Business guide to energy storage adoption in India

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India's power demand, already high at 1,375 TWh is expected to increase at the highest annual rate globally until 2040. The energy transition is a key part of India's planned climate action during the current decade. As India plans to make renewable energy a predominant part of its power mix with a threefold increase in renewable power capacity between 2020 and 2030, energy storage will play a central role in the power system transformation.

The Government of India has made concerted efforts to encourage the adoption of renewable power and recognizes the need for balancing sources like energy storage to support this shift while ensuring a resilient and reliable power grid.

Renewable Energy is intermittent in nature-solar energy and wind energy are driven by the forces of nature. Without storage, these forms of energy can only be supplementary and cannot function as a reliable base load. Currently, storage is expensive and till the cost of storage declines, Renewable Energy cannot be used to support the base load. If we truly wish to transform the global energy sector, then countries must work towards large scale deployment of storage technologies which will help bringing down electricity prices.

The Ministry of Power recently announced an energy storage obligation trajectory until 2029-30.This mandates distribution utilities, captive power producers and open-access consumers to purchase a minimum percentage of their annual power consumption from energy storage.Several other measures undertaken by the Government of india, such as production-linked incentive (PLI) scheme for manufacturing of giga-scale advanced chemistry cell battery storage with an allotment of INR 181 billion, guidelines for procurement and use of battery energy storage systems and large-scale bidding to procure more stable renewable power coupled with energy storage, are expected to boost the deployment of energy storage solutions.

Our collaboration with the private sector has been critical in leading the nation in adoption of renewable power. We hope this will be replicated in the case of energy storage adoption as well. Businesses play a crucial role by innovating both energy storage solutions aligned with power grid requirements and financing mechanisms, to deploy those solutions at scale in a most competitive manner.

RIGHT TO INFORMATION

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The World Business Council for Sustainable Development's (WBCSD) 'Business guide to energy storage adoption in India' highlights commercially viable use cases of energy storage adoption by distribution utilities and commercial & industrial companies over the short to medium term. We appreciate the efforts undertaken by the businesses involved with WBCSD for this work, across the renewable power and energy storage value chain, in putting together this guide for the larger business community. We are keen to support energy storage adoption by distribution utilities and commercial and industrial consumers to further their procurement of renewable power and promote sustainable development.

We look forward to continued coordination with businesses to accelerate the energy storage system deployment in India.

(Alok Kumar)

Foreword

India's commitment to combat the climate crisis is evident from the various policy announcements made by the government of India over the past two years. It comes as no surprise that focus on increasing renewable energy production is at the heart of this journey, and the pace and efficiency at which renewable energy is integrated with the existing power grid systsems shall determine success.

In this context, the release of WBCSD's Business Guide to Energy Storage Adoption in India could not be more timely. The Guide, which is an outcome of deliberations amongst policy makers, renewable energy companies, corporates, and financial institutions, will enable a nuanced understanding of the complex challenges associated with energy transition. Energy storage is crucial to power system transformation and to fast-track the deployment of energy storage assets in India, a conducive market environment will need to be put in place by policy makers and supported by corporate leadership in adoption. Further, banks and the world of finance will play a pivotal role in this effort.

Congratulations to WBCSD for this reference manual, which is a worthy addition to the must-reads for all stakeholders in India's power sector transformation.

Regards,

Sanjay Singh

Head of Territory and CEO, India, BNP Paribas

Executive summary

Energy storage is central to India's power system transformation. The projected cost reductions in energy storage systems that will come with economies of scale and technological advancements will likely make them cost-competitive with thermal alternatives for most applications by 2025-27. Fast-tracking the deployment of energy storage assets in India will require policy and regulatory authorities to put a conducive market environment in place and corporate leadership to adopt it.

With 1,375 terawatt hours (TWh), India has the world's third largest power demand. The International Energy Agency expects this to increase at 4.7% a year until 2040, the greatest increase in the world. The power sector is the largest contributor (around 50% in 2019) to India's CO_2 emissions, mainly because of a high dependency on coal as a power source (coal-based power generation met around 71% of the country's electricity needs from April 2021 to March 2022). The pace at which India deploys renewable energy (RE) and integrates it into its power grid, especially this decade, is critical to the country's competitiveness and global climate action. Energy storage will play a central role in the successful integration of RE.

Due to expected electricity demand growth and variability, i.e., wider fluctuations in daily peak power demand and a high share of fluctuating renewable power in the electricity mix, the hour-to-hour flexibility needs of the Indian power system are likely to increase three-fold between 2020 and 2030 compared to an average increase of 40% in most other large markets.[1] To ensure a resilient power grid, it will be critical to build energy storage installations alongside other solutions, including the flexible operation of existing thermal fleets and demand-side responses. In line with this, the Central Electricity Authority (CEA), which formulates plans for the development of electricity systems, estimates in its Draft National Electricity Plan that the country will need almost 71 gigawatts (GW)/392 gigawatt hours (GWh) of energy storage systems (ESS) by 2032, around 4% of India's power requirements by then.[2]

Adding to the requirement for energy storage from a power grid perspective are the net-zero emissions targets set by major commercial and industrial (C&I) companies, most of which are to be achieved much in advance of the national net-zero emissions target of 2070. To achieve their targets, companies must rapidly increase the share of renewable sources in their power consumption. Since renewable power generation is variable, storing excess energy is a suitable solution for companies. As a result, their demand for renewable power increases the need for energy storage solutions.

WBCSD has prepared this business guide to support electricity distribution utilities and C&I companies in India in **developing strategies and action plans for investments and deployment of ESS solutions.** The guide provides an overview of major market drivers, use cases that make or are likely to make ESS adoption commercially viable, and ownership models and contracting arrangements for ESS adoption. While this guide focuses on the relevance of energy storage solutions for distribution utilities and C&I consumers, it can also prove useful for other stakeholders, such as RE developers, ESS solution providers and financial institutions. The ultimate objective of this business guide is to enable the accelerated deployment of ESS in India.

MARKET DRIVERS FOR ENERGY STORAGE

The Government of India has taken several supportive policy and regulatory measures to boost energy storage deployment by distribution utilities and C&I companies. These include energy storage obligations, the draft resource adequacy guidelines and government tenders to procure renewable power for meeting peak load requirements, among others.

Still, a few regulatory and market barriers keep energy storage from realizing its full value. These include a lack of market-based mechanisms for ancillary services (AS), provisions for evaluating non-wired capital investments as an alternative to transmission planning and effective time-of-use tariffs.

The economic drivers, including the expected decline in ESS costs, the increasing cost of thermal electricity generation and the growing adoption of internal carbon pricing by companies, are likely to further boost ESS adoption.

REGIONAL POTENTIAL FOR ENERGY STORAGE

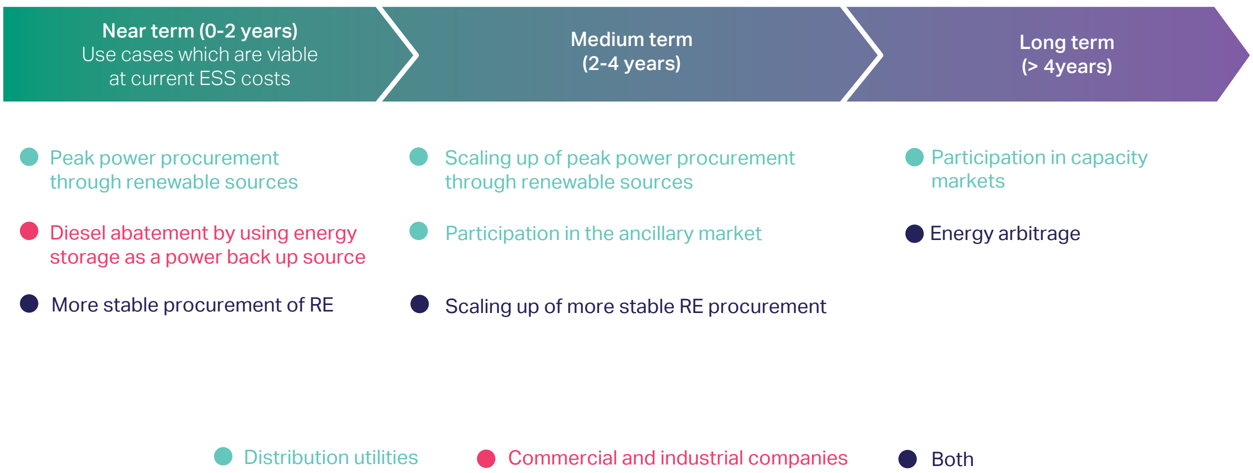
We assessed state by state potential for energy storage adoption by distribution utilities based on the share of renewable power, deviation penalties paid, and the need for additional generation capacities. The analysis reveals that the states with high-potential for storage adoption are Telangana, Tamil Nadu, Karnataka, Maharashtra, Madhya Pradesh, Gujarat and Kerala.

For energy storage uptake by C&I consumers, the analysis shows that Maharashtra, Gujarat, Karnataka, Uttar Pradesh and Tamil Nadu would be early adopters. This analysis is based on parameters including renewable power sourcing potential, conducive open access policies and the spread between the cost of more firm renewable power (including energy storage) and the retail industrial tariff.

ENERGY STORAGE APPLICATIONS

At present, it makes commercial sense for distribution utilities to adopt ESS for peak shaving and make renewable power more dispatchable. ESS provides a commercially viable alternative to contracting baseload thermal power plants to meet a utility's peak load when surplus capacities are insufficient. For instance, if a utility contracts a coal-based power plant to meet its peak load (which occurs around 3% of the time), the system cost of meeting that peak load could be as high as INR 55/kilowatt hour (kWh). Alternatively, the utility can deploy battery energy storage systems (BESS) at INR25/kWh.

Applicability of various ESS use cases



Since there are only limited use cases for which energy storage adoption makes commercial sense, given the current ESS costs and regulatory framework, stacking multiple use cases is critical to optimize the usage of ESS and unlock its full potential. If deployed at appropriate voltages, ESS can provide ramp support, arbitrage benefits, capital expenditure (CAPEX) deferral and loss reduction benefits, and increase grid use, thereby reducing the per unit capacity cost.

For C&I consumers, it makes commercial sense to adopt energy storage solutions for two main applications: capacity firming of renewable power and diesel abatement. For C&I consumers facing average power cuts of an average of 45 minutes per day, commercially viable energy storage solutions already exist to substantially reduce reliance on diesel generation sets. Moreover, industries with a fairly stable demand profile are increasingly adopting energy storage to firm up their renewable power supply. JSW Energy's bid in the Solar Energy Corporation of India's latest 500 megawatts (MW)/1000 megawatt hours (MWh) BESS tender and Arcelor Mittal's partnership with Greenko for the use of energy storage are two examples of such investments by C&I consumers.

OPERATING MODELS

Distribution utilities, renewable power producers and C&I consumers can either directly own the storage installation (direct ownership) or use the services of a third party that will be responsible for the asset's development (third-party ownership).

Going forward, we envisage that most ESS installations in India will happen under third-party ownership, in which end consumers can pass on the technical and operational risks to the project developer.

CALL TO ACTION:

While future price reductions and policy and regulatory support will determine the pace of energy storage adoption in India, we recommend the following for distribution utilities and C&I companies in order to make efficient use of energy storage while progressing on their power procurement targets in the short-term:

- Distribution utilities in India should evaluate the business case for energy storage before contracting new thermal power plants for peak power requirement.
- Both distribution utilities and C&I companies should issue technology-agnostic tenders for procurement of more stable renewable power, to enable achievement of their renewable power procurement targets in the most cost-effective manner.
- Collective efforts should be made to standardize contracts between ESS project developers and RE generators/ distribution utilities/C&I companies.

Energy storage is central to solving the renewable power procurement challenges that both distribution utilities and C&I consumers face in India. Expected cost reductions and a conducive market environment will enable both to develop business cases that capture several value streams and therefore improve the project's commercial viability and bankability. C&I consumers, in particular, can drive this market forward as they work to fulfill their RE procurement targets. The accelerated deployment of energy storage will ultimately benefit the Indian power grid as a whole.

1 Energy storage market overview in India

① Energy storage market overview in India

This section includes an assessment of expected growth in the front-of-the-meter (FTM) and behind-the-meter (BTM) ESS market, states with a potential to lead in adoption and market drivers and barriers.

DECOUPLING ENERGY DEMAND AND CO2 EMISSIONS GROWTH

India's per capita power consumption is one-third of the global average. Despite such low per capita power consumption, the country's CO_2 emissions are the third highest in the world. As per a recent modeling exercise undertaken by Deloitte on pathways to net-zero emissions in India by 2070, estimates show energy demand will double by 2050 from 2020 levels. The transition to a low-carbon energy future is only possible if India decouples its emissions growth from energy demand growth in the future.

RE has the potential to decouple the country's energy demand growth from increases in CO_2 emissions.

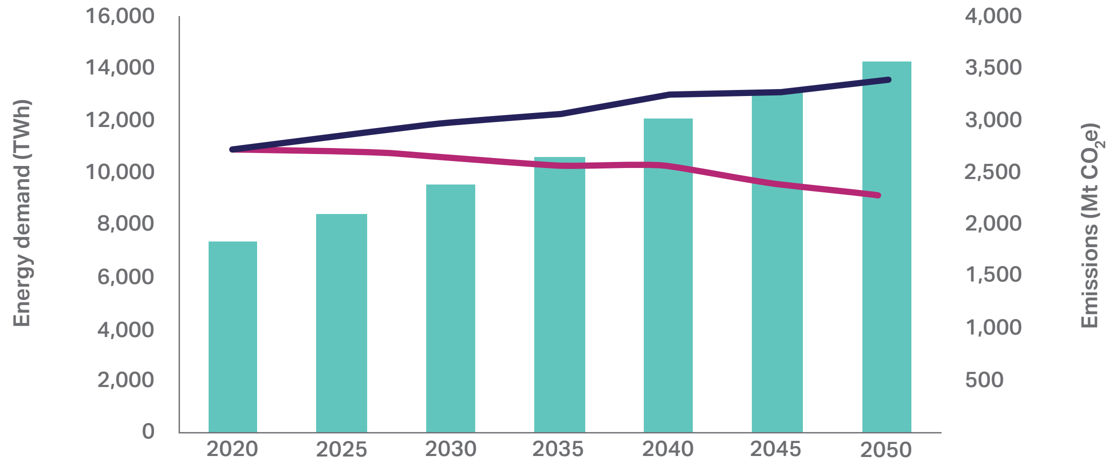
A variable RE-based energy transition to reduce carbon emissions and reach net-zero emissions by 2070 would require the deployment of energy storage solutions [2] to ensure that the power grid remains stable and resilient.

INDIA'S ENERGY TRANSITION: RENEWABLE ENERGY

The large-scale adoption of RE sources is the cornerstone of India's energy transition. This assumes significance as the country has committed to reducing projected carbon emissions by 1 billion tons by 2030 and achieving net-zero emissions by 2070. The rapid addition of RE resources at a compound annual growth rate (CAGR) of some 17% over the last decade has made India the fourth largest in the world in terms of installed RE capacity. [3] This has been a result of falling equipment costs and a decisive push by the government. The new target for 2030 is to achieve a capacity of 500 GW of renewable power (including hydro) by 2030.[4]

India is making rapid progress in adding renewable power capacity to the power mix. Over the last decade, it has added RE capacity at a CAGR of about 17%.

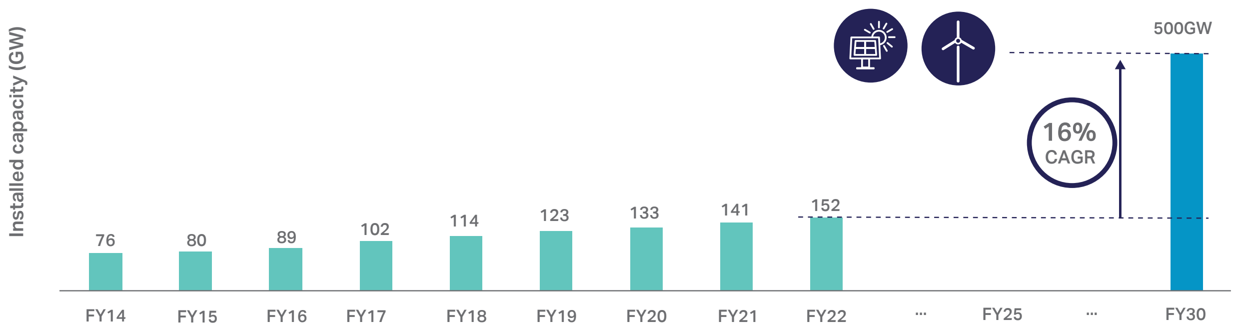
Figure 1: Projected energy demand and emissions growth



	2020	2025	2030	2035	2040	2045	2050
Demand (BAU)	7,353	8,369	9,527	10,630	12,026	13,087	14,248
Emissions (BAU)	2,722	2,875	2,996	3,078	3,262	3,282	3,403
Emissions (accelerated)	2,722	2,707	2,659	3,566	2,570	2,383	2,288

Source: Deloitte analysis; International Energy Agency (IEA) (2021). India Energy Outlook 2021.

