	11.30%	4.80%	-2.80%
REPT	33,000	74	446	NA	NA	4.14%	0.40%	-7.60%
Sunwoda Electric	62,000	45	1,378	6.18%	4.59%	15.17%	5.30%	2.60%
LG energy	5,21,000	350	1,489	NA	NA	13.29%	13.20%	1.32%
Great power	20,000	24.5	816	-4.96%	-3.00%	7.84%	4.60%	-4.06%
Samsung SDI	1,06,000	NA	NA	3.03%	1.90%	23.73%	12.90%	3.61%
Total	32,05,000	1,478						
Total (ex CATL)	11,05,000	802						

Valuation metrics	Multiple
Market/GW	2169
Market/GW (Ex CATL)	1379
P/E 25E	30.95
P/E 26E	30.40
P/E 27E	16.15
EV/EBITDA 25E	18.20
EV/EBITDA 26E	11.55
EV/EBITDA 27E	9.45

China vs India's solar players valuation:

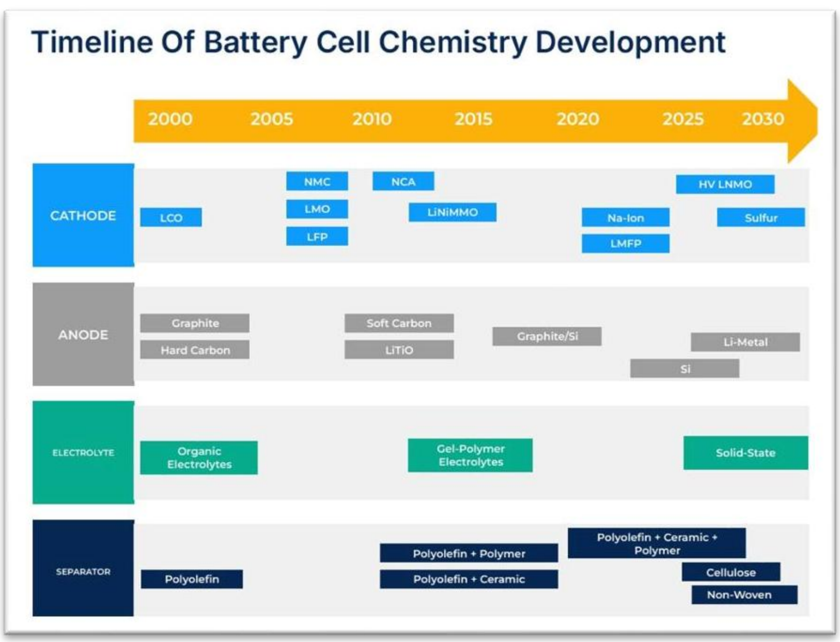
Company Name	EV	Trailing P/E	EV/EBITDA	EV/Revenue	ROE	ROCE	GP%	EBITDA%	PAT%	Wafer	Cell	Module
Premier energy	461	44.2	21.6	14	53.60%	41.10%	39.00%	29.00%	15.67%		3.2	5.1
Vikram solar	121	86.1	23	4	16.60%	26.40%	25.00%	14.00%	4.09%	0	0	4.5
Websol Energy System Limited	55	27.5	17.6	8	80.20%	59.20%	69.20%	43.90%	26.80%	0	1.2	0
Waaree Energies Limited	926	44.6	25.4	6	27.40%	34.90%	29.50%	20.00%	13.35%	0	5.4	15
Average		50.6	21.90	7.88								
LONGi	110.64	22.87	-61	1.44	-13.10%	-8.60%	0.00%	-2.20%	-5.60%	170	80	120
Trina Solar	63.63	15.28	-22	0.93	-9.80%	-3.30%	7.70%	-3.60%	-2.60%	55	75	95
JinkoSolar	62.01	10.72	9	0.8	0.40%	-0.50%	6.40%	7.80%	-0.20%	85	90	110
JA Solar	54.59	8.97	12	0.96	-15.30%	-1.90%	4.30%	6.40%	-1.10%	85.5	85.5	95
Average		14.46	11	1.03								
Premium over Chinese market		***3.50***	***2.07***	***7.63***								

Stories in Charts

Below are the graphs/representations covering points not covered in detail above.

