Study on
Advanced Grid-scale Energy Storage Technologies

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Acknowledgement

The study carried by us is for developing the recommendations for advanced grid-scale energy storage technologies covering mechanical (pumped storage hydro, compressed air energy storage, flywheel, gravity storage), electrochemical (lithium-ion, flow batteries/ vanadium redox), solar thermal (sensible-molten salt), and chemical (power to power (fuel cells), power to gas (electrolysis)). Based on all the technical and market aspects of energy storage technologies in the Indian context, viz. the technology readiness level, deployment status in India, manufacturing status and supply chain maturity in India, market readiness/ acceptability of the technology, life cycle assessment, techno economic analysis, legal status and regulations in-force/ needed along with policy recommendations for the uptake of particular energy storage technologies, the study report has been prepared.

We would like to express our sincere thanks to Mr Bhupinder S. Bhalla, Secretary, Ministry of New and Renewable Energy, Mr. Pankaj Agarwal, Secretary, Ministry of Power, Mr Ghanshyam Prasad, Chairman, Central Electricity Authority, Government of India and Prof. K.K. Pant, Director, IIT Roorkee, Roorkee for writing forewords for this report that underscored the importance of this research in development and deployment of energy storage in India.

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We hope the study shall be useful to all energy storage stakeholders in doveloping energy storage infrastructure, policy and regulations.

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Executive Summary

I. India: Rapidly Increasing Demand for Electricity and Push for A Greener Power Grid

India is the third-largest producer and consumer of electricity globally with an annual electricity production of 1624 Billion Units (BU) in 2022-23. During the last decade, electricity production in India grew at an annual growth rate of about 5%, excluding the last year, where the growth rate was even higher at about 8.87%. The Electricity Act of 2003 delicensed power generation activity, which gave impetus to generation capacity addition and led to rapid coal-based generation capacity expansion during 2007-2017.

As of April 2023, the installed generation capacity of the country stood at 416 GW, with 237 GW of thermal power generation, 172 GW of renewable power generation (Wind, Solar, Hydro, and Biomass), and 6.78 GW of nuclear power generation. Hydro power generation with an installed capacity of 46.85 GW of large hydro (above 25 MW capacity) and 4.9 GW of small hydro (below 25 MW capacity) is 30% of the renewable generation mix. Wind generation capacity accounts for 25% (42.89 GW), and solar power accounts for 40% (67.97 GW) of the total renewable energy (RE) installed capacity.

India witnessed peak electricity demand of 215 GW in June 2022. The annual per capita electricity consumption has increased from 592 kWh in 2003-04 to 1255 kWh in 2021-22. At COP 21 in Paris (2015), India committed to meeting 33-35% of its energy requirement from non-fossil fuel-based sources by 2030, and target of 175 GW RE capacity was envisaged for December 2022. India achieved its commitment nine years ahead of time in November 2021 by achieving 40% of RE capacity. At COP 26 at Glasgow (2021), India committed to 500 GW of non-fossil fuel-based installed capacity by 2030 and carbon neutrality by 2070.

II. Need for the Study: Energy Storage for Flexibility in a Greener Grid

It has become clear to all power system stakeholders that grid flexibility is critical to ensuring reliable, high-quality delivery of electricity under increasing levels of variable and intermittent renewable energy. Some Indian states have already experienced over 50% instantaneous solar PV generation. India's power grid has been able to absorb the current levels of renewable energy because of the extensive build out of its high voltage transmission infrastructure. Going forward, however, more sources of grid flexibility will be needed given the aggressive renewable energy targets of India for 2030 and 2070.

Grid flexibility in India can be achieved in various ways including flexibilization of coal based power plants, encouraging demand response, making changes to the electricity market design to incentivize fast ramping resources, and building energy storage plants that provide bi-directional power flow. Grid-scale energy storage technologies are the focus of this study as energy storage is receiving much attention from policy makers and Government of India as evidenced in the latest CEA report (April 2023) that projects need for 18-25 GW of pumped storage plants (PSPs) and 22-49 GW of battery energy storage system (BESS).