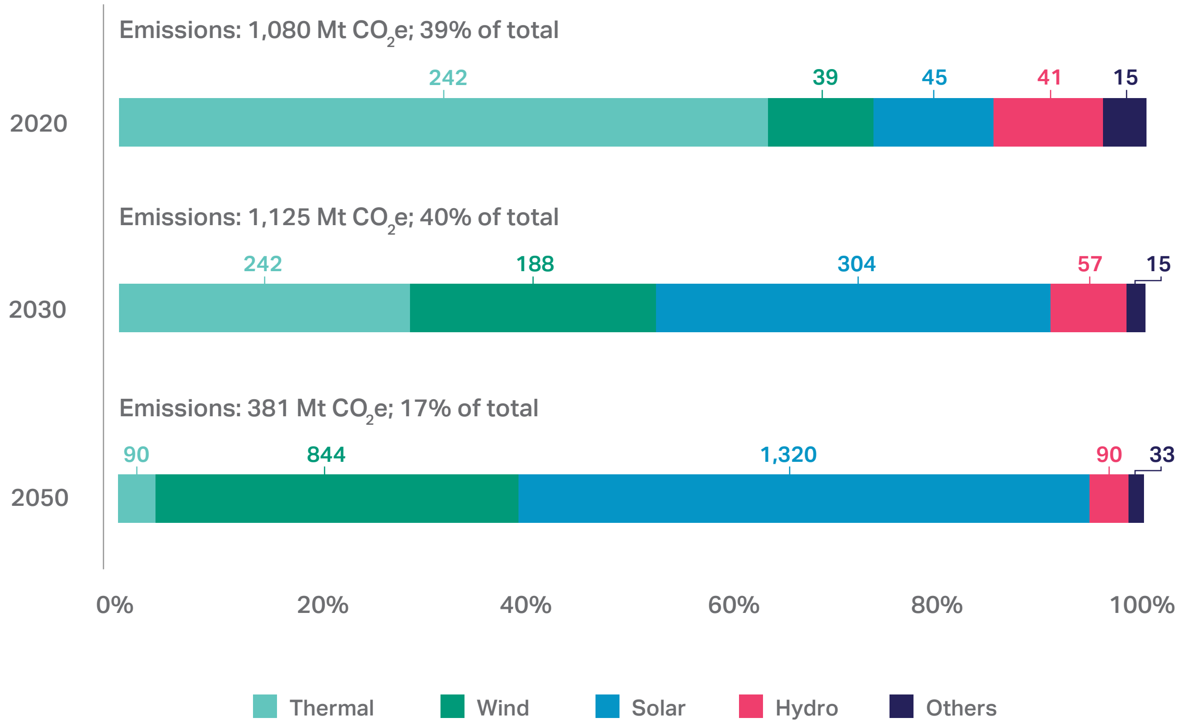
Figure 2: Cumulative RE installed capacity of India and target for 2030



Note 1: Installed capacity also includes large hydro | Note 2: Financial year (FY) – April to March

Source: CERC (2022) "Report on short-term power market in India: 2021-2022"; CEA(2022) "All India installed capacity report – March 2022"

Figure 3: Projections for installed capacity of power in India (GW)



Source: CEA(2020), Monthly installed capacity reports, Deloitte analysis

INDIA'S ENERGY TRANSITION: ENERGY STORAGE

India is on the cusp of a potential energy storage revolution. The country must add an energy storage capacity of more than 200 GW by 2040, which is the largest of any country [5], to achieve net-zero emissions by 2070. The unpredictable nature of RE sources leads to variability in the demand-supply balance, fluctuating power grid frequency levels and sudden changes in voltage profiles. Energy storage solutions can well address power grid stability, given their inherent capability to respond within a few seconds.

As countries reduce their numbers of coal-based power stations to open the way for renewable power, long-duration energy storage solutions will enable these renewable energies to supply the base load in the future. However, in the next 3-5 years, energy storage is likely to be a preferred solution to cater to peak loads and provide more firm renewable power supplies (meaning a greater supply of power from renewable sources than available naturally over a defined period of time) to distribution utilities and C&I consumers. Recent tenders from several distribution utilities and power procurement nodal agencies have indicated their inclination to procure energy storage solutions, bundled with the hybridization of renewable energies. Table 1 provides examples of such tenders issued by various utilities in 2022.

Table 1: Tenders issued by various utilities in 2022

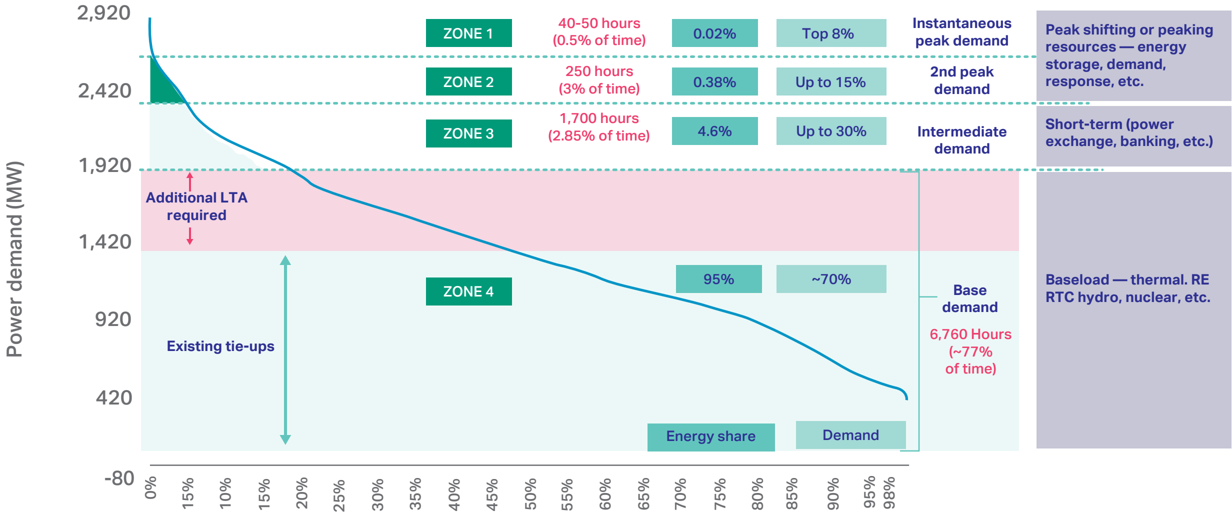
Procurer	Capcity	Location	Status	Details
MSEDCL (Maharashtra State Electricity Distribution Company Limited)	250 MW	Maharashtra	Tender – open	MSEDCL issued the tender for procurement of flexible and schedulable power from grid-connected RE projects with an energy storage facility on a long-term basis
SECI (Solar Energy Corporation of India Ltd)	500 MW/ 1000 MWh	Rajasthan	Project allotted to JSW Energy	SECI acted as the implementing agency and will procure power on behalf of the utilities SECI has contracted 60% of the project capacity, with the remaining 40% capacity being available for the developer to participate in the merchant market
NTPC Renewable Energy	3000 MWh capacity with min. 500 MW	Anywhere in India	Tender – open	NTPC intends to use an energy storage facility to meet its round-the-clock (RTC) RE requirement, with a wind-solar profile under service model from inter-state transmission system (ISTS)-connected ESS projects

Source: Tender documents- MSEDCL, SECI, NREL, News Reports

A predominantly RE-led future will require the significant deployment of energy storage. This, coupled with renewable power, will be key to helping distribution utilities meet 24/7 power supply obligations with increasing share of renewable power going forward.

The government is renewing its focus on ensuring the availability of power 24/7 by introducing states to resource adequacy as a framework and bringing in electricity market reforms. As surplus energy availability ceases to exist in most states due to higher than usual demand increases and a lack of new procurement tenders, states are exploring ways to procure more firm and peak power solutions from renewable sources to meet their deficit situations and long-term demand obligations.

Figure 4: Load curve of a typical distribution utility in India with various load requirements

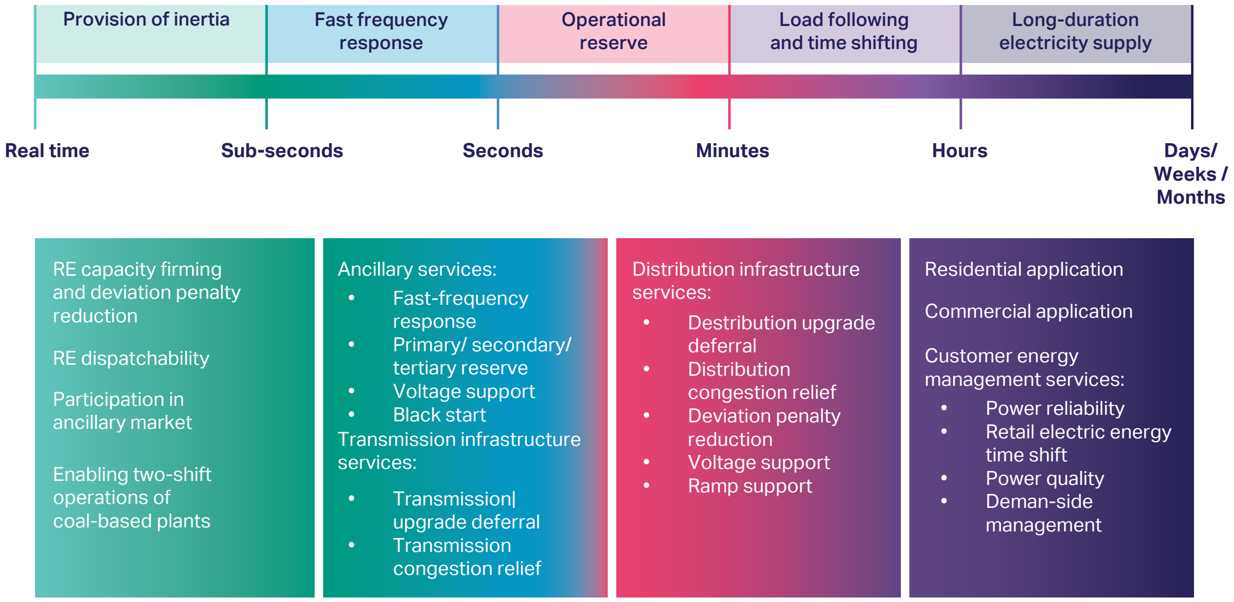


Source: Deloitte analysis

Note: This figure is illustrative of an annual load curve of a distribution utility

As RE will meet future distribution utility load growth, spanning the requirement to meet base load, peak load, seasonal load differences, hourly load differences and ramp requirements, energy storage will be a crucial resource in providing the required flexibility and adaptability to meet load preferences.

Figure 5: Potential role of energy storage in power grid support and integration along different timescales



STATUS OF ESS DEPLOYMENT IN INDIA

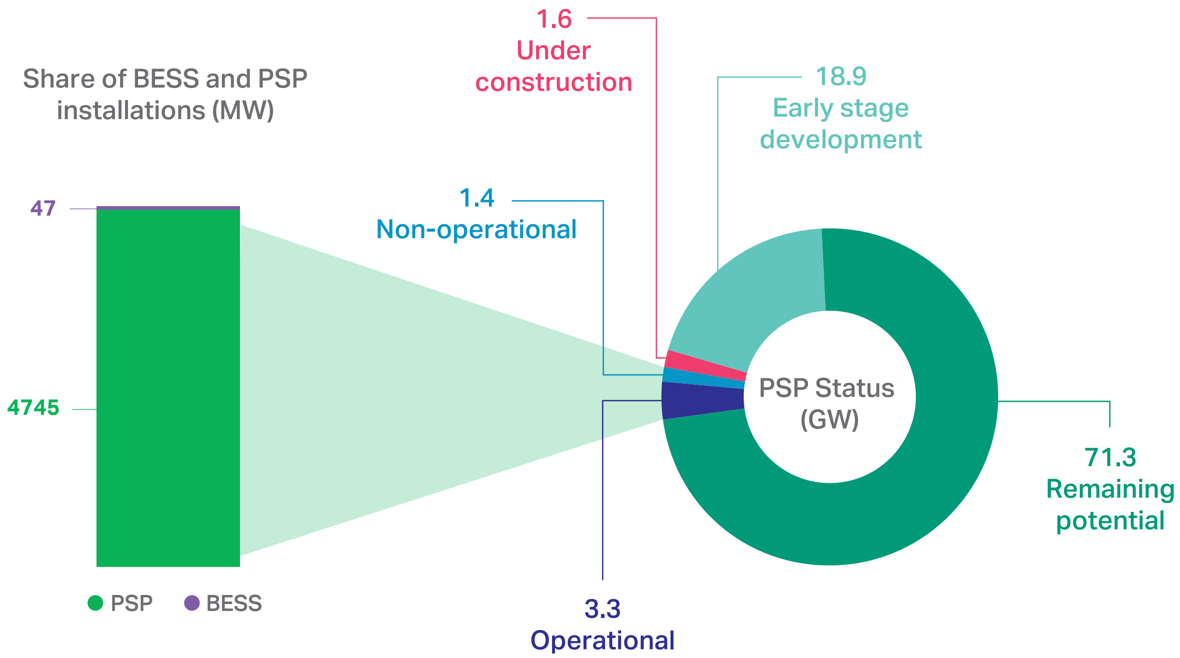
There are multiple ESS technologies under different stages of commercialization and lab-scale development. Pumped hydro storage is one of the oldest storage technologies and still has massive technical potential in India. The estimated potential of pumped hydro storage in India is 90.30 GW. At present, eight plants with aggregate installed capacity of 4.75 GW are commissioned. Out of these, only six plants with aggregate installed capacity of 3.3 GW are operational.

Other than pumped hydro, battery energy storage systems (BESS), especially lithium-ion (Li-ion) based BESS, are seeing increasing deployment for power grid-related applications over pumped hydro storage. Although the levelized cost of electricity for pumped hydro storage projects (PSP) is lower than most BESS applications, the Li-ion BESS possesses higher energy, power density and round-trip efficiency and has fewer geographic risks in its development cycle. PSPs have the inherent disadvantage of being site-specific and of limited potential because of the availability of such sites in India being scarce. They also require a long gestation period to develop, owing to the rehabilitation challenges associated with such projects. Naturally, estimates show that BESS, with reducing cost curves will dominate energy storage deployments in the next decade until the use of green hydrogen becomes commercially proven to provide seasonal storage.

Driven by the need to offer higher performance and reduced supply chain and environmental risks, other technologies such as fuel cells, super-capacitors, solid-state batteries, sodium-ion and metal-air battery storage solutions are in early stages of development. This report does not cover these evolving technologies.

Annex 1 presents a detailed list of ESS installations in India. **Annex 2** provides a review of ESS technologies.

Figure 6: Status of pumped hydro storage in India



Source: CEA(2022), "Status of Pumped Storage Development in India", Niti Aayog(2022), "Need for advanced chemistry cell energy storage in India"

MARKET DRIVERS

The following sections provide details on the key drivers that will ease the adoption of BESS in India for both the front-of-the meter (by generation, transmission and distribution utilities) and behind-the-meter (by C&I consumers in their own premises) market.

FRONT-OF-THE METER MARKET

Regulatory drivers

Recognizing the importance of energy storage solutions to support the scaling up of India's renewable power, the Ministry of Power has recently notified distribution utilities and other entities, including large C&I consumers, of the hydro purchase and energy storage obligation which is in effect until the financial year 2030. It has calibrated the energy storage obligation from 1% in 2023-24 to 4% in 2029-30 of the total electricity consumption and treats the obligation as fulfilled only when the utility procures at least 85% of the total energy stored in the energy storage asset from RE sources.

The Indian government's notification of energy storage obligations and its direction to all states to consider energy storage as an integral part of their optimal portfolio planning process will be a key market driver in promoting ESS.

Table 2: Regulatory drivers for energy storage adoption in the FTM market

Driver	Summary

Stringent renewable purchase obligation (RPO) regulations	• In addition to resetting the RPO target to 43.33% by 2030, the government recently released the energy storage obligations trajectory, which will go from 1% in 2023-24 to 4% in 2029-30. The mandate to procure this minimum percentage of total power procurement from renewable power bundled with energy storage sources will ease the development of the energy storage market in India.
	• Penalty proposed in draft amendment to EA 2003 and Tariff Policy 2016 for not meeting the RPO target specified by central government:
	  • INR 0.25-0.50/kWh in 1st year of default
	  • INR 0.5-1/kWh in 2nd successive year of default and
	  • INR 1-2/kWh continuing after 2nd year of default.
	• The government expects compliance with these obligations to be high, given increasing instances of imposition of penalties on distribution utilities and captive consumers for non-compliance. Recent examples include that of DERC (Delhi Electricity Regulatory Commission) penalizing TPDDL (Tata Power Delhi Distribution Limited), BYPL (BSES Yamuna Power Limited) and BRPL (BSES Rajdhani Power Limited); and Chhattisgarh State Regulatory Commission (CSERC) for penalizing captive power producers in the state for non-compliance.

Scientific resource planning procedure to meet power demand reliably	• The draft Resource Adequacy guidelines and Indian Electricity Grid Code (IEGC) have put a renewed focus on integrating RE into power sector planning and fulfilling resource adequacy using energy storage solutions. Resource adequacy would ensure that distribution utilities undertake a scientific study (integrated resource plan) to have an adequate supply of generation or demand-responsive resources to serve expected peak demand reliably over the next 5-10 years. • Resource adequacy targets are set by adopting appropriate loss of load indices. Adhering to such targets would require a reduction in load shedding by distribution utilities and ensuring adequate capacity to meet load using the generation mix with the least cost. • Resource adequacy exercises will provide the basis for appropriate regulatory commissions to approve distribution utility investments in energy storage solutions, as scientific modeling exercises based on least-cost principles would guide the requirement.

Driver	Summary
Transparency in BESS procurement process	• The government issued the guidelines for procurement and use of BESS as part of generation, transmission and distribution assets along with ancillary services for the procurement of energy from BESS through competitive bidding from grid-connected projects under build-own-operate or build-own-operate-transfer models. These guidelines provide standardization and uniformity to the BESS procurement process. • The minimum individual project capacity specified is kept low, at 1 MW for intra-state energy storage projects and 50 MW for inter-state BESS projects, to ensure maximum participation. • Guidelines have set a minimum battery energy storage purchase agreement term of eight years, which offers developers future visibility for planning. • A standardized procurement process will make the bidding process easier for BESS developers and will make it more convenient for them to bid for multiple BESS tenders in different states.
Stringent deviation settlement mechanism regulations	• The Deviation Settlement Mechanism Regulations 2022 increases the penalty rates for deviations from electricity injection and withdrawal schedules and links it to either the weighted average of the market clearing price of the day-ahead market, real-time market or ancillary services markets, whichever is highest. • The tolerance band where a penalty is not applicable for RE generators has gone down from 15% to 10%. This would lead to the increased need for the accurate forecasting and adoption of energy storage systems by RE players to avoid paying hefty penalties. • Earlier, generators who over-injected power into the grid during off-peak hours if frequency rose above specified levels were paid to do so. The revised regulations reduce the payment for such generators, encouraging them to store the additional energy for later use.

Participation in the ancillary services market	• According to the latest ancillary services regulations, the procurement of secondary ancillary services (response within 30 seconds) would take place through an administered mechanism and tertiary ancillary services (response within 15 minutes) through a market-based mechanism.
	• The mechanism for procuring secondary services prioritizes resources with fast ramping capability in the following ways:
	  • Payment of incentive done corresponding to the extent of compliance with automatic generation control signals sent by the system operator
	  • Preference for dispatch given to resources with higher ramp rate and lower cost
	  • Repeated non-compliance with automatic generation control signals leads to disqualification in participation for one week.
	• The regulations have created an additional avenue for storage providers to participate in secondary response and tertiary response services.

Providing an avenue for RE to participate in market-based platforms	• RE can participate in the day-ahead segment and term-ahead power exchange segment. This provides an additional avenue for renewable power procurers other than long-term PPAs and RE certificates. • This would enable increased RE absorption in the grid and enhance the role of storage to manage their intermittency.
Need for inertia in the transformed power system	Conventional power plants have large rotating generators, which have the tendency to remain in rotation for a few seconds following a power failure. This enables conventional power plants to store energy in their rotating parts and temporarily make up for any power failure, a mechanism called inertia. • Renewable sources of energy do not synchronize with the grid in a way that provides inertia, so as older coal and gas plants come off the system, it is important to find new ways to provide the requisite grid support in case of a power failure, which was covered by inertia in the conventional power system. • Energy storage, which has an inherent ability to respond quickly, provides an ideal solution in this case.
Easier regulatory mechanisms for ESS adoption	• Standalone ESS business is no longer licensed, making energy storage adoption easier. • A generating company, transmission licensee, system operator or ESS provider can develop, own, lease and operate an ESS, providing business model clarity to potential investors.