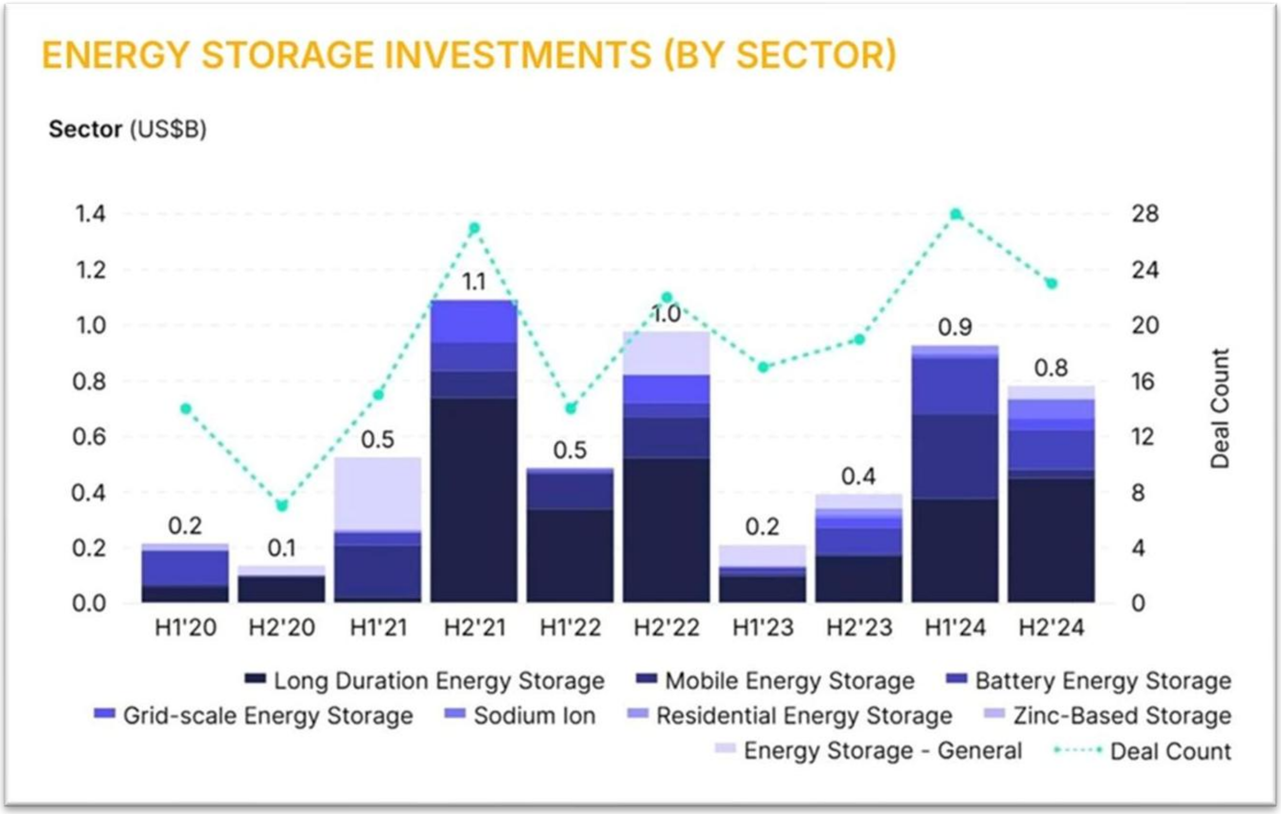
Chemistries/technology

Technology	Market readiness	Storage duration (hours)	Round-trip efficiency (%)	Geographical footprint (kWh/m^2)
Vanadium Flow batteries	Early commercial	4-24+	60-80%	20-50
Lithium-Ion (LFP, NMC)	Commercial	2-10	85-96%	90-95
Sodium-Ion	Early commercial	4-20	60-85%	2-43
Zinc Air	Early commercial	10-100	40-45%	2-43
Zinc Bromine Flow	Early commercial	4-12	60-70%	2-43
Iron Air	Early commercial	100	40-45%	75-225
Non-Metal chemical storage	Emerging	0-200	40-50%	300-1500