Energy storage projections such as those developed by CEA help project developers in assessing the market size of energy storage in India. These projections should be complemented with an assessment of the supply chain and cost of various energy storage technologies. Moreover, most suitable energy storage technologies for India, when will they be needed to ensure grid reliability, and what kind of policies should be put in place to encourage manufacturing of these technologies in India for domestic consumption and export, are key questions that must be answered today.

III. Scope of the Study

The key objective of this study was to do a deep dive into various energy storage technologies shown in Fig. ES-1, identify existing supply chains and gaps, and develop policy options to address these gaps to encourage local manufacturing of energy storage technologies.

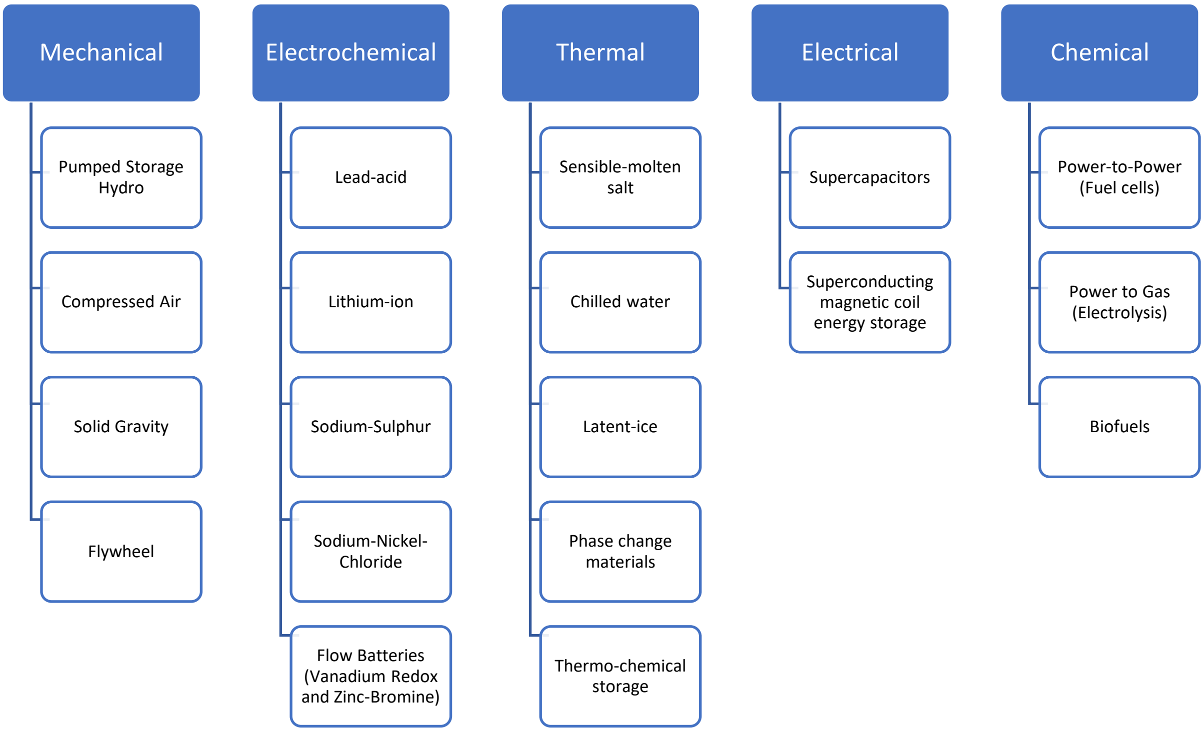

Fig. ES-1. Energy Storage Technologies

The present study focused on grid-scale technologies, where a single project with one point of interconnection with the utility has an installed capacity of more than 5 MW. Therefore, aggregation of rooftop solar, electric vehicles, and other small-scale energy storage technologies to create a MW-scale, flexible resource is not covered in this study.

Although the title of national scheme for advanced grid-scale energy storage technology was envisaged, due to prevailing schemes for different technologies, the study outcome was focused on policy recommendations for improving the supply chain, market development and speedy deployment.

IV. Energy Storage Technologies

Various energy storage technologies studied are presented focusing on working principle, maturity level, deployment status globally and in India, pros and cons for the grid, development and supply chain challenges and opportunities, and existing provisions in India to incentive technology development and deployment.