Increasing renewable power procurement and conducive regulatory provisions make way for distribution utilities to increase energy storage installations.

BEHIND-THE-METER MARKET

Green energy transition of C&I companies

Major C&I companies have set targets to achieve net-zero emissions before 2050. For example, ITC aims to achieve net-zero emissions by 2030, Mahindra, Infosys, Wipro by 2040, and Arcelor Mittal and Akzo Nobel by 2050. Companies in hard-to-abate energy-intensive sectors, such as Vedanta, Tata Steel, ACC, Ambuja Cement, Aditya Birla and JSW Energy, have also set a net-zero emissions timeline of 2050.

To achieve the targets, these companies would need to transition to low-carbon electricity sources much faster than the power grid would. Therefore, the development of a round-the-clock renewable power-led procurement strategy is necessary. The hybridization of RE with ESS is the most efficient way to replace grid power with a firm power supply and thus would act as a primary driver in this segment. A case in hand is the recent government tender issued by the Solar Energy Corporation of India (SECI) for 500MW/1000 MWh BESS procurement, where JSW Energy has emerged as the winning bidder. While SECI will procure 60% of the tendered capacity for further use by distribution utilities, JSW Energy will use the remaining 40% of the merchant capacity of BESS, which is 400 MWh, to provide firmer RE solutions to group companies, including JSW Steel. The group's internal carbon pricing scheme for investments and net-zero emissions goals makes this possible.

One of the primary drivers of the growing requirement for energy storage for C&I companies in India is linked to servicing firm green electricity for industries. Electricity demand from such C&I businesses provides a substantial opportunity for RE players to service this demand. The adoption of energy storage is an enabler in providing more firm renewable power to businesses and enabling them to optimize the use of existing and planned renewable power plants. C&I consumers with significant dependence on captive thermal power consumption offer considerable opportunity in terms of replacing captive consumption with reliable and firm RE to meet their individual net-zero emissions targets. While the complete replacement of thermal fleets with firm RE is not commercially viable at present, a few businesses have been replacing part of their thermal fleet with a mix of RE capacity and bundling it with PSP/smaller-sized batteries and exchange-traded power. As BESS becomes economical, more such thermal captive with RE replacements bundled with energy storage solutions are expected.

Table 3: Distribution of installed captive generation capacity

Installed capacity range	No. of generating industries	Installed capacity		Gross energy generation	
		Aggregate (MW)	% of total capacity	Aggregate (in millions of units – MUs)	% of total generation
> 1 & <= 10MW	5,061	13,630.69	18.12%	9,453.67	4.44%
> 10 & <= 20MW	415	5,983.37	7.96%	10,595.85	4.97%
> 20 & <= 30MW	208	5,271.91	7.01%	12,907.06	6.06%
> 30 & <= 40MW	85	3,004.17	3.99%	7,513.45	3.53%
> 40 & <= 50MW	55	2,548.91	3.39%	8,584.25	4.03%
> 50 & <= 100MW	134	9,629.71	12.8%	36,321.91	17.05%
> 100 MW	93	35,138.37	46.72%	127,697.6	59.93%
Total	**6,051**	**75,207.13**		**213,073.7**	

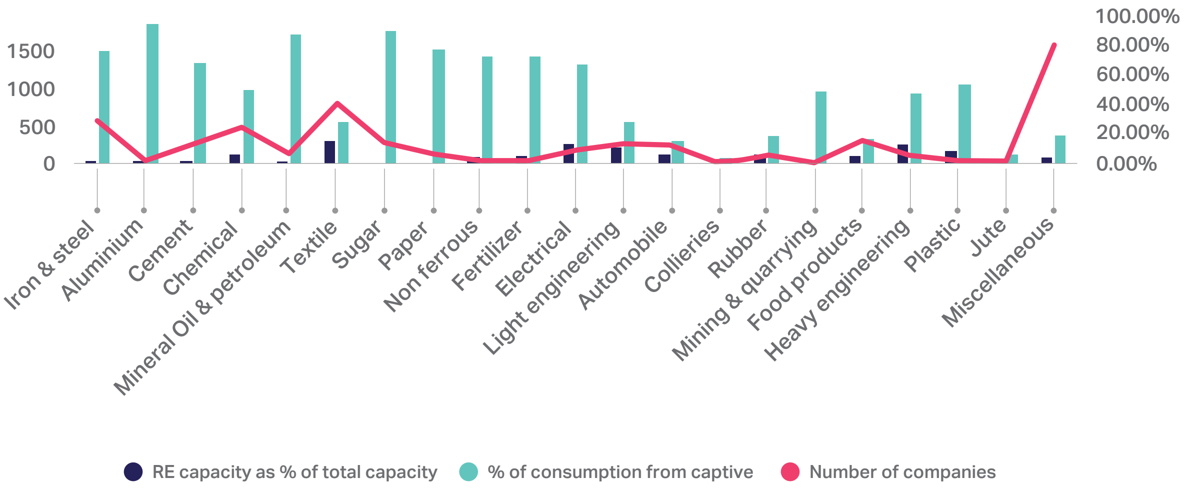
Source: CEA (2021), General Review 2021

The salient features of the current market are as follows:

- Some 82% of the installed captive capacity is greater than 10 MW, with only 990 generating industries; these generating industries cumulatively account for about 96% of the total energy generation by captive industries.
- Only 93 captive industries have installed capacity greater than 100 MW, accounting for about 47% of the total installed captive capacity in India and collectively generating some 60% of total captive energy generation.

The share of RE remains below 5% of the installed captive power generation capacity for most industries. The infirm nature of RE, capacity utilization factors being lower than thermal, and regulatory challenges in procurement of RE through open access and group captive routes are some of the reasons for the low uptake of RE. As energy storage would make RE more firm and as these industries adopt more RE to move forward on their decarbonization targets, energy storage would be a key solution for these captive consumers.

Figure 7: Share of RE in total captive power generation capacity of industrial consumers



Source: CEA (2021), "General Review 2021"

REGULATORY DRIVERS

Table 4: Regulatory drivers for energy storage adoption by C&I companies

Driver	Summary

Reduction in RE procurement cost through open access	• The revised renewable power procurement rules for electricity (Promoting RE Through Green Energy Open Access, 2022) are likely to further accelerate corporate procurement of renewable power. The reduction of the open access transaction limit from 1 MW to 100 kW and appropriate provisions for cross-subsidy surcharges, additional surcharges and standby charges will incentivize a larger group of C&I consumers to get green power at reasonable rates.
	
	• Time-bound processing by setting the mandatory approval timeline of 15 days, failing which the application will be deemed approved, will substantially support the timely implementation of projects, as a lack of open access project approval was a major barrier in renewable power adoption by C&I consumers earlier.
	
	• Additionally, the Draft Electricity (Amendment) Rules 2022 provisions that:
	
	    • The open access surcharge (cross-subsidy surcharge and additional surcharge) shall not be more than 20% of the applicable tariff;
	    • The cross-subsidy surcharge shall be applicable for a maximum period of 1 year from the date of opting for open access.
	
	As RE procurement costs through open access reduce further with these provisions, renewable power developers will have more fiscal space to make energy storage bundled with RE competitive with thermal alternatives.

Scientific resource planning procedure to meet power demand reliably	• States such as Karnataka have reduced energy banking periods or withdrawn the facility. Some states, such as Tamil Nadu and Gujarat, have high banking charges, which makes saving excess RE on the grid for later use commercially unviable. Going forward, with more and more states implementing forecasting and scheduling regulations and 15-minute energy accounting, energy banking may disappear completely. • Many states, such as Maharashtra, Tamil Nadu and Haryana, also impose restrictions on net-metering. With reduced means on the grid to save excess renewable power for later use, C&I consumers will be drawn to adopt energy storage technologies behind their meters for optimal renewable power use.

COST DRIVERS

Table 5: Cost drivers for energy storage adoption by C&I companies

Driver	Summary
Increasing costs of thermal generation	• With the Ministry of Environment, Forest and Climate Change order, it has become compulsory to install flue gas desulfurization (FGD) systems in existing and new thermal power plants to curb SOx emissions. This would see a generation cost increase of about INR 0.25-0.75/kWh. • With cheaper renewable power on the grid, many existing coal generation plants with high variable costs will be forced to shut down for a period of 4 to 6 hours when renewable power generation is at its peak. Daily hot starts to meet the evening peak could be reality for many such generation plants by 2025-26. This would have a significant financial impact on unit operations in terms of additional cost of oil and additional operation and maintenance (O&M) costs due to cycling-induced equipment and system damage. The estimated additional impact of daily starts on the cost of generation for 200 and 500 MW units ranges from INR 5 to INR 7 per kWh. Apart from additional costs due to cycling, significant changes are envisaged in operating procedures, which require investment in training and skill development.
Decreasing costs of energy storage	• The National Renewable Energy Laboratory (NREL) has forecast that battery energy storage may experience a 28-58% reduction in capital cost by 2030 and 28-75% capital cost reduction by 2050. • Prices for lithium-ion batteries rose 10%-20%, to USD $110 per kWh in the latter half of 2021, predominantly for LFP (lithium-iron-phosphate) cells, which is the favored technology for grid energy storage. The anticipated rise in global LFP cell production capacity by the end of 2023-24 will temper these price hikes, which soaring raw material costs and demand from automakers are driving. • Many states, such as Maharashtra, Tamil Nadu and Haryana, also impose restrictions on net-metering. With reduced means on the grid to save excess renewable power for later use, C&I consumers will be drawn to adopt energy storage technologies behind their meters for optimal renewable power use.
Increasing adoption of internal carbon pricing mechanisms	• In India, 85 companies have introduced an internal carbon pricing framework or are planning to do so in the next year. As an increasing number of companies are expected to adopt this framework, it will further improve the commercial aspects of energy storage adoption going forward.
Savings on captive procurement	• Captive consumption of power presents additional savings on cross-subsidy surcharges and additional surcharges (when compared to third-party open-access power procurement). • This presents a lucrative option for consumers to switch their power procurement source from distribution utility.

The above market, regulatory and cost drivers are instrumental in creating C&I company demand for energy storage technologies and solutions. RE developers that enter power purchase agreements (PPAs) for firm power supply with C&I consumers will prefer to adopt energy storage solutions to ensure firmness in supply to end-consumers. Wind, solar and energy storage solutions can most efficiently structure power availability of around 85% throughout the year for the next 5-10 years. In the absence of energy storage, the oversizing of wind and solar achieves similar outcomes but with a much-inflated risk element of surplus power sales in the merchant market.

As energy storage solution costs are currently prohibitively high, most developers are providing firmer RE by oversizing renewable power plants, barring a few successful closures using energy storage solutions effectively. Arcelor Mittal has formed an alliance with Greenko Group as part of its strategy to reduce its carbon footprint. Under this alliance, Arcelor Mittal will invest USD $600 million to own and fund a 975 MW RE project in Andhra Pradesh. The project will leverage Greenko's pumped hydro storage plant to provide continuous green energy to ArcelorMittal Nippon Steel India.

The optimal use of existing and planned renewable power plants, falling RE and storage costs and the realization of net-zero emission targets are fueling the need for energy storage adoption in the C&I segment.

LEADING STATES FOR FRONT-OF-THE-METER STORAGE ADOPTION IN INDIA

Some of the states offer greater potential for energy storage adoption than others, depending on both the need for such solutions and existing policy and regulatory frameworks. This section identifies the leading states for energy storage based on our analysis and provides a direction of travel for distribution utilities and C&I consumers.

We believe that the leading states with maximum grid-scale energy storage deployment potential within the next 5-7 years are Maharashtra, Telangana, Tamil Nadu, Karnataka, Madhya Pradesh, Gujarat and Kerala. We have considered the following parameters to identify these potential states with high FTM BESS attractiveness. **Annex 3** provides a detailed methodology and state results.

Based on the parameters in Figure 8, we prepared a shortlisting framework to perform a state ranking of the potential for adopting FTM BESS in the country.

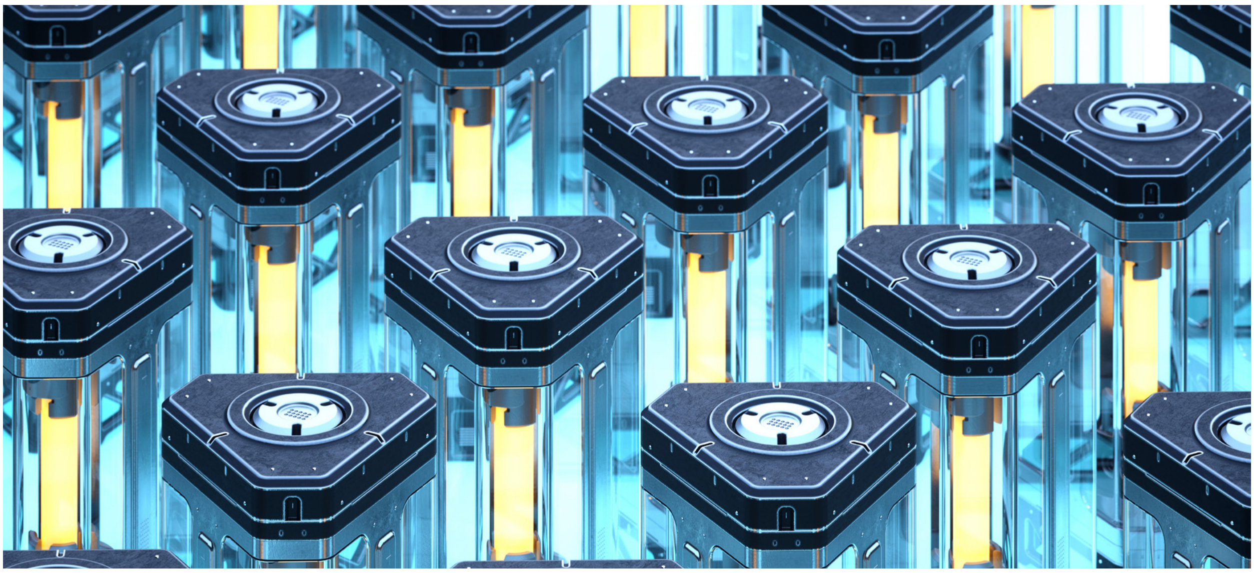
It is worth noting that Tamil Nadu already has 400 MW of pumped hydro storage projects (PSP) operational and an additional 500 MW under construction. The state has plans to develop 2,000 MW of PSP in the future.

Deloitte conducted a detailed analysis of the potential of grid-scale energy storage for three states in the country: Madhya Pradesh, Gujarat and Tamil Nadu. The analysis suggests that, depending on BESS price curves in future, these states could see a total of 15,000 to 30,000 MWh of BESS deployed by 2030, or 6 to 12% of the total BESS demand estimated by the CEA Draft National Electricity Plan for 2031-32 (258 GWh).

By virtue of their demand-supply patterns and share of renewable power in their capacity mix, the southern and western states would be the front runners for grid-scale energy storage adoption.

Figure 8: Parameters to identify potential states

1. RE Share in overall energy mix	2. DSM penalty	3. PPA replacement opportunity	4. Generation adequacy
High portion of RE in overall energy mix	Payment of high deviation charges over the last 3 years	High quantum of PPAs expiring before 2030	Instance of installed capacity falling short of meeting 70% of the load well before 2030



LEADING STATES FOR C&I STORAGE ADOPTION IN INDIA

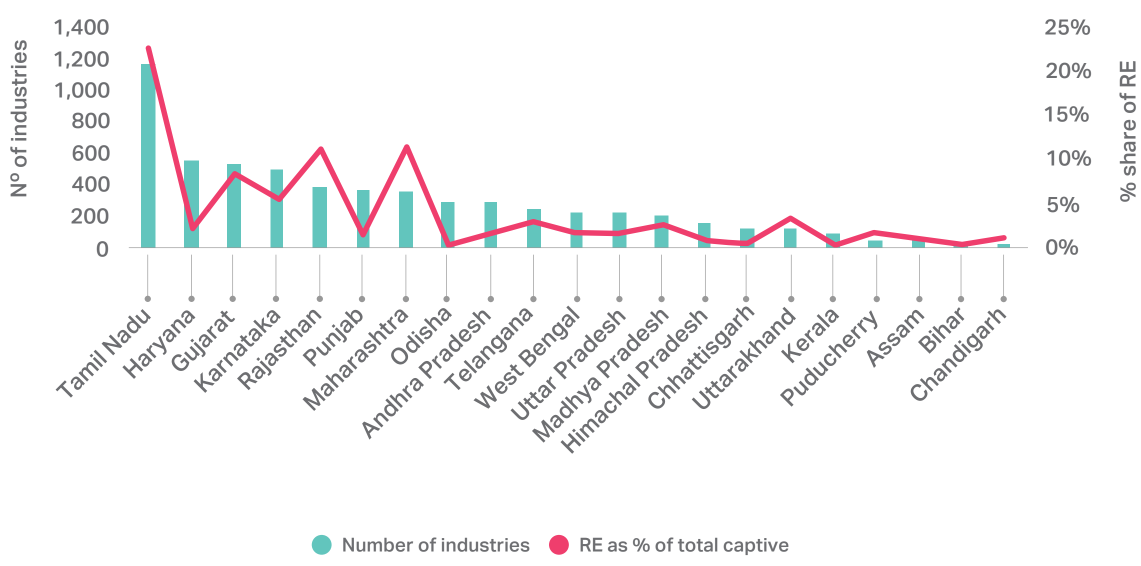
The top five states for energy storage installation by C&I companies are Maharashtra, Gujarat, Karnataka, Uttar Pradesh and Tamil Nadu. To identify these leading states for C&I companies, we considered the following parameters.

1. **Present C&I demand and** share of RE in captive capacity in the state (weight-30%): States with high C&I demand would indicate a market that may potentially shift toward green energy procurement much faster compared to other states. Figure 9 highlights the state distribution of RE captive generation; **Annex 4** provides further detail.

2. **Favorable open access policy, conducive to RE procurement in the state (weight-30%):** To present C&I segment consumption trends and non-utility consumption, we have considered favorable state-level open access policies and business environment to shortlist high-potential states. Annex 5 illustrates the distribution of non-utility-based consumption across states along with total C&I demand.

3. **Tariff spread of RE with industrial tariff in the states (weight-40%):** Table 6 summarizes the approximate current cost of captive RE supply compared to the industrial tariff category for the distribution utilities in key states.

Figure 9: State distribution of C&I demand and share of RE captive power capacity, 2019-20



Source: CEA (2021), "General Review 2021"

A net-zero emissions target and cost arbitrage offered by RE against thermal captive will drive C&I demand in states with favorable open access policies and practices.