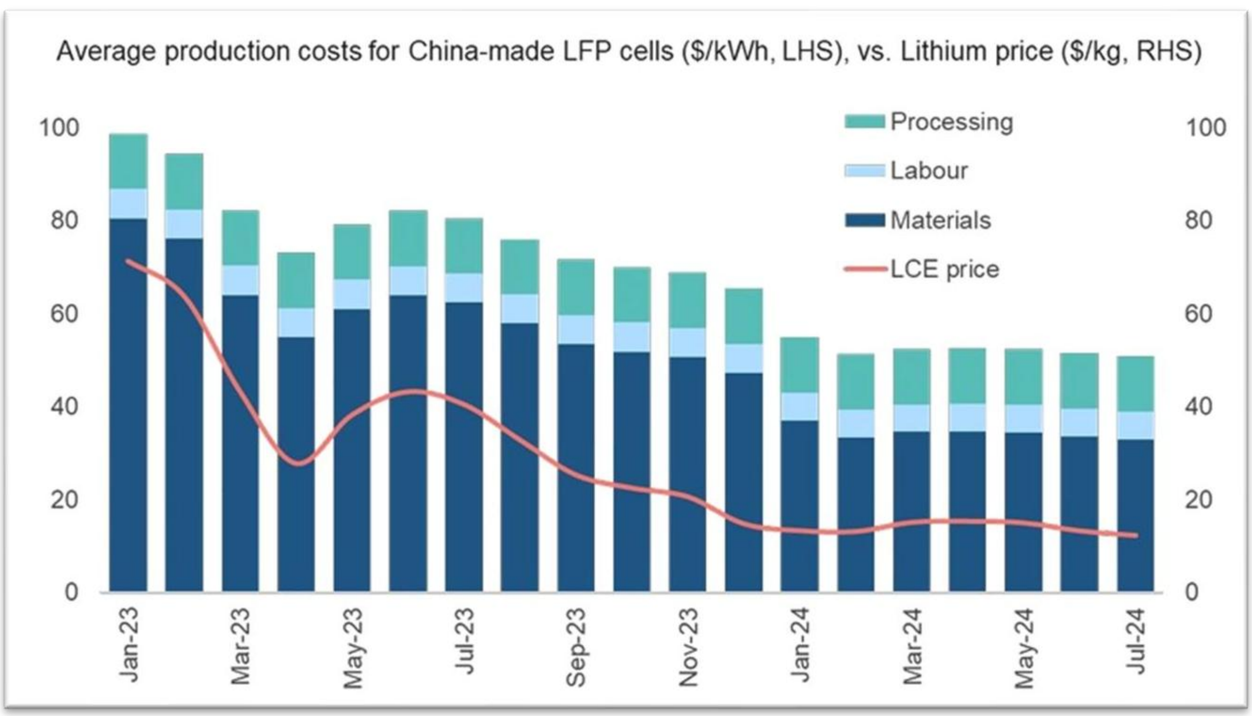


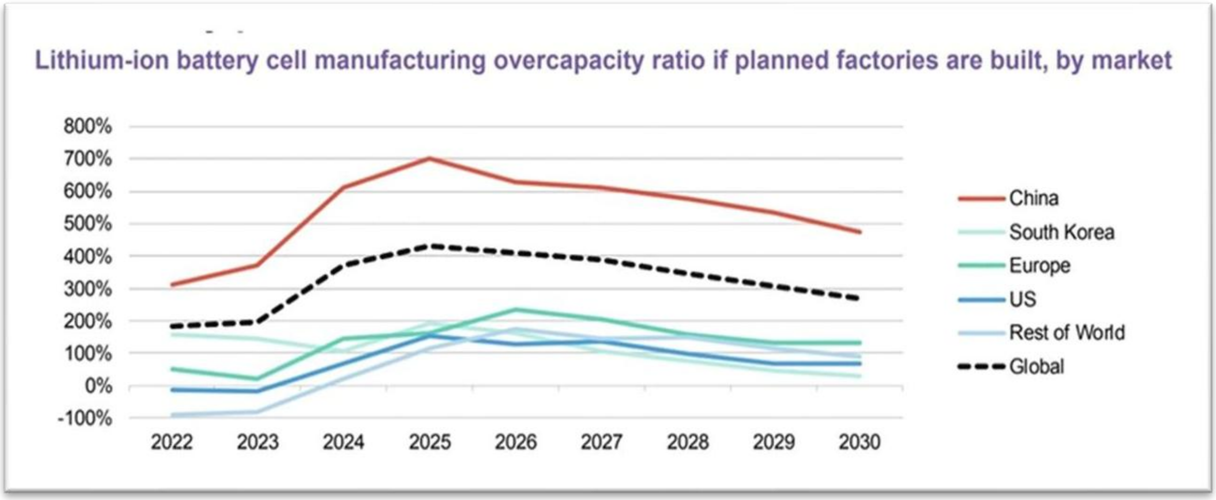
Supply Chain

Investments



Others




Lithium-ion battery cell manufacturing overcapacity ratio if planned factories are built, by market
800%
700%
600%
500%
400%
300%
200%
100%
0%
-100%
2022
2023
2024
2025
2026
2027
2028
2029
2030
China
South Korea
Europe
US
Rest of World
Global

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