Four technologies were reviewed under mechanical energy storage viz Pumped Storage Hydropower (PSP or PSH), Compressed Air Energy Storage (CAES), Solid Gravity Energy Storage (SGES), and Flywheel Energy Storage.

IV-1. Pumped Storage Hydropower

PSP is the most mature grid scale energy storage technology that provides GW-GWh level of storage. Many PSP plants are in operation for several decades. At present India has 4.7 GW of installed PSP capacity and several projects in different states at various stages of development.

There are three types of PSP plants – fixed speed, variable speed, and ternary PSP with hydraulic short-circuit. Fixed speed PSP plants are called so because the motor/generator always rotates at the grid frequency. It is the most widely used and most mature PSP technology globally with decades of deployment history. Variable speed PSP comprises of rotor-connected or stator connected power electronic converters that allow the motor/generator to operate at speeds different than grid frequency. This can be an attractive attribute for varying power consumption during pumping and to maximize pumping efficiency under large head variations. Variable speed PSP is being developed at Tehri Hydro Power Plant in India. Ternary pumped storage is the third type of PSP that uses the concept of hydraulic short-circuit to allow rapid changes in generation or pumping power levels and rapid pumping-generation transitions (<1 minute). This is a new PSP technology with no project in India.

The biggest advantage of PSP for the grid is its ability to provide GW-level power for 6 hours and beyond. Moreover, operators are familiar with this technology, particularly fixed-speed PSP, which allows its seamless integration in grid operations. Natural inertia, voltage support, blackstart, and contribution to short-circuit current are other benefits of fixed-speed and ternary PSP technologies. The per kW cost and per kWh levelized cost of storage (LCOS) of PSP are also not very high at Rs. 35,000/kW and Rs. 3.91/kWh (without considering cost of pumping power), respectively. However, the capital cost may vary for specific site.

PSP supply chain is also highly indigenous, particularly for fixed speed PSP. However, some heavy engineering and high technology components are still imported including >160 mm thick steel plates and high-power, power electronics converters. While these can be manufactured in India, the domestic demand for these components is not enough to make an economic case for their manufacturing unless right incentives are available to manufacture these components in India for export.

Government of India has initiated several measures to encourage PSP development, particularly off-river PSP, where environmental and social concerns are much less compared to on-river PSP. Some of these incentives include waiver of interstate transmission charges for projects whose construction work is awarded by June 30, 2025, provision of debt/equity ratio of 80/20, at par treatment with renewable projects for long-term loans (20-25 years), no liability to provide free power, single season based environmental clearance, tariff based competitive allotment, among others.

IV-2. Compressed Air Energy Storage

CAES is a grid-scale energy storage technology that can provide MW-GW level, long-duration (greater than 24 hours) energy storage. It works on the principle of compressing air into large, natural salt caverns and then using this air to generate electricity by running specialized gas turbines. The biggest limitation of CAES is the availability of suitable caverns to store the compressed air. Unfortunately, such caverns are limited, particularly in India, which shows the limited development of CAES projects globally. In India, currently there is no CAES project or pilot.

Another drawback of CAES is its lower roundtrip efficiency at 65-75% compared to 80% for PSP. Moreover, the currently mature CAES technology burns natural gas to reheat air for power generation. Technology, however, has been developed to capture heat generated during air compression and use it to reheat air during power generation.

Because CAES interfaces with the grid using conventional synchronous machines, it provides the same benefits to the grid as fixed speed PSP. However, at Rs. 88,000-112,000/ kW CAPEX it is 2-3 times as expensive as PSP, but its LCOS is Rs. 3.58/kWh, which is slightly lower than PSP. These cost values may reduce, however, if CAES is deployed more widely, particularly in India, where no project currently exists.

IV-3. Solid Gravity Energy Storage

Gravity energy storage (GES), or more appropriately Solid Gravity Energy Storage (SGES) works by converting electrical energy to gravitational potential energy of a weight and vice-versa using electromechanical equipment by vertically moving a heavy object in a gravitational field. Use of high-density solids achieves better geographical adaptability, higher energy density, cycle efficiency, and better economy. It provides similar grid supportive characteristics as PSP and CAES.