Table 6: Summary of state distribution company tariff and landed cost of captive RE

States (FY2020)	Total C&I sales (MUs)	HT industrial sales (MUs)	Energy tariff industrial (INR/kWh)	Landed cost for RE – captive (INR/kWh)	Remarks	Maximum storage cost at which RE + storage remains attractive
Gujarat	83,030	61,410	6.10	Hybrid:4.34	Favorable hybrid policy	1.76
Maharashtra	64,890	39,188	7.52	Solar: 4.98	One of the most favorable industrial state	2.54
Odisha	61,509	58,823	4.25	Solar: 4.30	Low share of utility sale; market not opened	
TN	54,486	33,921	6.35	Solar: 4.0 Wind: 3.95	Long history of C&I market	2.32-2.4
Chhattisgarh	35,139	33,018	6.20-7.30	Solar: 3.80	Low share of utility sale; incentives capped up to first 500 MW	2.4-3.5
UP	33,721	22,652	6.80	Solar, non ISTS: 4.22 Solar, ISTS: 4.33	Favorable policy	2.47-2.58
Karnataka	31,131	22,347	7.75	Solar: 5.05 Wind: 4.07	Favorable C&I market	2.7-3.68
MP	30,735	26,139	5.20 – 7.10	Solar: 5.66	Low share of utility sale; market not opened	1.44

Source: CEA (2021), "General Review 2021"

ESTIMATION OF FTM STORAGE POTENTIAL IN INDIA

Multiple studies estimate the energy storage potential in India, the most recent and relevant being the National Electricity Plan, published by CEA in September 2022.

The objective of the Draft National Electricity Plan 2032 was to find the optimal generation capacity mix to meet the projected peak electricity demand and energy requirement in blocks of 5 years from 2022, meaning 2027 and 2032. CEA has estimated that almost **52 GW/260 GWh of BESS is required by 2032**. However, there is no such BESS requirement by 2027 as prior to that PSP will be able to cater to the storage demand and the economics of BESS will make sense only in the latter half of the decade. A recommended **19 GW/114 GWh of PSP** should be added in the system by 2032 compared to 7 GW/42 GWh of PSP by 2027.

Estimates show the energy storage requirement will pick up toward the end of the decade due to the increased potential of energy arbitrage as battery prices decline and the cost of conventional thermal (coal) increases and greater quantities of cheaper RE are available for charging at low cost. Greenfield PSP sites are limited in the country and new projects require a long gestation period. This poses a challenge in adding scaled amounts of PSP in the country, though the current costs are not as high as BESS. Challenges in site acquisition and rehabilitation expenses can increase project expenses, making these projects unviable (greater than INR 6-7/kWh); there is an increased focus on developing PSP in closed-loop operations (off-river PSPs), which should keep prices competitive. CEA has considered a major addition of such closed-loop PSP projects by 2032.

ESTIMATION OF C&I MARKET POTENTIAL IN INDIA

Industrial electricity consumption is 43% of the country's total electricity consumption and it has grown at a rate of 6.6% (CAGR) from FY2001 to FY2020. Captive consumption has mostly been restricted to high voltage industrial consumers. Commercial consumption is another 10% of the country's demand and has grown at a CAGR of about 8.5% from FY2001 to FY2020. RPO obligations, regulatory drivers for open access and cost arbitrage offered for captive consumption have driven an increase in industrial consumers shifting to consumption from RE sources. The C&I potential for energy storage in the country ranges from about 10.8 GWh to 13.2 GWh/about 2.7 to 3.3 GW by 2030. We have estimated energy storage demand through following steps:

1. Estimation of total C&I demand
2. Identification of share of captive consumers
3. Estimation of RE demand for captive consumers
4. Estimation of round-the-clock RE demand and corresponding energy storage demand for captive consumers.

Annex 6 provides our detailed approach.

2 Possible ESS and BESS use cases & ownership models

② Possible ESS and BESS use cases & ownership models

ESS installations offer use cases throughout the entire power system value chain, be it in generation, transmission, distribution or to end-consumers. This chapter delves into the critical use cases that are likely to make energy storage adoption commercially viable for distribution utilities and C&I consumers and lists suitable contracting arrangements for ESS adoption.

ESS USE CASES FOR DISTRIBUTION UTILITIES

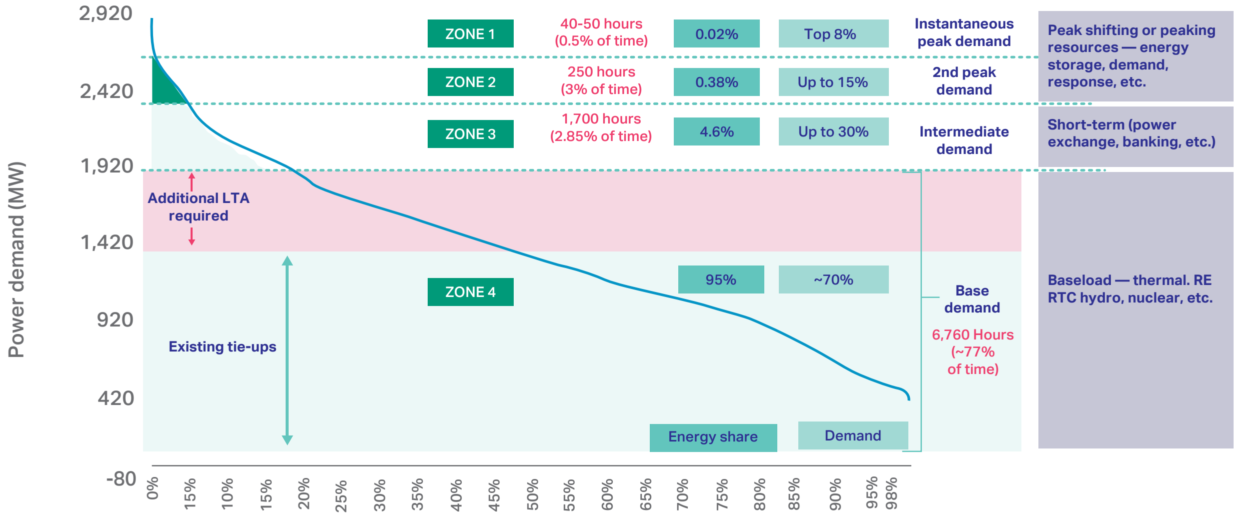
Figure 10: Possible energy storage use cases for distribution utilities or load-serving entities

	Peak load management	Alignment with electricity drawal and injection schedule	Avoiding power outages	Network upgrade deferral	Participation in ancillary service market	Enabling RE dispatchability
USE CASE	To meet peak load, DISCOMs often enter into contracts with peaking/ costlier sources of power	Utilities are subject to stringent penalties for non-adherence to commited shedules	Ensuring grid reliability & adequacy by reducing outages and loss of load	Distribution utilities have to upgrade their network due to congestion even if the same occurs for a very short time	Ancillary services is procured through regulatory mechanism	To make renewable power available when needed by the grid
APPLICATION	ESS can be discharged during time of high demand and charged when there is surplus generation in the system and prices are low	ESS can ramp up almost instantaneously to meet the ramping requirement following a change in solar/ wind generation: and help utilities to comply with commited schedules	ESS can offer localized power supply to a group of consumers during outage/ congestion	ESS can be used as non-wire alternative for transmission and distribution network planning and avoid investments in additional transformers and lines.	BESS can effectively participate in both energy market and AS market	ESS can be hybridized with infirm renewable power to provide round--the-clock RE supply to DISCOMs
VALUE STREAM	Reduction in peak power procurement cost	Reduction in DSM penalties	Additional revenue and meeting LOLP (loss of load probability) targets	Savings in infrastructure upgrade costs	Additional revenue from energy & AS markets	Reduction in power procurement cost

Three of the six use cases mentioned above stand out based on superior commercial prospects of adopting energy storage solutions as well as criticality of use cases for power transition: peak load management, enabling renewable power dispatchability and avoiding power outages. The recent power procurement tenders on behalf of distribution utilities also validate this, including SECI's standalone 500 GW/1,000 MWh tender and RE bundled with energy storage, 1,200 MW peak power supply tender and 400 MW round-the-clock (average annual capacity utilization factor of 80%) tender. The following sections explain each of the three use cases.

PEAK LOAD MANAGEMENT

Figure 11: Load curve of a typical distribution utility in India ith various load requirements



Source: Deloitte analysis

Note: This figure is illustrative of a daily load curve of a distribution utility

The peak demand for any distribution utility can be broken into three sub segments (Figure 11):

a) Instantaneous peak demand, which for most distribution utilities in India typically occurs for around 40-50 hours in a year, meaning 0.5% of the time;

b) Second peak demand, which lasts for around 250 hours in a year, 2.85% of the time; and

c) Intermediate peak demand, which lasts for around 1,700 hours, about 20% of the time in a year.

To meet instantaneous peak and second peak demand (3.35% of the time i.e 300 hours in a year), if a utility contracts a base load coal-based thermal station, the effective cost could be as high as INR 55/kWh (fixed charge of INR 2/kWh calculated at 85% when used for about 3.35%, translates to INR 51/kWh + variable charge of INR 4/kWh). Alternatively, a standalone BESS can be deployed to cater to instantaneous peak and second peak demand at a lower price of INR 25/kWh (Assuming 1hr BESS at AFC INR 8 million per year used to meet only 300 hours of peak load).

If a distribution utility contracts a coal-based thermal station to meet its entire peak load (a+b+c above), meaning around 25% of the time in a year, the cost could be as high as INR 12/kWh (fixed charge used at 25% + variable charge). While a standalone ESS may not be a commercially viable option in this case, the utility can procure energy from a hybrid renewable power plant (solar + wind) coupled with an ESS deployed to meet its peak demand at a reduced cost. This is evident from a recent peak power procurement tender issued by SECI 6 in which the successful bidders – Greenko and ReNew – had bundled hybrid renewable power with PSP and BESS, respectively, at a tariff ranging from INR 6.12 to INR 6.85/kWh for peak periods and INR 2.88/kWh for off-peak periods. With the success of such procurement, SECI announced in November 2022 a similar procurement of a 1,200 MW inter-state transmission system (ISTS)-connected wind-solar hybrid power project with assured peak power supply.

ENABLING RENEWABLE POWER DISPATCHABILITY

The planned rapid increase in the share of renewable power generation, excluding hydro and biomass, in the power mix (about 75% of new capacity addition by 2027) will require energy storage to make renewable supply more dispatchable, meaning available on demand to meet grid requirements.[7]

At current ESS price points, specifically BESS, renewable power companies have been able to enhance the dispatchability of renewable power generation mainly by oversizing hybrid (solar + wind) power plants and including a relatively small component of BESS to store surplus renewable power for later use. This is evident from the results of SECI's 400 MW round-the-clock renewable power tender in 2020, which put forth a competitive levelized tariff of INR 3.6/kWh to supply renewable power at an average annual capacity utilization factor of 80% by oversizing the hybrid power plant at an estimated capacity of 3 to 4 times and installing smaller BESS capacity for just a part of the peak generation. Companies with access to favorable locations for PSP installations, which are rare given the complex requirement of environmental permissions, have been able to increase the ESS size and reduce the need for oversizing renewable power plants to meet the same requirement.

For BESS to make renewable power more dispatchable and available for at least 70% on a monthly basis without requiring significant oversizing of the hybrid renewable power plant in a commercially viable way will require a 45% reduction[8] in BESS costs from current levels.

AVOIDING POWER OUTAGES

Reliability is key to power system operations and ensuring the adequacy of supply is an integral part of power system planning. A robust resource planning exercise by distribution utilities should ensure that power outages (loss of load events) are restricted within acceptable limits. CEA sets such limits, as measured by metrics such as the loss of load probability (LoLP) and the expected energy not served, at 0.2% and 0.05%.

Distribution utilities currently emphasize accurate demand forecasting and make good on any short-term deficiency by procuring electricity from spot markets and selling any surplus electricity back to the same spot market. With this practice, distribution utilities have been able to manage minimal or no power outages for preferential C&I consumers while resorting to power outages for other consumers in the absence of any penalty imposed for such power cuts.

However, the increasing shares of variable RE sources being integrated into the grid, distribution utilities seeking to transition away from long-term power purchase contracts, and the government considering imposing penalties on utilities for power outages required a fresh look at the way distribution utilities contract power.

In line with this, CEA has already put a draft resource adequacy framework to be followed by distribution utilities in place to ensure that there is an adequate supply of generation or demand-responsive resources to serve expected peak demand reliably.[9] The framework encourages utilities to add resource types in their power portfolio after equating the cost of resource additions with the assessed value of lost load. Any loss of load beyond the specified LoLP targets and expected energy not supplied would carry a penalty in terms of the value of lost load. For example, one unit loss of load for an industrial consumer could be as high as INR 190/kWh,[10] which is treated as a punitive value while planning for resource addition.

The country should institutionalize its resource adequacy framework by the end of 2023, providing another revenue stream for ESS adoption. Distribution utilities are likely to then scale up ESS adoption through standalone adoption and contracting renewable power coupled with ESS to avoid penalties for power outages.

OTHER USE CASES

One of the major barriers to the adoption of energy storage for other use cases is its current high price. For BESS solutions, the surge in raw material prices is emerging as a major challenge in cost reductions and adoption. India currently lacks a strong domestic manufacturing industry and is dependent on imported lithium cells for BESS solutions. In recent years, the global price of both cobalt and nickel has increased by 85% and 55%, respectively, while battery-grade lithium prices have gone up over 700% since early 2021.

The winning tenders for 2-hour stand-alone BESS (SECI 500 MW/1000 MWh tender [11] and Kerala State Electricity Board Limited (KSEBL) 10 MW/20 MWh [12] tender) indicate that the levelized annual fixed costs of current systems are around INR 13 million/year per MW. Considering the use of 1.5 cycles per day, this works out to a levelized cost of storage (LCOS) of INR 13.6 per unit of discharge (not considering the cost of charging). This cost is higher than the costs of most thermal stations in the country, suggesting that BESS is not yet viable for most other use cases.

Figure 12: Levelized cost of 2-hour BESS

YEAR		1	2	3	4	5	6	7	8	9	10	11	11	
AFC (Rs MN)		13	13	13	13	13	13	13	13	13	13	13	13	
BESS throughput	Start of year	100%	97.5%	95.0%	92.5%	90.0%	87.5%	85.9%	82.5%	80.0%	77.5%	75.0%	72.5%	
	End of year	97.5%	95.0%	92.5%	90.0%	87.5%	85.0%	82.5%	80.0%	77.5%	75.0%	72.5%	70.0%	
	Average capacity	98.75%	96.25%	93.75%	91.25%	88.75%	86.25%	83.75%	81.25%	78.75%	76.25%	73.75%	71.25%	LCOS
Total discharge (MWH)	2 cycles p/ day	1442	1405	1369	1332	1296	1259	1223	1186	1150	1113	1077	1040	Rs 10.2 /kWh
	1.5 cycles p/ day	1081	1054	1027	999	972	944	917	890	862	835	808	780	Rs 13.6 /kWh

The market is likely to see steep reductions in BESS costs by 2030, making it viable by the end of the decade. This is illustrated by comparing the levelized cost of a 4-hour BESS [13] with that of a marginal thermal station with a variable cost of INR 7/kWh. Considering a 3.45% [14] year-on-year escalation of the marginal thermal energy charge rate, the LCOS of 4-hour battery storage will reach parity by 2025. Considering an additional cost of INR 1.5/kWh for charging per cycle, the cost parity is achieved in 2027, making BESS a large-scale viable option for peaking power supply (beyond the instantaneous and second peak, as well as energy arbitrage in general).

The availability of higher discounts, reductions in the goods and services tax (GST) or import duties on batteries and higher than projected reductions in BESS costs may make the large-scale adoption of energy storage solutions commercially viable by 2025.

Figure 13: Projected BESS cost decline trajectory

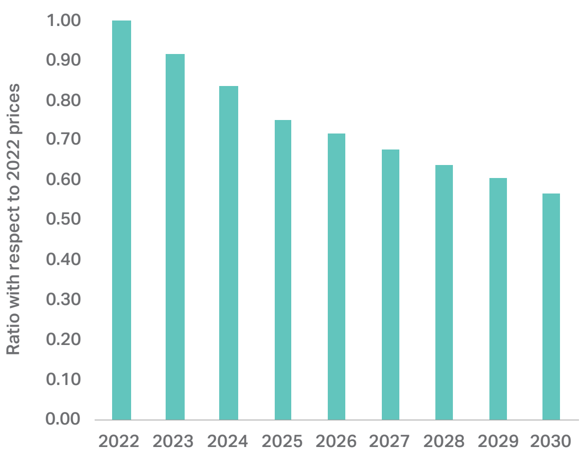
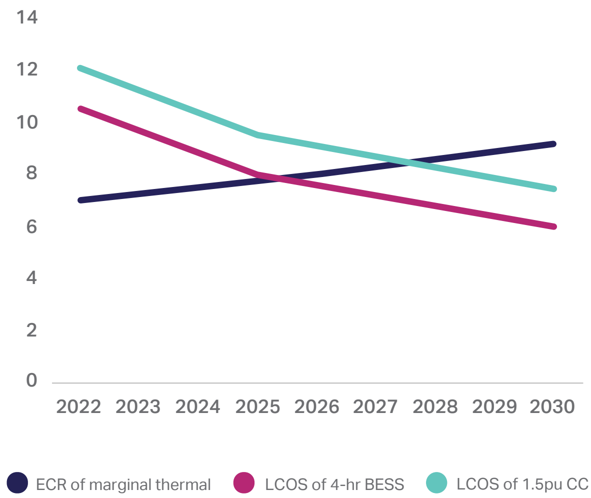


Figure 14: Energy charge rate for marginal thermal vs. levelized cost of BESS (INR/kWh)



Source: CEA (2022). Draft National Electricity Plan 2022.

VALUE STACKING OF APPLICATIONS BY DISTRIBUTION UTILITIES

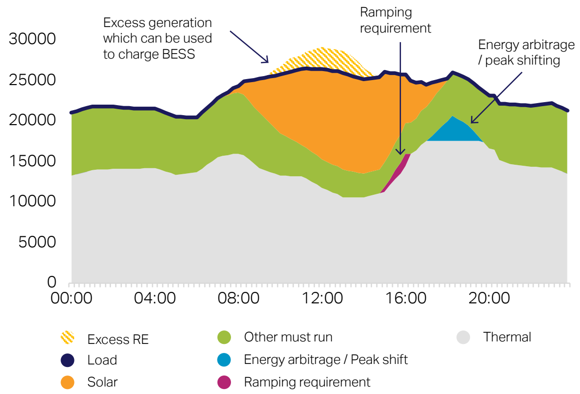
The stacking of multiple use cases is critical to unlocking the full value of energy storage. Figure 14 illustrates the value stacking of benefits for a distribution utility from the same energy storage asset. As shown, BESS can provide ramp support, energy arbitrage benefits, CAPEX deferral and minimize energy loss for distribution utilities if deployed at appropriate voltages and increase use efficiency, thereby reducing the per unit capacity cost. While each of these individual use cases may not provide adequate revenue streams to justify investment in ESS, joining these together can support the commercial viability of adoption by increasing revenue streams, resulting in more efficient use of the ESS.

For instance, if a BESS with a cycle life of 5,000 to 7,000 cycles configured for only 1 use case is used for 300 to 350 cycles a year (1 cycle operation on average in a day), at current costs, the capacity charge could be upwards of INR 14 to 15/kWh; [15] whereas, if it is possible to configure the same BESS for 2-3 use cases and the use increases to more than 550 to 600 cycles a year (2 cycle operations on average in a day), the capacity charge could decrease to about INR 10/kWh.[16]

For a value stack to become a reality, it is necessary to activate the various revenue streams of an energy storage asset by putting in place a conducive regulatory framework. For instance, there is a need to:

1. Create formal structures for the procurement of reactive power and voltage control services;
2. Estimate the amount of secondary frequency regulation required in day-ahead and real-time markets and introduce a performance and market-based mechanism for the procurement of secondary frequency regulation.

Figure 15: Value stacking of various use cases of an energy storage asset by a distribution utility



1 **Benefits from ramping support:** Coal-based thermal power generators cannot be used when there is a sudden reduction in renewable power generation due to ramping constraints.

2 **Benefits from energy arbitrage:** BESS will run at slots with peak demand and help in peak reduction. The BESS will charge when the energy cost is low and dispatch during peak power demand.

3 **Excess generation:** As the country shifts to more RE generation, there will be excess of generation at certain time intervals which can be used to charge the BESS at low cost

4 **Capacity deferral:** The battery system is used for deferring distribution capacity enhancements.

USE CASES FOR C&I CONSUMERS

There are six ESS uses cases that are appliable for C&I consumers.

At current ESS costs, the commercial viability of ESS is restricted to a few C&I consumers for just two of the use cases mentioned below: diesel abatement and enhanced renewable power procurement.

Figure 16: Possible energy storage use cases for C&I companies

	Demand charge reduction	Enhanced power quality	Diesel abatement	Enhanced renewable power procurement	Energy arbitrage	Reactive power support
USE CASE	Reduce contracted demand from distribution utilities	Frequent power supply fluctuations can lead to revenue loss	Diesel abatement for providing uninterrupted power supply	Increase utilization of existing and planned renewable power plants	Energy arbitrage by ESS provides an additional revenue stream	There is a need for local reactive power support in tail-end of distribution network to maintain adequate voltage profile
APPLICATION	ESS provides a part of peak demand and eases reduction of contracted demand from distribution utility to that extent	ESS can provide reliable power supply to consumers who are located in areas which are prone to supply quality issues	ESS can help in providing uninterrupted power supply to C&I consumers who have tight supply tolerances	ESS saves surplus renewable power for later use by consumer	ESS can be charged at negligible cost during surplus hours and can provide energy services during peak times	ESS inverter/converter has the ability to locally compensate the reactive power, hence, influence the supply voltage
VALUE STREAM	Reduction in demand charges in electricity bills	Savings in revenue loss due to improved power quality	Replacement of costilier sources of alternate supply	Reduction in power procurement cost	Time-of-use rate/market-based arbitrage	Reduction in costs of reactive power compensators

DIESEL ABATEMENT

A large number of C&I companies in India depend on diesel as a power backup source. The adoption of ESS makes commercial sense to reduce diesel consumption as a backup source for those C&I consumers who face power cuts upwards of an average of 45 minutes/day.[17] This is mostly the scenario for an industry operating in tier 2 and 3 cities (with relatively lower population- 20,000-100,000) or located in remote locations that are not well connected by the transmission and distribution network.

A BESS coupled with captive RE generation (INR ~20/kWh) would be more economical than burning diesel, which would cost INR 30-35/kWh if such power disruptions are consistent on a daily basis.

ENHANCED RENEWABLE POWER PROCUREMENT

Major C&I companies have shown a commitment to achieving net-zero carbon emissions before 2050, much in advance of the national target by 2070. To achieve these targets, such companies will need to shift to a greener portfolio much faster than the grid will. This will require the appropriate bundling of renewable power with ESS to enhance the use of existing and planned renewable power project installations by C&I consumers. However, at current BESS price points, consumers have the option to resort to procuring more renewable power through open access routes (although an option that comes with regulatory uncertainty) or through green tariffs (by paying a flat premium over the retail tariff to notionally consume more renewable power) at a much lower cost than installing behind-the-meter storage to optimally use existing renewable power plants.

The increasing adoption of internal carbon prices, which places a monetary value on carbon emissions, will make ESS adoption more commercially lucrative by apportioning a value to carbon emissions saved and adding a revenue stream for energy storage use.

For instance, JSW Energy recently won a SECI tender of 500 MW/1000 MWh BESS procurement. JSW Energy will use 40% of the merchant capacity of BESS to provide more firm renewable power supply to group companies, including JSW Steel. The group's internal carbon pricing applicability to investments and net-zero emissions goals justify the investment.[18]

While behind-the-meter installations by C&I companies are unlikely to make commercial sense in the next 2-3 years beyond diesel abatement and enhancing renewable power procurement to meet decarbonization targets, there is strong merit for most C&I companies to consider renewable power procurement bundled with energy storage through a renewable power project developer.

For instance, in Karnataka, the retail industrial tariff is INR 9.4/kWh.[19] In comparison, the landed cost of renewable power procurement on a round-the-clock basis with a minimum average capacity utilization factor of 70% (through oversizing and without energy storage) is INR 3.5 – 4.5/kWh for procurement under captive/group captive models. This would lead C&I consumers to effectively increase their RE offtake to a substantial extent but will restrict them from completely transitioning to RE. The resulting cost-savings of around INR 5.50/kWh over the retail tariff is currently inadequate to justify further investments in ESS to improve the renewable profile beyond an 80% capacity utilization factor. With a higher and monthly/block availability rather than annual criteria from C&I consumers, bundling ESS with RE could become a necessity and help these consumers transition to RE round-the-clock (RTC) profiles, even if the delivered tariff in such cases is 20-30% higher than RTC with annual availability requirements. Organizations are currently exploring such solutions as they still provide a sizeable benefit and economic rationale to shift away from grid power and structure a captive/group captive solution. Arcelor Mittal and Greenko joining hands to construct 975 MW of wind and solar bundled with pumped hydro storage to provide 250 MW of uninterrupted renewable power is a similar example.

Apart from BESS cost reductions, a change in market regulations may also support ESS adoption by C&I companies. An example is enabling aggregators to aggregate distributed energy resource (DER) providers like C&I's ESS installations to participate in energy and ancillary markets: current ancillary services regulations allow resource providers connected at 132 kV and higher voltages to participate in the ancillary services market (market-based procurement of tertiary reserves and administrative-basis procurement of secondary reserve regulation services). The introduction of aggregators that can aggregate behind the meter energy storage systems (installed at lower voltage levels) and participate in the energy and ancillary services market could add a supplementary value stream for C&I consumers.

BESS OWNERSHIP MODELS

Power system entities can reap different benefits from ESS installation via varying ownership models, depending on the type of user– a distribution utility or a C&I consumer or an RE project developer, as considered in our report, and relevant use cases. This section covers major ownership models and contractual arrangements used globally and in India for ESS installations and the suitability of various ownership models for distribution utilities and C&I consumers in India.

BESS installation setups globally have two predominant ownership models:

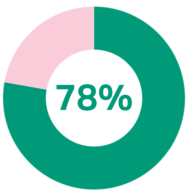
- Direct ownership
- Third-party ownership

According to the US Department of Energy database[20] of 775 grid-connected BESS installations globally (some 1.800 MW to September 2021), utilities, generators or C&I consumers have installed around 78% under direct ownership and the remaining 22% under the third-party ownership model.

The global tilt toward direct ownership is mainly because of the design of various government incentive programs, which provide part of the CAPEX investment required for ESS, with the user paying the remaining CAPEX to own the asset.

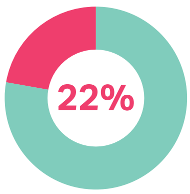
However, in recent years, the third-party ownership model has started gaining momentum. With a limited understanding of the technology solutions, and when some of the technologies are still in their nascent stage of deployment, most utilities and C&I consumers prefer third-party ownership or procuring battery-as-a-service, as these models transfer the majority of the operational and technical risks to the developers.

Figure 17: Prevailling ownership models and their global share



Direct ownership

- ✔ Outright purchase of the BESS by utility, generator or any individual
- ✔ Buyer operates it as per the desired usage
- ✔ Can be operated either by owner or a third-party



Third-party ownership

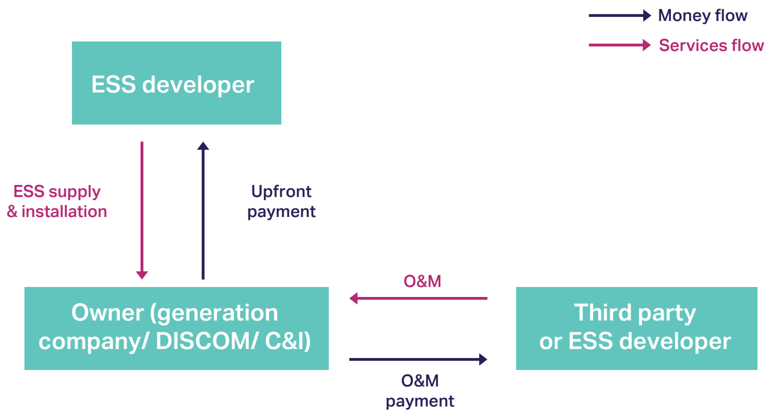
- ✔ Includes "service-contracting" without the need of owning a BESS
- ✔ Third-party develops and operates BESS facility
- ✔ Services offered as a per defined agreement

DIRECT OWNERSHIP

This model is generally suitable for procurers or consumers with large demand or generators owning a large generation asset. In this model, the end-user benefitting from the ESS actually owns the asset. The owner can decide to either outsource the operation of the ESS to a third party or handle the operations on its own.

This business model could be suitable for businesses having adequate existing or potential load requirements and relevant uses cases to optimally use a dedicated storage asset and having the ability to make an upfront CAPEX payment to the developer.

Figure 18: Direct ownership model



CONTRACT TYPES UNDER THE MODEL

The most prominent contracting arrangement under this model is the turnkey arrangement. In this arrangement, the procurer, which may be a distribution utility, C&I company or RE project developer, completes a turnkey purchase of an ESS asset from a contractor, which may be an energy storage project developer or a system integrator, at an agreed upon price. Under this arrangement, the contractor takes responsibility for all key parameters, such as performance guarantees, technical specifications of the BESS, safety guidelines and operation and maintenance. The procurer provides the contractor with access to the site and pays for its services as per the agreed-upon terms.

Key pros and cons for end users adopting direct ownership model:

Pros

- Enables higher flexibility to use the storage system as per owner requirements
- Allows additional revenue recognition opportunities that might come up from emerging use cases with time

Cons

- High capital investment due to upfront payment by the procurer
- Procurer needs to undertake technology evaluation
- Requires procurer to acquire technical and operational competencies in the absence of an O&M contract witha third party

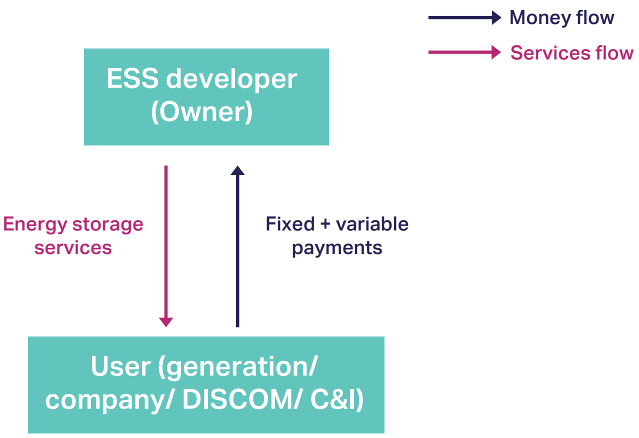
THIRD-PARTY OWNERSHIP

In this model, a third party – an energy storage project developer – develops and owns the ESS facility and provides energy storage-as-a-service to the distribution utility or the C&I consumers as per a pre-defined agreement. The third party is responsible for developing, owning, operating and maintaining the system. The end-user of the ESS pays the ESS developer two charges: a fixed capacity charge for its right to use the storage system's capacity and a variable operating charge for actual energy dispatched from the system. The variable operating charge may differ as per the use by the user. For instance, there might be provisions for the user to pay an additional charge over the base charge for using the BESS system above the agreed-upon limit in the contract between the developer and the user.

While developers provide a standard agreement, it is necessary to tailor the provisions according to the use of the end-user, requiring the end-user to be well-versed in the existing and potential use of the asset for the duration of the contract. This model would generally be favorable for customers that are not willing to invest high CAPEX in an asset and foresee a limited set of use cases for the energy storage asset in the near future.

This model is akin to the third-party open access as well as the captive and group captive models prevalent for the sale and purchase of renewable power in India.

Figure 19: Third-party ownership model



CONTRACT TYPES UNDER THE MODEL

Multiple contracting arrangements are feasible under this ownership model, including tolling agreements, capacity agreements and hybrid PPAs.

Under **tolling agreements**, the developer is responsible for developing, owning, operating and maintaining the energy storage project and retains technical operational control. In return, the end-user pays the ESS developer a fixed capacity charge for its right to use the battery's capacity and a variable operating charge for dispatching the energy.

Under **capacity agreements**, only the capacity and capacity attributes of the storage project are sold to the utility, generator or C&I company. The ESS developer is free to use the energy storage asset for its own requirements, provide ancillary services to the grid or sell energy on the power exchange. It also retains operational control of the system as well as full authority over system charging and discharging. The utility, generator or C&I company pays the ESS developer a monthly capacity charge but no variable or energy charge. The utility, generator or C&I company thus receives the assurance that capacity is there when it's needed.

Under **RE bundled with ESS**, the developer is responsible for the installation of RE generation project, which is bundled with the ESS (typically co-located). ESS is charged and discharged to moderate the variability associated with the RE to adhere to the power output requirement of the buying utility/consumer. The developer retains full authority over the charge and discharge of ESS. The developer sells the contracted energy and receives a per-unit tariff (could be fixed or with an annual escalation) from the utility/consumer. The developer is free to participate in the energy market to adjust any surplus/deficit resulting from the hybrid project.

Pros and cons for the end-users adopting third-party-owned ownership models:

- Lower operational risk as the third party is responsible for ownership and operation
- Lower capital risk as ESS deployment incurs no heavy capital expenditure

- As ESS use is limited to the agreed contract conditions, users may miss out on additional revenue opportunities from unforeseen use cases (this will depend on the contract structure)
- Since the predefined terms of the contract between the developer and ration of the system, the end-user has to be over-vigilant in drafting the contract terms and may need to invest in a third-party subject expert to review it

PROJECT EXAMPLES

BESS installations worldwide reap the benefits of the potential use cases for different power system entities. Table 7 provides a snapshot of some global BESS installations developed under different ownership models. **Annex 8** provides the details of each of these installations.

Table 7: Global BESS installations as per ownership models

Global/ domestic	Ownership model	Project	Specifications
Global	Direct ownership (utility)	**San Diego Gas & Electric – Escondido Substation Project – California**	• 30MW/120 MWh Li-ion battery system • Services provided: energy arbitrage, balancing variable generation, energy time shifting, flexible peaking capacity
Global	Direct ownership (C&I consumer)	**Inter-Continental Hotels Group Storage System – California**	• 54 kW batteries each for two hotels • Services provided: energy cost reduction, demand charge management, time-of-use mitigation
Global	Third-party ownership (utility)	**Alamitos Battery Energy Storage System – Southern California Edison**	• 100 MW/400 MWh Li-ion battery system • Services provided: energy arbitrage, grid stabilization
Global	Third-party ownership	**Moss landing battery storage project – Pacific gas & Electric Company**	• Phase 1: 300 MW/1,200 MWh Li-ion battery system • Phase 2: 100 MW/400 MWh Li-ion battery system • Services provided: grid stabilization, grid balancing, peaking capacity

Domestic	Direct ownership (C&I consumer)	**BESS at Bharat Heavy Electricals Ltd. (BHEL) R&D Center**	• Battery system:
			  • 500 kWh Li-ion
			  • 300 kWh advanced lead-acid
			  • 200 kWh flow battery
			• Services rovided: capacity firming, ramp-rate control

Domestic	Direct ownership (C&I consumer)	**Big Basket's behind-the-meter installation**	• 150 kW/281 kWh Li-ion battery system • Services provided: Power backup

Domestic	Third-party ownership	**Puducherry Battery Energy Storage System – PGCIL**	• Package 1: 500 kW/250 kWh advanced lead-acid system
			• Package 2: 500 kW/250 kWh Li-ion battery system
			• Services provided:
			  • Under operation: frequency regulation, energy time shift
			  • Under implementation: dynamic frequency regulation, RE capacity firming, load following renewable peak shaving, voltage/reactive power support, integrated applications

Domestic	Third-party ownership	**AES and Mitsubishi Corporation – TPDDL Project**	• 10 MWh Li-ion battery system • Services provided: deviation settlement mechanism (DSM) penalty reduction, frequency regulation, grid balancing service, RE integration & energy time shift
Domestic	Third-party ownership	**Nexcharge Community Energy Storage System – TPDDL**	• 150 kW/528 kWh Li-ion battery system • Services provided: reactive power support, peak shaving, volt-amps reactive (VAR) compensation, frequency response, emergency backup

3 Conclusion

3 Conclusion

As countries and businesses devise their action plans to meet their respective decarbonization targets with a high percentage of their power requirements coming from renewable power, energy storage will become a critical solution for both power grids and C&I companies. The attributes of energy storage solutions, including fast response capabilities, suitability to meet peak power load requirements and the ability to make renewable power supply firmer, make them critical to solving the renewable power procurement challenges of distribution utilities and C&I companies in India.

While the need to adopt energy storage solutions is evident, the biggest barrier to large-scale adoption is their existing price levels, specifically of more advanced technologies such as BESS. At current price levels, energy storage makes commercial sense for distribution utilities for two use cases: meeting peak load requirements and procuring more firm renewable power from RE generators. Given the cost differential of contracting thermal power plants at INR 55/kWh compared to ESS adoption at INR 25/kWh to meet instantaneous and second peak load requirements, distribution utilities should not even consider contracting new thermal power to do so.

For C&I companies, the commercial viability of energy storage applications at current costs has been mostly restricted to diesel abatement and, in some instances, the procurement of more firm renewable power (supplying power for more than 70% of the time in a year). With the government and C&I companies issuing increasing number of tenders to procure more firm and peak power from renewable electricity solutions enabled by ESS bundling, many industries are actively exploring the procurement of more firm renewable power. Going forward, C&I companies should include requirements for monthly and daily power supply availability from renewable sources to be met in a technologically agnostic manner in their power procurement tenders. This is likely to yield promising results in terms of RE bundled with ESS projects.

For both distribution utilities and C&I companies, value stacking of various use cases to increase ESS use is currently the best bet to optimize revenue streams from the same ESS asset and make it commercially more attractive to adopt.

Based on our analysis, we call on:

- Distribution utilities in India to evaluate the business case for energy storage before contracting new thermal power plants for peak power requirement.
- Both distribution utilities and C&I companies to issue technology-agnostic tenders for procurement of more stable renewable power, to enable achievement of their renewable power procurement targets in the most cost-effective manner.
- RE generators, distribution utilities, C&I companies and ESS project developers to work collectively to standardize energy storage procurement contracts.

Looking ahead, with the expected reductions in BESS prices (28-58% by 2027) due to rapid technological advancements and economies of scale, a number of other use cases, such as energy arbitrage, participation in the ancillary services market, network upgrade deferral and ramping up support, will also become applicable for their large-scale adoption by distribution utilities and C&I companies.

Apart from price reductions, which will play a crucial role in enabling the large-scale adoption of energy storage, a more conducive market and regulatory framework can also help accelerate deployment and bring forward the large-scale adoption of energy storage.[21]

India is currently at a major turning point in its electricity transition. Energy storage systems are poised to be one of the main enablers of the transition from a fossil fuel-dominant electricity market to a RE-dominant market in the future. As this new solution makes inroads into the Indian power system, stakeholders on the supply and demand sides need to increase their understanding of the solutions and ways to evaluate the benefits compared to the costs of adoption.

Annexes

Annex 1: List of PSP and BESS projects and installations

Operational pumped hydro storage projects in India

Name of the project	State	Installed capacity (MW)
Kadamparai	Tamil Nadu	400
Bhira	Maharashtra	150
Srisailam LBPH	Telangana	900
Purulia PSS	West Bengal	900
Ghatghar	Maharashtra	250
Kadana St. I&II	Gujarat	240
Nagarjuna Sagar	Telangana	706
Sardar Sarovar	Gujarat	1,200
		4,745

Source: CEA(2022), "Status of Pumped Storage Development in India", Interactions with concerned state utilities

Pumped hydro storage projects in India that are under-construction or under planning

Project	Location	Size (MW)	Status	Expected commissioning
Tehri St.-II	Uttarakhand	1.000	Under construction	By 2030
Kundah (Stage I, II, III & IV)	Tamil Nadu	500	Under construction	
Koyna Left Bank	Maharashtra	80	Construction is held up	
Turga	West Bengal	1.000	detailed project report con-curred by CEA	Beyond 2030
Bandu	West Bengal	900	4 prospective developers selected through invitation of request for quote	
Pinnapuram	Andhra Pradesh	1.200	Under examination in CEA	
Upper Indravati	Odisha	600	Under survey & investigation	
Upper Kolab	Odisha	320	Under survey & investigation	
Balimela	Odisha	500	Under survey & investigation	
Upper Sileru	Andhra Pradesh	1.350	Under survey & investigation	
Kodayar	Tamil Nadu	500	Under survey & investigation	
Sillahalla St.-I	Tamil Nadu	1.000	Under survey & investigation	
Sharavathy	Karnataka	2.000	Under survey & investigation	
Saundatti	Karnataka	1.260	Under survey & investigation	
MP30 Gandhi Sagar	Madhya Pradesh	1.440	Under survey & investigation	
Warasgaon	Maharashtra	1.200	Under survey & investigation	

Source: CEA(2022), "Status of Pumped Storage Development in India", Interactions with concerned state utilities

BESS projects in India

Project developer/sponsor	Capacity	Location	Status
Central Electronics Ltd. (CEL)	500 kWh/1,000 kW(electrochemical)	Uttar Pradesh	Tendered
National Thermal Power Corporation (NTPC)	17 MW solar PV + 6.8 MWh/6.8 MW BESS	Andaman & Nicobar Islands	Tendered
Railway Energy Management Com-pany Ltd. (REMCL)	14 MWh/7 MW	Nagpur	Tendered
SECI	160 MW wind-solarHybrid + 20 MWh/10 MW BESS	Andhra Pradesh	Tendered
SECI	20 MW floating PV + 60 MWh BESS	Lakshadweep	Tendered
SECI	20 MW solar PV + 50 MWh/20 MW BESS	Leh, Ladakh	Tendered
SECI	100 MW solar + 150	Chhattisgarh	Tendered
SECI	MWh/50 MW BESS 2,000 MWh		Tendered
SECI	1,000 MWh/500 MW (electrochemical)	Pan-India	Tendered
Solar Energy Corporation of India (SECI) Ltd.–HPSEBL	2.5 MW solar wind hybrid project + 1,000 kWh/100 kW BESS	Himachal Pradesh	Tendered
Tamil Nadu Generation and Distri-bution Corporation Ltd. (TANGEDCO)	1 MW solar PV + 3 MWh/1 MW BESS	Tamil Nadu	Tendered
SECI	2 x 21 MWh/7 MW	Leh & Kargil	Announced
NTPC	4 MW solar PV + 1,000 kWh/1,000 kW BESS	Delhi	Announced
ACME Cleantech Solutions Pvt. Ltd.	270 kWh/250 kW (electrochemical)	Gurgaon, Haryana	Commissioned
Gram Power	3,000 kW (electrochemical)	Rajasthan	Commissioned
Imergy Power Systems	120 kWh/30 kW (vanadium flow battery)	Karnataka	Commissioned
SciEssence International	5 GJ (1,400 kWh/15,000 kW) giga capacitor-based (electrochemical)	Telangana	Commissioned
Bharat Heavy Electricals Ltd. (BHEL)	500 kW(Li-ion), 100kW(advanced lead-acid), 50 kW (flow)	Telangana	Commissioned
CEL–Exicom	160 kWh/40 kW (advanced lead-acid)	Uttar Pradesh	Commissioned
CEL–Raychem RPG	350 kWh (Li-ion) and 150 kWh (flow battery)	Uttar Pradesh	Commissioned
CEL–Raychem RPG	500 kWh/1,000 kW (Li-ion)	Uttar Pradesh	Commissioned
Electricity Department of Govern-ment of Puducherry	1,000 kWh/250 kW (electrochemical)	Puducherry	Commissioned
Neyveli Lignite Corporation Ltd. (NLC) and Larsen & Toubro (L&T)	20 MW solar PV + 8 MWh/16 MW BESS (Li-ion)	Andaman and Nicobar Islands	Commissioned
PGCIL–Zhejiang Narada	250 kWh/500 kW (advanced lead-acid)	Puducherry	Commissioned
PGCIL–Zhejiang Narada	250 kWh/500 kW (Li-ion)	Puducherry	Commissioned
Tata Power Delhi Distribution Limited (TPDDL)— AES (Fluence)	10,000 kWh/10,000 kW (Li-ion)	Delhi	Commissioned

Project developer/sponsor	Capacity	Location	Status
Andhra Pradesh Eastern Power Distribution Company Ltd. (APEPDCL)	5 MW solar PV, 4 MWh BESS (Li-ion)	Andhra Pradesh	Announced
SECI	2 x 21 MWh/7 MW	Leh & Kargil	Announced
NTPC	4 MW solar PV + 1,000 kWh/1,000 kW BESS	Delhi	Announced
NTPC	8 MW solar PV+ 3.2 MWh/3.2 MW BESS	Andaman & Nicobar Islands	Announced
NTPC	1,000 MWh	Pan-India	Announced
Panasonic India Pvt. and AES India Private Ltd.	10,000 kWh/10,000 kW (electro-chemical)	Haryana	Announced
SECI & Andhra Pradesh Southern Power Distribution Company Ltd. (APSPDCL)	2,500 kWh/5,000 kW	Andhra Pradesh	Announced
SECI and Karnataka Solar Power Develop-ment Corporation Ltd. (KSPDCL)	4 X 2,500 kWh/5,000 kW	Karnataka	Announced
Sun Source Energy	4 MW solar + 1 MWh/2 MW BESS	Andaman & Nicobar Islands	Announced
Tamil Nadu Generation & Distribution Com-pany (TANGEDCO)–Larsen & Toubro (L&T)	125 kW (electrochemical)	Tamil Nadu	Announced
Tata Power	100 MW solar + 120 MWh/40 MW BESS	Chattisgarh	Announced
SunCarrier Omega Pvt. Ltd. & Gildemeister	45 kW (electrochemical)	Madhya Pradesh	
Tata Power and Delectrik	40 kW (vanadium redox flow)	Delhi	
TMEIC Industrial Systems India Private Ltd.	750 kW (Li-ion)	Karnataka	

Source: IESA (2021), "Overview of ESS Tenders & Projects India" , Shakti Foundation(2022), "Energy Storage at the Distribution Level – Technologies, Costs and Applications", Interactions with concerned state utilities

Annex 2: Concessions on open access charges for RE procurement

Concessions on open access charges for RE procurement

State	Open access charges (applicable for both 3rd party and captive)	Banking provision	Cross subsidy surcharge (applicable only for 3rd party)	Additional surcharge (applicable only for 3rd party)
Gujarat	• Captive (hybrid): 50% of wheeling charges & losses • Captive (wind and solar): no concessions • Third party: no concessions	• Wind: monthly • Solar: intraday for high tension (HT)/extra-high voltage (EHV); monthly for low tension (LT) • Banking charges: varies between 1.10-1.50 per unit	• Wind and solar: no concessions • Hybrid: 50% of cross-subsidy surcharge and additional surcharge	• Wind and solar: No concessions • Hybrid: 50% of cross-subsidy surcharge and additional surcharge
Odisha	20% of normal charges and 100% of normal losses	Not defined	Exempted	Zero
Tamil Nadu	50% of normal charges and 100% of normal losses	Monthly No banking charges	70% of normal charges	Zero
Chhattisgarh	Charges exempted Total losses capped at 6%	Yearly, drawl not allowed in peak months 2% of banked energy	Solar: exempted Wind: 50% of charge	Zero
Uttar Pradesh	50% of normal charges and 100% of normal losses 100% exemption of intra-state transmission system transmission charges for ISTS project	Yearly 6% of energy banked	No concessions 100% exemption for ISTS	Zero
Karnataka	Solar projects: 100% of normal charges and losses Wind projects: 25% of transmission and wheeling charges, 100% of losses	Annual Banking charges 2% of the energy injected	No concessions	25% of normal charges
Madhya Pradesh	No concessions	Banking charges 2% of the energy injected	No concessions	No concessions

Source: State open access policies

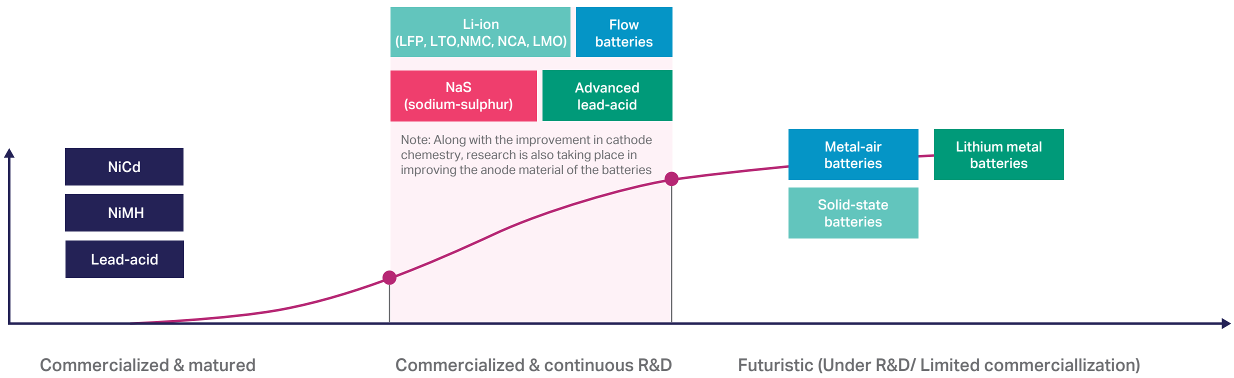
Annex 3: Existing and emerging battery technologies

An understanding of battery technologies is vital for end-users to grasp their suitability for different applications. The following section highlights the various battery technologies, their pros and cons, key technical features and cost projections.

BATTERY TECHNOLOGY LANDSCAPE

Following is a high-level summary of key chemistries and their market maturity stages.

Figure 20: Stages of maturity and commercialization of key battery technologies



Source: Deloitte analysis

The Li-ion battery technology dominated the energy storage market among advanced technologies in 2020 and 2021, across the total global BESS installations.[22] There also has been a move toward Li-ion battery technologies as observed from recent stationary storage installations in India. The market for various Li-ion chemistries is split as per the required use cases of battery energy storage systems, as explained in the table below.

Battery type	Characteristics	Key applications
Energy cell (NMC, LCO, NCA)	• Can deliver a steady amount of power but enough energy to operate for longer periods of time • Can store large amount of energy	• Emergency backup services • Peak shaving • Continuous discharge to meet expected deviations from schedules • Energy arbitrage
Power cell (LFP, LMO, LTO))	• Can deliver a quick burst of power in a short time frame and a lot quicker than energy cell	• Ramping support to meet load variations • Firming variable output from generation • Frequency regulation • Demand charge reduction

The choice of battery chemistry depends on the application required. However, it is possible to alter battery materials in one battery type to improve performance, for instance by mixing power cell materials with that of an energy cell to achieve improved performance and serve multiple applications.

There are other promising technologies, such as lithium-polymer, metal-sulfur, lithium-metal and metal-air, which show promising energy density and cycle life. These technologies have, however, certain shortcomings as highlighted below, which have restricted their large-scale commercialization. In spite of that, continuous R&D and pilot deployments have been done to test such technologies.

- 980 MWh sodium-sulfur batteries are operational in various locations, such as Japan, Italy and the United Arab Emirates. Terna has deployed such batteries in Italy. NGK, Kyushu Electric Power Co. and Futamata Wind Development Co. have deployed sodium-sulfur batteries in Japan.
- Hokkaido Electric Power installed a 60 MWh flow battery in Japan.
- Companies such as Guodian Longyuan (Shenyang) Wind Power Co., Ltd., State GridCorporation of China (SGCC) and State Grid North China have installed a cumulative 26 MWh flow battery in China.
- Antigua and Barbuda have seen the installation of 12 MWh flow batteries.
- A total of 920 MWh in flow batteries are under construction in China, Canada and Kazakhstan.
- Raychem installed a flow battery system for CEL in Uttar Pradesh, India for a capacity of 150 kWh.

Key technical characteristics of some of the most prominent battery technologies

Battery type	Energy density (Wh/kg)	Power density (W/kg)	Cycle life (cycles)	Round-trip efficiency	Applications
Lead-acid batteries	30-50	30-50	500-1.000	79-90%	EVs, stationary storage, forklifts & sweeper trucks, marine, telecom towers
Advanced lead-acid batteries	30-50	180	2.500-4.500	79-90%	EVs, grid service, other commercial applications
Li-ion	100-325	4.000-6.500	1.000-4.000	85-95%	EVs, stationary storage, consumer electronics, medical applications
Flow battery	10-70	0.5-2	12.000-14.000	60-85%	Grid service, renewable integration, backup power and uninterruptible power source
High-temperature battery	150-240	120-160	2.500-4.500	70-90%	Grid service, railway, space
Nickel-cadmium	45-80	150	2000	70%	Standby power, aircrafts
Nickel-metal-hydride batteries	60-120	250-1.000	700-1.000	66-92%	Mobile phones, digital camera, EVs
Metal-air battery	350-500	100	>1.000	<60%	Grid service, EVs
Solid-state batteries	>1.000	N/A	Up to 10 years	N/A	EVs, grid service, consumer electronics
Sodium-ion batteries	160	N/A	~3.000	92%	Grid service, EVs

Lithium-ion batteries will be the mainstay for grid applications by virtue of their superior performance characteristics. However, technologies such as sodium-ion, solid-state and metal-air are under development and will emerge as potential alternatives in the future.

The section below covers details of various battery technologies.

LEAD-ACID BATTERY

A lead-acid battery is the least expensive and one of the oldest rechargeable batteries available on the market. It contains lead dioxide in the positive plate, lead in the negative plate and an electrolyte solution with a high concentration of aqueous sulfuric acid in a charged state.

Pros and cons of lead-acid batteries:

- Typically have a lower purchase cost (average cell cost of USD $65/KWh) and installation costs
- More tolerant to overcharging, making them less prone to catching fire or exploding compared to lithium-ion batteries
- Have a temperature tolerance of -40° C to +50° C.

- Most are heavy
- Risk of sulfation due to insufficient charging at times, meaning some lead sulphate does not recombine into electrolyte and coverts into stable crystalline form that does not dissolve on recharging, resulting in longer charging times, low efficiency and higher battery temperature
- Lead and sulfuric acid both can contaminate soil and groundwater if they leak, which can further cause fire, explosion and damage ecosystems

ADVANCED LEAD-ACID BATTERY

Advanced lead-acid batteries have significantly improved charge-discharge performance while retaining the high-power density of lead-acid batteries. These batteries have increased reliability and safety but it cannot cope with some of the more complex working conditions.

Pros and cons of advanced lead-acid batteries:

- A longer cycle life (2,500-4,500 cycles) compared to lead-acid batteries (500-1,000 cycles)
- Reduction in sulfation compared to lead-acid batteries
- Wide temperature tolerance range (-30°C to +65°C)

- Prone to serious environmental concerns due to use of toxic lead
- Technology still under development and experimentation phase

LITHIUM-ION BATTERY

Lithium-ion batteries are far superior to lead-acid batteries in terms of energy density, power, cycle life and charge/discharge rate. Further, Li-ion batteries are considered more reliable with low maintenance costs.

Pros and cons of lithium-ion batteries:

- Compact size, compared to bulky lead-acid batteries
- Longer service life (1,000-4,000 cycles) compared to lead-acid batteries (500 – 1,000 cycles)
- Faster charging rate compared to lead-acid batteries
- Prone to memory effects, meaning that after repeated charging/ discharging, some batteries memorize the decreased life cycle; thus, with every subsequent charge, it will have a shorter operating life
- Lower self-discharging rate of 0.35 – 2.5% compared to lead-acid batteries, which have a self-discharge rate of 5%

- Protection circuitry needed to establish safe operation limits because overcharging can create unstable conditions inside the battery, increasing pressure and causing thermal runaway
- Unusable after deep discharge, which could potentially damage the lithium-ion battery permanently
- Sensitivity to high temperatures and must not be charged above 45°C and discharged above 60°C
- Raw material security, as key materials used include lithium and nickel, both of which have very low identified reserves globally; cobalt, although available in abundance, is largely concentrated (70% of all reserves) in Congo, which poses huge supply chain risks

Based on the material used to manufacture the cathode and anode, Li-ion batteries are classified in multiple categories.

Figure 21: Key technical characteristics of Li-ion chemistries

	LFP	NMC	LCO	NCA	LMO	LTO
	Lithium Iron Phosphate	Nickel Cobalt Manganese Oxide	Lithium Cobalt Oxide	Lithium Nickel Cobalt Aluminium Oxide	Lithium Manganese Oxide	Lithium Titanate
Anode	Graphite	Graphite + Silicon	Graphite	Graphite	Graphite	LTO
Energy density (WH/ KG)	140-180 Wh/kg	150-220 Wh/kg	150-200 Wh/kg	150-260 Wh/kg	100-150 Wh/kg	<110 Wh/kg
Discharge (C-rate)	1C; 25C possible	1C; 2C possible	1C	1C typical	1C; 10C possible	10C possible
Cycle life	>2000	>2000	~1000	>1000	~1000	3000 - 7000
	Very flta voltage discharge curve but low capacity	Provides high capacity; most preferred chemistry for many applications	Very high specific energy, limited specific power; cobalt is expensive; serves as Energy cell	Shares similarities with Li-cobalt; Serves as Energy Cell	High power but less capacity; Safer than Li-cobalt; Commonly mixed with NMC to improve performance	Lon life, fast charge, wide temperature rande, low specific energy and expensive
	Preferable for applications where high power is required for short durations	Preferable for applications where energy is required to be discharged for long durations	Preferable for applications where energy is required to be discharged for long durations; It is costly due to cobalt	Preferable for applications where high power is required for short durations; It is costly due to cobalt	Preferable for applications where high power is required for short durations; High-current discharging capacity is useful for utilities	Preferable for applications where high power is required for short durations;
Use	**Power cell**	**Energy cell**	**Energy cell**	**Energy cell**	**Power cell**	**Power cell**
Utility compability	✓	✓	✗	✗	✓	✓
Industrial compability	✓	✓	✗	✓	✗	✓

Lithium-iron-phosphate (LFP) and nickel-manganese-cobalt (NMC) have been the preferred chemistries in the Li-ion family for grid-scale and industrial applications. However, other chemistries such as lithium-metal-polymer (LMP) and lithium-titanate-oxide (LTO), by virtue of their high discharge rate and cycle life, also show significant potential for adoption.

FLOW BATTERY

A flow battery is an electrochemical device that converts the chemical energy in the electro-active materials directly to electrical energy. The electro-active materials in a flow battery, however, are stored mostly externally in an electrolyte and are introduced into the device only during operation. Most redox flow batteries consist of two separate electrolytes, one storing the electro-active materials for the negative electrode reactions and the other for the positive electrode reactions. An ion-selective membrane is often used to prevent mixing or cross-over of the electroactive species, which results in chemical short-circuit of electro-active materials.

Pros and cons of flow batteries:

- A lower levelized cost of storage means these batteries easily offer a service life of 25 years and have much lower operating cost than lithium-ion batteries
- Can operate in wide ambient conditions (-10 to 60°C) without requirement for air conditioning or ventilation compared to utility scale lithium-ion batteries
- Non-flammable, non-toxic and have lesser risks of explosion, unlike lithium-ion batteries

- Require larger tanks to store the liquid electrolyte, which increases the overall weight
- Complex battery systems as they require pumps, sensors, secondary containment vessels, etc. for operation, making the battery system larger and heavier and hence involve additional maintenance

HIGH TEMPERATURE BATTERY SUCH AS SODIUM-SULFUR AND LITHIUM-SULFUR

These batteries have a unique combination of high energy, long life, high-power density and low-cost materials to solve grid-scale electricity storage problems. The components of these high-temperature batteries remain solid at room temperature and can be stored inactive for a long period of time. During activation at high temperatures, the anode, cathode and electrolyte layers spread due to their immiscibility and relative densities.

Pros and cons of high temperature batteries:

- Lower cost compared to lithium-ion batteries
- Such batteries are immune to degradation of microstructural electrode
- Have the capability to store energy for long hours
- Key raw material is sodium, which is available in abundance

- Active cell components are highly corrosive
- Leads to possibility of solubility of metal electrodes in molten salt
- Require a heat source to maintain operational conditions, which also drains battery efficiency
- Presence of a heat source makes it immobile, even for residential purposes

Other battery technologies

METAL-AIR BATTERY

Metal-air batteries have metal anodes with an aqueous or non-aqueous electrolyte. It creates voltage from the availability of oxygen molecules (O_2) at a cathode which reacts with positively charged metal ions to form oxide and generate electric energy.

Pros and cons of metal-air batteries:

Pros:

- Less charging time (10 mins) compared to lithium-ion battery or any other chemistry
- Higher energy density (350-500 Wh/Kg) compared to lithium-ion batteries (100-325 Wh/Kg)

Cons:

- Dendrite formation during the charging cycle, where the chemical and electrochemical processes drive a complex reaction resulting in the deposition of dendrites inside the battery, which could lead to short-circuits
- Anode corrosion can happen due to presence of air
- Has low round trip efficiency

SOLID-STATE BATTERIES

A solid-state battery uses both solid electrodes and solid electrolytes instead of the liquid or polymer gel electrolytes used in other Li-ion batteries. Solid-state batteries are futuristic, highly advanced, next-generation batteries that deliver high performance and safety.

Pros and cons of solid-state batteries:

Pros:

- Non-toxic compared to other battery technologies
- Very low self-discharge rate of 1.5-2% compared to lithium-ion batteries, which have a self-discharge rate of less than 5%
- Are safer and more stable than lithium-ion batteries with liquid electrolytes
- Possess high energy density
- Non-flammable
- Have high cycle life

Cons:

- Mass production and manufacturing methods are quite expensive and complex compared to other battery chemistries
- Less conductivity at low temperature
- Dendrite formation is common during electrodeposition during the charging and discharging cycle

SODIUM-ION BATTERY

A sodium-ion battery (SiB) uses the same principle as lithium-ion batteries, in which sodium ions shuffle between cathode and anode for energy charge and discharge. The major electrolytes used in SiBs are sodium-based NaFP6 rather than the LiFP6 used in lithium-ion batteries.

Sodium-ion, solid-state, metal-air, etc. are emerging chemistries and offer multiple advantages compared to conventional Li-ion chemistries. However, their full-scale commercialization depends on R&D efforts and is expected in the long-term.

Pros and cons of sodium-ion batteries:

- Low cost compared to lithium-ion batteries as it does not use Rare Earth materials and involves raw materials that are abundantly available in comparison to lithium-ion batteries
- Can operate in broader operating temperatures
- Has the capability to be transported at zero volts compared to Li-ion batteries, which need to retain a certain level of charge to preserve performance
- Has higher cycle life

- Has lower energy density compared to Li-ion batteries
- Has a lower operating voltage since sodium has less ionization potential
- Heavier than lithium-ion batteries

Annex 4: Detailed methodology for state ranking in FTM storage adoption

Step 1 – Determining yearly cost of BESS deployment and operation:

- Annualized average fixed cost (AFC) of BESS determined using assumptions on BESS deployment and financing arrangements
- Per unit cost of AFC of BESS determined to 2030 using assumptions on cycle life, round-trip efficiency and depth of discharge (DoD)
- Cost of BESS charging through RE estimated

Step 2 – Determining the year of BESS deployment based on deviation settlement mechanism (DSM) penalty savings

- Per unit DSM penalty for top 10 paying states since 2019 determined and compared with per unit cost of BESS deployment and operation
- Year in which per unit cost of BESS deployment is less than per unit DSM considered as ideal for BESS adoption

Step 3 – Determining ideal year for BESS deployment based on expiring PPAs and increasing demand

- Expiration year of long- and medium-term power purchase agreements (PPAs) determined for RE-rich states, with a focus on PPAs expiring before 2030
- The year in which 70% of demand exceeds the quantum of contracted supply determined

SHARE OF RE IN OVERALL ENERGY MIX

Overall installed capacity of the states and share of RE in the overall installed capacity ascertained.

States then ranked based on the share of RE in the overall energy mix.

Percentage of RE in overall energy mix of states

Rank	State	Installed RE capacity (MW)	% share of RE
1	Karnataka	15912	52
2	Rajasthan	17513	51
3	Tamil Nadu	16460	46
4	Gujarat	17108	39
5	Andhra Pradesh	9214	36
6	Telangana	4965	28
7	Maharashtra	10694	24
8	Madhya Pradesh	5485	22
9	Uttar Pradesh	4485	15
10	Punjab	1768	12

DSM PENALTY AND GROWTH ASSESSMENT

Top 10 states identified based upon the DSM penalties paid by them and growth of these penalties. The process to identify the top states included the following key activities:

- State DSM data (yearly) collected
- States analyzed to understand the status of over-withdrawal or under-withdrawal of the energy by the state in the past
- Average penalty paid and growth trend observed in additional DSM penalty and sign change penalty
- Then top 10 states initially identified based on their average penalty payment data
- Final ranking for the states provided based on the percentage growth in the penalties from 2019 calendar year (CY) onwards

State Ranking based on DSM penalty and growth assessment

Rank	State	Average DSM penalty (INR Cr) (2019 onwards)	Growth (%)
1	Rajasthan	88.47	-43.47%
2	Uttar Pradesh	115.21	-46.59%
3	Haryana	49.18	-46.76%
4	Tamil Nadu	61.51	-65.73%
5	Himachal Pradesh	37.11	-66.98%
6	Maharashtra	43.06	-69.47%
7	Gujarat	59.95	-71.19%
8	Punjab	41.62	-71.72%
9	Madhya Pradesh	39.68	-72.96%
10	Jammu & Kasmir	69.87	-82.78%

PPA REPLACEMENT OPPORTUNITY

Next we analyzed the states to understand the PPA replacement opportunities presented by each state. The process to identify the top states included following key activities:

- The first step included collecting the data on existing PPAs;
- The next step involved sorting of the PPAs on the basis of their expiration date (year);
- The final step was to rank the states on the basis of capacity tied-up with PPAs expiring on or before 2030.

PPA replacement opportunity

Rank	State	PPA size expiring by 2030 (MW)	Total number of PPAs
1	Tamil Nadu	2672	13
2	Andhra Pradesh	2500	5
3	Maharashtra	1247	7
4	Madhya Pradesh	1155	7
5	Telangana	570	1
6	Chhattisgarh	359	9
7	Punjab	300	1
8	Gujarat	250	1
9	Bihar	240	1
10	New Delhi	104	2
11	West Bengal	60	1
12	Odisha	10	1
13	Sikkim	10	2

LOAD DURATION CURVE VS LONG-TERM PPAS

The last parameter for assessment of the states included identifying the year when the installed capacity of the state would fall short of meeting the peak load of the state:

- The first step included data collection on load generation (slot), installed capacity (thermal, RE, etc.), declared capacity for the states;
- The next step involved slot demand projection for the coming years using percentage escalation of demand and plotted load duration curve (escalation rate taken as per CEA's 19th Electric Power Survey Report);
- The load met from long-term PPAs (tied up with the state) then determined
- Next the year in which the contracted capacity of that state falls short of meeting 70% of the load estimated;
- Finally, states ranked based on how early the milestone is reached by any particular state in the country.

Timeline when installed capacity falls short of meeting 70% of peak load

	State	Year when installed capacity would fall short of meeting 70% of the load
1	Telangana	2022
2	Kerala	2024
3	Maharashtra	2022
4	Tamil Nadu	2023
5	Karnataka	2023
6	Madhya Pradesh	2026
7	Rajasthan	2028
8	Andhra Pradesh	2028
9	Gujarat	2028

DSM penalty and growth assessment

Rank	State (1/2)	Avg. Penalty (INR Lakh)	Growth (%)
1	Uttar Pradesh	11,520.66	- 47%
2	Rajasthan	8,846.74	-43%
3	Jammu And Kashmir	6,986.72	-83%
4	Tamil Nadu	6,150.73	-66%
5	Gujarat	5,995.06	-71%
6	Haryana	4,917.86	-47%
7	Maharashtra	4,305.87	-69%
8	Punjab	4,161.98	-72%
9	Madhya Pradesh	3,967.67	-73%
10	Himachal Pradesh	3,711.01	-67%
11	Andhra Pradesh	3,690.98	-58%
12	Telangana	3,357.31	-66%
13	Bihar	3,326.72	-10%
14	Delhi	3,286.48	-92%
15	Uttarakhand	2,998.82	-76%
16	Karnataka	2,978.88	-62%
17	Orissa	2,740.64	-64%

DSM penalty and growth assessment

Rank	State (1/2)	Avg. Penalty (INR Lakh)	Growth (%)
18	West Bengal	2,630.61	- 28%
19	Chhattisgarh	2,291.81	-81%
20	Arunachal Pradesh	2,144.86	-99%
21	Chandigarh	1,209.78	-96%
22	Assam	1,168.37	-91%
23	Jharkhand	1,054.70	-59%
24	Goa	978.67	-97%
25	Tripura	696.22	-88%
26	Nagaland	684.16	-98%
27	Mizoram	666.03	-98%
28	Puducherry	406.08	-84%
29	DNH	351.61	-92%
30	Manipur	330.61	-95%
31	Kerala	264.52	-81%
32	D&D	242.63	-83%
33	Meghalaya	229.61	-81%
34	Sikkim	151.77	-85%

Starting year of DSM savings opportunity

Overall BESS cost (capacity + energy)									
BESS purchase year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Overall BESS cost (capacity + energy) (Rs./ kWh)	6.31	5.84	5.42	5.02	4.66	4.32	4.02	3.73	3.47

Sr.No	State	Total penalty paid (Rs. Cr)	Total overdrawal units (kWh)	Penalty per unit (Rs./ kWh)	Starting year
1	Rajasthan	112.94	550182958	2.05	2026
2	Uttar Pradesh	150.19	293028117	5.13	2025
3	Haryana	64.18	179894014	3.57	2030
4	Tamil Nadu	91.62	507836631	1.8	NA
5	Himachal Pradesh	55.80	286005873	1.95	NA
6	Maharashtra	65.97	434735179	1.52	NA
7	Gujarat	93.09	401926430	2.32	NA
8	Punjab	64.89	177344300	3.66	2030
9	Madhya Pradesh	62.46	340800421	1.83	NA
10	Jammu and Kashmir	119.20	119521069	9.97	2021
11	Andhra Pradesh	51.95	396947683	1.31	NA

Details of PPAs expiring before 2030:

State-wise PPAs expiring by 2030:

Sr. No.	State	Capacity (MW)	No. of PPAs
1	Tamil Nadu	2.672	13
2	Andhra Pradesh	2.500	5
3	Maharashtra	1.247	7
4	Madhya Pradesh	1.155	7
5	Telangana	570	1
6	Chhattisgarh	359	9
7	Punjab	300	1
8	Gujarat	250	1
9	Bihar	240	1
10	Delhi	104	2
11	West Bengal	60	2
12	Odisha	10	2
13	Sikkim	10	1

Power demand vs long-term PPAs:

State	Effective capacity 2021 (MW)	Demand during 70% of the time (MW)								
		2022	2023	2024	2025	2026	2027	2028	2029	2030
Telangana	9,867	9,947								
Kerala	3,671	3,467	3,634	3,808						
Maharashtra	23,152	24,215								
Tamil Nadu	16,165	15,321	16,228							
Gujarat	22,453	16,577	17,572	18,626	19,744	20,928	22,184	23,515		
Karnataka	10,311	10,251	10,808							
Rajasthan	14,250	10,580	11,186	11,827	12,505	13,221	13,979	14,780		
Andhra Pradesh	14,943	9,289	9,975	10,712	11,504	12,345	13,267	14,247		
Madhya Pradesh	12,751	10,331	10,973	11,656	12,381	13,151				

Annex 5: Distribution of captive generation capacity by state

Distribution of captive generation capacity by state

State	No. of industries	Total captive (MW)	Wind captive (MW)	Solar captive (MW)	RE (solar & wind) as % of total captive
Andhra Pradesh	290	11,391	19	19	1.2%
Assam	47	8,299	0	6	1.2%
Bihar	31	8,137	0	1	0.4%
Chandigarh	21	6,767	0	1	1.3%
Chhattisgarh	130	6,647	0	31	0.5%
Gujarat	523	6,240	636	132	8.5%
Haryana	545	6,120	0	56	2.3%
Himachal Pradesh	160	3,694	0	5	1.1%
Karnataka	488	3,121	155	187	5.7%
Kerala	87	3,014	0	2	0.4%
Madhya Pradesh	199	2,548	217	8	2.7%
Maharashtra	357	1,831	327	345	11.6%
Odisha	296	1,545	0	58	0.5%
Puducherry	52	1,496	0	2	1.9%
Punjab	366	548	0	20	1.4%
Rajasthan	380	499	106	239	11.4%
Tamil Nadu	1173	479	1490	256	22.7%
Telangana	252	256	1	57	3.3%
Uttar Pradesh	227	224	0	56	1.8%
Uttarakhand	120	137	0	17	3.4%
West Bengal	228	99	0	24	1.6%
All India	6,090	76,239	2950	1525	5.9%

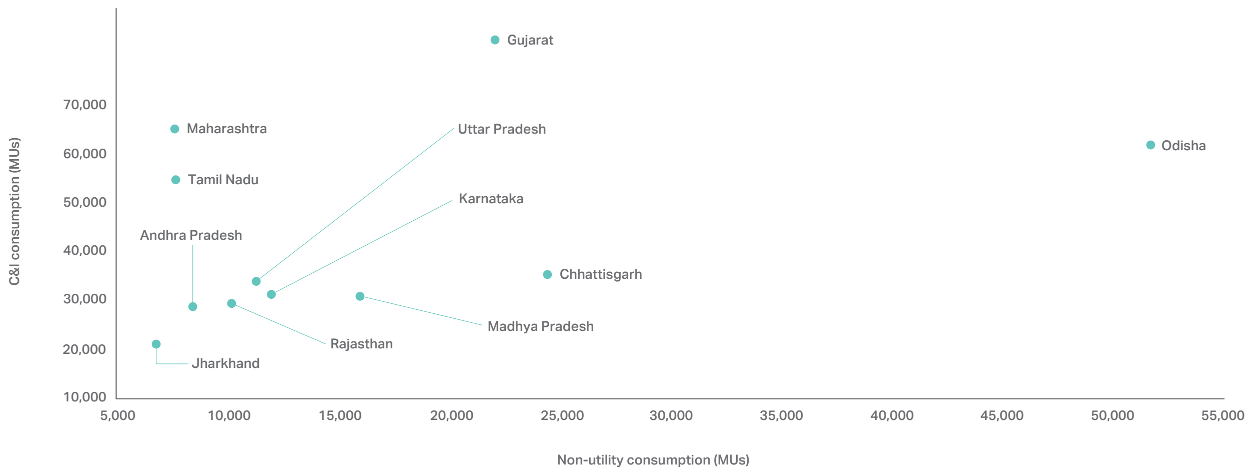
Source: CEA (2021), "General Review 2021"

Gujarat, Maharashtra, TN, Karnataka, Haryana and Uttar Pradesh have high C&I demand as well as account for almost **46% of the country's total captive installed capacity.** These states, in addition to having a high captive installed capacity, are also **rich in RE.**

With just **~8.5% of the total captive capacity being RE based** in these states, there is lot of potential for development of RE-based captive units in the above industrially developed states, most of which also have good RE potential.

Annex 6: Distribution of non-utility consumption and total C&I consumption by state

Figure 22: Distribution of non-utility consumption and total C&I consumption by state



Source: CEA (2021), "General Review 2021"

Annex 7: Estimation of C&I segment energy storage potential

To estimate the C&I market potential for energy storage, we used the following approach.

1. Estimation of total C&I demand

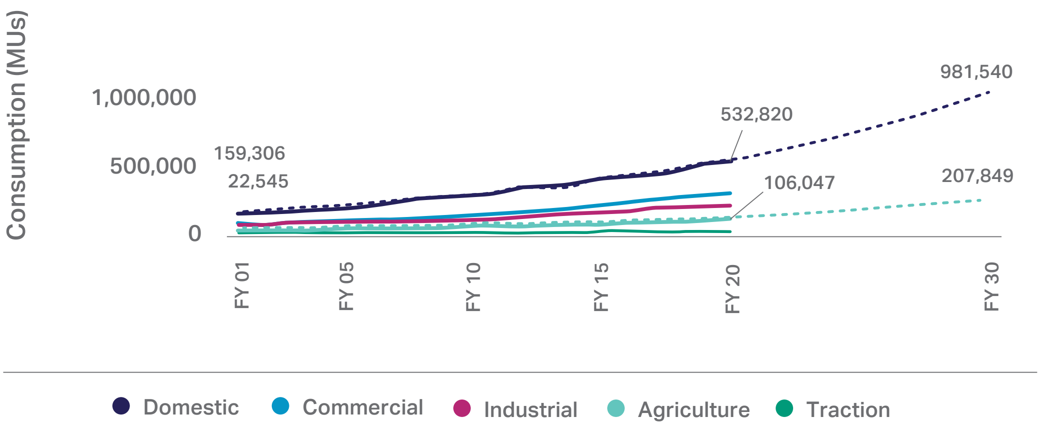
a. Going forward, the total growth in C&I demand will have a sizeable contribution from the behind-the-meter (BTM) market. Hence, a top-down approach has been used to estimate BTM demand, which includes forecasting the total consumption of C&I segment as the primary step.

b. The C&I demand for FY30 has been estimated considering the growth rate of commercial and industrial categories as per CEA's 19th Electric Power Survey Report.

We considered the compound annual growth rate (CAGR) from FY16 – FY27 to extrapolate the growth for FY30, giving the following growth rates:

- Commercial: 7%
- Industrial: 6.3%

Figure 23: Pojection of energy consumption in India by category (utility and non-utility consumption)



Source: CEA (2021), "General Review Report 2021"

2. Identification of share of captive consumers

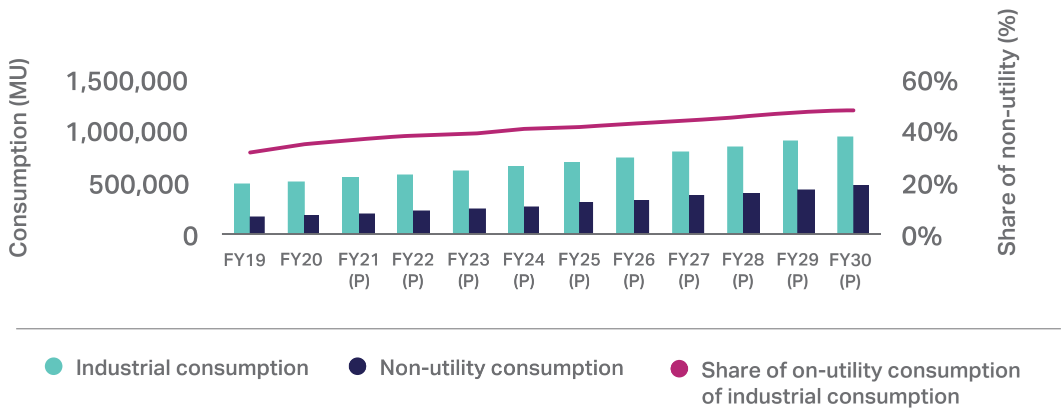
a. The FY20 non-utility consumption (energy consumption procured from other than the area distribution utilities) of C&I consumers has been considered as base value for captive consumption. This accounts for ~33% in FY19 and 37% in FY20 of total Industrial consumption.

The non-utility consumption for commercial category of consumers is zero and the same has been considered going forward.

b. Considering an increasing trend of captive consumption and a shift in consumers from DISCOM to open access captive consumption, the share of non-utility consumption by industrial category of consumers has been gradually increased to 50% by FY30. This trend is on account of net-zero emissions pledges, renewable purchase obligations, regulatory drivers for open access and cost arbitrage offered by RE captive consumption.

Based on the above assumptions and approach, the non-utility consumption for FY30 (P) is estimated at ~490 BU.

Figure 24: Non-utility consumption projection FY30



Source: Deloitte Analysis, CEA (2021), "General Review Report 2021"

3. Estimation of RE demand for captive consumers

a. Considering energy storage requirement to support firming up of variable RE generation, C&I demand for captive consumers has been estimated.

b. The renewable contribution has been increased from 21.18% (FY22 approved value) to two scenarios as highlighted below:

- **Scenario 1:** 45% – The CEA's Report on Optimal Generation Capacity Mix for 2029-30 estimates ~40% of total generation to be met from renewable sources by FY30 (solar, wind, hydro). Taking into account industries that will green faster than the grid, 45% of RE contribution has been considered.
- **Scenario 2:** 55% – Most industrial consumers have committed to transition 50% or more (some have 100% RE targets by 2030) of their consumption to greener fuels; hence, a moderately higher RE contribution of 55% has been considered under this scenario.

c. Based on the above, RE consumption ranges from ~220 – 270 BU by FY30 for captive C&I consumers

4. Estimation of round-the-clock RE demand and corresponding energy storage demand for captive consumers

a. Considering a typical monthly supply requirement of at least 70% capacity use factor, a contracted capacity of 1 GW of RE round-the-clock (RTC) power would supply ~6.1 BU annually. Therefore, to meet ~220 – 270 BU of RE demand in FY30, ~36 – 44 GW of RE RTC power is required to be contracted.

b. Least-cost modeling studies indicate that to meet 100 MW of RE RTC demand with a minimum of 70% monthly capacity use factor criteria, the optimal capacities required are ~100 MW of solar, ~200 MW of wind and 30 MWh of BESS.

c. Extrapolating these results, the energy storage requirement to provide round-the-clock RE supply is ~10.8 GWh – 13.2 GWh. Considering a storage discharge duration of 4 hours, the storage capacity requirement has been estimated as ~2.7 – 3.3 GW by 2030 for captive C&I consumers.

Annex 8: Details of key BESS installations as per ownership models

San Diego Gas & Electric – Escondido Substation Project – California [23]

Particulars	Description
Owner	San Diego Gas & Electric
Location	Escondido, California
Ownership model	Direct ownership
Grid connectivity	Yes
Storage location	Transmission
Services rendered	Balancing variable generation, energy time shifting, flexible peaking capacity, voltage control, frequency regulation

The project was built after the California Public Utility Commission (CPUC) directed Southern California investor-owned electric utilities to fast-track additional energy storage options to enhance regional energy reliability. Utilities needed a fast-response energy source to deploy quickly in the densely populated areas around Los Angeles and San Diego. purposes: balancing large solar generation entering the Southern California grid and energy time shift.

Key features of the BESS:

- It is the largest lithium-ion battery storage project in North America.
- It is built in partnership with Fluence. The 30 MW storage facility comprises approximately 400,000 batteries installed in 20,000 modules within 24 containers.
- It can provide electricity to 20,000 homes for four hours.
- The facility has two primary purposes: balancing large solar generation entering the Southern California grid and energy time shift.
- Time shifting allows San Diego Gas & Electric to charge customers lower rates during high-cost peak demand.

Punkin Battery Energy Storage System [24]

Particulars	Description
Owner	Arizona Public Service Company (APS)
Location	Arizona, US
Ownership model	Direct ownership
Grid connectivity	Yes
Storage location	Distribution
Services rendered	Transmission & distribution enhancement

Key features of the BESS:

- Owned and operated by Arizona Public Service Company (APS), the 2 MW/8MWh BESS, from Fluence, is used to defer feeder-level wires capacity upgradation.
- The BESS provides the utility with an alternative to upgrade 20 miles of 21 kV cables that surround the town. As construction in the hilly terrain was difficult, the utility decided that the battery storage option was cheaper at half the upfront cost of a transmission line.
- The batteries are used when local and system peaks strain the wires, about 20 – 30 days in a year.
- When not used for local demand, the BESS provides energy arbitrage.
- AES will provide maintenance services for 10 years.

Ballarat BESS – Australia [25]

Particulars	Description
Owner	AusNet (transmission system operator)
Location	Australia
Ownership model	Third-party ownership
Grid connectivity	Yes
Storage location	Transmission
Services rendered	Energy arbitrage, frequency control ancillary services

Key features of the BESS:

- Fluence has supplied the 30MW/30MWh Li-ion battery system.
- There is a fixed tariff PPA between AusNet and EnergyAustralia for offtake for a term of 15 years.
- AusNet has contracted Fluence under a 15-year service agreement to make sure that the system is available for use according to the operating parameters.
- The energy retailer bids BESS on the market for ancillary services and energy arbitrage.
- AEMO (Australian Energy Market Operator) operates the BESS based on the schedule received from EnergyAustralia.

Alamitos Battery Energy Storage System – Southern California Edison (SCE)[26]

Particulars	Description
Owner	AES
Location	California, US
Ownership model	Third-party ownership
Grid connectivity	Yes
Storage location	Distribution
Services rendered	Energy arbitrage, grid stabilization

Key features of the BESS:

- 100 MW/400 MWh Advancion5 batteries supplied by Fluence.
- World's first stand-alone energy storage project for local capacity.
- The project is a part of USD $2 billion repowering initiative in Long Beach to replace aging natural gas peakers with a combination of efficient combined-cycle gas capacity and battery energy storage.
- The BESS can supply power to tens of thousands of homes in milliseconds.
- The contract is 20-year PPA between SCE and AES.
- SCE will pay monthly capacity charges and other O&M charges to AES

Presidio Battery Energy Storage System[27]

Particulars	Description
Owner	Electric Transmission Texas
Location	Texas, US
Ownership model	Direct ownership
Grid connectivity	Yes
Storage location	Distribution
Services rendered	Outage management, capacity deferral, grid stabilization

Key features of the BESS:

- American Electric Power has developed the 4 MW/32 MWh sodium-sulfur (NaS) battery storage system. Electric Transmission Texas (ETT) owns and operates it.
- The capital expenditure incurred on the project was USD $25 million.
- The battery system has helped to defer transmission capital costs and allowed for maintenance on the transmission line without loss of electric power. In the event of an outage, the battery can provide 8 hours of uninterrupted power supply to 4,000 households.
- The NaS battery system has also provided improved power quality and reduced momentary outages caused by voltage fluctuations.

Puducherry Battery Energy Storage System[28]

Particulars	Description
Owner	Power Grid Corporation of India Ltd (PGCIL)
Location	Puducherry, India
Ownership model	Third-party ownership
Grid connectivity	Yes
Storage location	Transmission
Services rendered	• Under operation: frequency regulation, energy time shift • Under implementation: dynamic frequency regulation, RE capacity firming, load following renewable peak shaving, voltage/reactive power support, integrated applications

Key features of the BESS:

- Battery system:
  - Package 1: advanced lead-acid 500 kW/250 kWh
  - Packge 2: Li-ion 500 kW/250 kWh.
- Narada Power, Raychem and RPG manufactured the BESS system; PGCIL owns it.
- Battery facility was developed to test frequency regulation, grid balancing service and energy time shift.
- Performance of the BESS: Under the frequency control mode of operation when the frequency of the system falls below 49.95 Hz, the BESS goes into discharging mode; when the system frequency goes above 50Hz, the BESS goes into charging mode. For system frequencies between 49.95Hz and 50Hz, the state of charge governs the battery mode.

BESS at BHEL's R&D Center[29]

Particulars	Description
Owner	Bharat Heavy Electricals Limited (BHEL)
Location	Hyderabad, India
Ownership model	Direct ownership
Grid connectivity	Yes
Storage location	Behind the meter
Services rendered	Ramp-rate control, capacity firming

Key features of the BESS:

- BESS system consists of three different types of battery installations:
  - Li-ion (LFP) – 500 kWh
  - Advanced lead-acid – 300 kWh
  - Flow battery – 200 kWh
- The battery systems are interconnected with a 500 kWp solar PV plant at common 6.6kV AC bus.
- The system is also designed for applications such as reactive power control mode, peak load shaving, load leveling, frequency regulation and power quality improvement; however, performance validation has been done only for ramp-rate control and capacity firming.
- The response time of the system is less than 20 milliseconds.

Big Basket's behind-the-meter installation

Particulars	Description
Owner	Big Basket
Location	Delhi, India
Ownership model	Direct ownership
Grid connectivity	Yes
Storage location	Behind the meter
Services rendered	Power backup

Key features of the BESS:

- Key features of the BESS:
- One Big Basket warehouse has installed a solar-integrated 150 kW/281 kWh Li-ion BESS system.
- It installed the system to reduce the warehouse's dependency on diesel generators for power backup.

InterContinental Hotels Group Storage System – California [30]

Particulars	Description
Owner	InterContinental Hotels Group (IHG)
Location	California, US
Ownership model	Direct ownership
Grid connectivity	Yes
Storage location	Behind the meter
Services rendered	Energy cost reduction, demand charge management, time-of-use mitigation

Key features of the BESS:

- The project involved the installation of two battery systems, one each at InterContinental San Francisco and Mark Hopkins Hotel, San Francisco.
- IHG partnered with Stem Energy to install energy saving systems in its hotels.
- Stem deployed its proprietary combination of real-time data analytics and energy storage system. Each storage system installed by Stem is 54 kW.
- Since the installation of the storage systems, each hotel has seen nearly USD $15,000 in annual savings from the automated storage component alone.
- The InterContinental San Francisco has reduced its demand volatility by more than 3.5 times year-over-year – lowering costs and making them easier to predict.

AES and Mitsubishi Corporation – Tata Power Delhi Distribution Limited (TPDDL) Project[31]

Particulars	Description
Owner	AES India (subsidiary of AES Corporation and Mitsubishi Corporation)
Location	Delhi, India
Ownership model	Third-party ownership
Grid connectivity	Yes
Storage location	Distribution
Services rendered	Frequency regulation, grid balancing service, RE integration & energy time shift

Key features of the BESS:

- The battery system is located at a distribution substatio n operated by Tata Power Delhi Distribution Limited.
- AES and Mitsubishi own the BESS system. Fluence, a company jointly owned by Siemens and AES, has supplied its energy storage technology for the system.
- The system comprises Li-ion (NMC) batteries with a total system capacity of 10 MWh, consisting of four blocks of 2.5 MWh and connected to step-up transformer (400 V/11 kV).
- The system provides ancillary services, including frequency regulation, grid balancing service, RE integration & energy time shift. The system is also used for distribution-level applications, including load following/voltage regulation and network upgrade deferrals.
- The system can also provide services to preferential consumers in emergency situations.
- As the deviation settlement mechanism (DSM) penalties for the utility were very high for FY19 and FY20, the operation of the BESS for DSM application has led to considerable savings (approx. INR 22 Lakh to Aug. for FY21).
- The reactive power control mode of operation has led to voltage improvements of 2.51% by operating the system in 13 instances.
- The BESS injects power into the grid when the frequency falls below 49.85 Hz. During this period, BESS operates under discharge mode. When the frequency of the system goes over 50Hz, BESS goes into charging mode.

Moss landing battery storage project – Pacific Gas & Electric Company (PG&E)[32]

Particulars	Description
Owners	Vistara Energy
Location	California, US
Ownership model	Third-party ownership
Grid connectivity	Yes
Storage location	Transmission
Services rendered	Grid balancing, peaking capacity

Key features of the BESS:

- The system consists of a battery system installed in two phases:
  - Phase 1 : 300 MW/1,200 MWh
  - Phase 2 : 100 MW/400 MWh
- Vistra developed the project in two phases under Resource Adequacy Agreements with PG&E.
- The BESS is connected to the California Independent System Operator (CAISO) grid via an existing 500 kV substation at Moss Landing power plant.
- Fluence was the engineering contractor for the project.
- For phase 1, PG&E signed a 20-year energy storage resource adequacy agreement (ESRAA) in Nov. 2018.
- For phase 2, PG&E signed a 10-year ESRAA in Aug. 2020.
- For the ESRAA tenure, Vistra shall be responsible for O&M activities as per the agreement.
- PG&E will make monthly capacity payments to Vistra; compensation includes a monthly fixed payment and a variable O&M charge based on energy delivered.

Nexcharge Community Energy Storage System – Tata Power Delhi Distribution Limited (TPDDL)[33]

Particulars	Description
Owner	Nexcharge
Location	Delhi, India
Ownership model	Third-party ownership
Grid connectivity	Yes
Storage location	Distribution
Services rendered	Peak shaving, volt-amps reactive (VAR) compensation, frequency response, emergency backup

Key features of the BESS:

- Nexcharge owns the installation.
- The is BESS located at the Rani Bagh distribution substation belonging to TPDDL (Tata Power Delhi Distribution Limited).
- Dense population and load growth cause overloading of distribution assets in Rani Bagh, Delhi.
- The 0.52 MWh battery energy storage system provides peak shaving, volt-amps reactive (VAR) compensation and deviation penalty reduction at the substation level with power backup to preferential consumers in case of a grid outage.
- The setup helps provide continuous and reliable power to key consumers when needed.

Abbreviations

BESS: battery energy storage system

BTM: behind the meter

C&I: commercial & industrial

CEA: central electricity authority

DSM: deviation settlement mechanism

ESS: energy storage systems

FGD: flue gas desulfurization

FTM: front of the meter

IPP: independent power producers

ISTS: Inter-state transmission system

LCOS: levelized cost of storage

LCO: lithium-cobalt-oxide

LFP: lithium-iron-phosphate

LiB: lithium-ion battery

LMO: lithium-manganese-oxide

LMP: lithium-metal-polymer

LTO: lithium-titanate-oxide

NaS: sodium-sulfur

NCA: lithium-nickel-cobalt-aluminum-oxide

NiCd: nickel-cadmium

NiMH: nickel-metal hydride

NMC: nickel-manganese-cobalt

O&M: operation and maintenance

PPA: power purchase agreement

PSP: pumped hydro storage projects

RE: renewable energy

RPO: renewable purchase obligation

RTC: round-the-clock

SiB: sodium-ion battery

VAR: volt-amps reactive

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This report has been co-authored by multiple parties.

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