The technology is still at R&D stage with small-scale pilot starting to be deployed around the world. In India also, Gravitricity has partnered with NTPC to perform a pilot project. Due to its initial states of deployment and no large-scale pilots or projects unlike PSP, no SGES specific policy or manufacturing incentive exists in India.

IV-4. Flywheel Energy Storage

Flywheel energy storage works on the principle of the conservation of momentum and energy. When the flywheel is brought to its rated speed and left to spin in vacuum, its momentum stays the same (in ideal conditions). During the conversion of this energy into electrical energy, the conservation of energy results in kinetic energy being converted into electrical energy.

Advanced flywheel energy storage provides high energy density and high efficiency with minuscule losses and is best suited for periods ranging from a few minutes to several hours. These high-speed flywheels rotate at speeds of 10,000 to 100,000 rpm.

Grid-scale flywheel energy storage systems are primarily used in e-mobility and isolated grids currently. In large grids such as India, availability of inertia in the form of rotating mass of synchronous machines of coal and thermal power plants is likely to be enough to meet grid requirements.

IV-5. Batteries

Amongst the various battery technologies available in the market (like lithium-ion batteries, vanadium redox flow batteries, molten-sodium batteries, and lead-acid batteries), lithium-ion battery (LiB) and vanadium redox flow batteries (VRFB) offer the best options for grid-scale storage applications in terms of cost, performance, cycle life, and technological maturity. At the grid level, BESS installations have been demonstrated at the level of a few hundreds of MWs employing both LiBs and VRFBs. The world’s biggest battery energy storage system (BESS) project so far, Moss Landing Energy Storage Facility (USA) at the capacity of 400MW/1,600MWh, is built employing LiB technology. Similarly, VRFB is also employed for enabling large BESS projects, e.g., the peak-shaving power station in Dalian (China) features a 200MW/800MWh BESS with VRFB technology.

LiB and VRFB technologies can be helpful to balance the grid in terms of smoothing renewable energy generation, grid backup, resilience, load shifting, ancillary services, and hence ensuring a consistent supply of energy. The deployment strategy for battery-integrated grid-scale storage should involve an assessment of the grid requirements like frequency regulation, peak demand, and load. Additionally, evaluation of the suitability of the battery technology in terms of levelized cost analysis, reliability, and environmental impact is required based on the grid requirements. The battery pack design, safety aspects, maintenance of the system, and integration of the BESS with the grid should also be analyzed before deployment of the BESS.

Regarding the supply chain, most of the raw materials for manufacturing LiBs and VRFBs are scarcely available in India. India imports lithium-ion batteries readymade in the form of cells and packs, majorly from China, Hong Kong, and Vietnam. Taking this into consideration, the government is pushing for domestic manufacturing through different initiatives, e.g., the PLI scheme 2021. Graphite, lithium, nickel, cobalt, manganese, aluminum, iron, copper, phosphorous, fluorine, etc. are among the major raw materials required for LiB manufacturing. As of now, there are scarce resources for lithium and cobalt in India. Through Khanij Bidesh India Limited (KABIL), the government is working towards identifying potential partners to supply these materials. The Geological Survey of India recently found large lithium reserves in Jammu & Kashmir and Rajasthan. The production/processing for other raw materials takes place in India but on a smaller scale. For VRFBs, vanadium alone accounts for 35 to 45% of installation costs and India imports it mainly from South Africa and Brazil. The bipolar plates, carbon felt, and membranes are other components for flow batteries which are also imported presently from Germany and US. As per the Indian Bureau of Mines (IBM) 2018 database, the overall Indian reserves of vanadium ore are estimated to be 24.63 million tons with estimated content of 64,594 tons of vanadium pentoxide. As of now, vanadium in India is produced as a byproduct from steel plants. RIL, NALCO, and Vedanta group are working on projects to recover the vanadium from the byproducts (gasifier slag, sludge from Bayers process) of other processes.

Other than batteries, the components of BESS, like protection circuit boards, relays, semiconductor chips, capacitors, and resistors, are also being imported from Taiwan, the USA, and Japan. The machinery and equipment required for manufacturing and testing these batteries are also imported from China. The present cost of the LiBs is around INR13,600-20,000/kWh and 24,000-32,000/kWh, respectively. As per the BNEF and NITI Aayog, the cost of the LiBs will be around INR 5,500/kWh by 2030. IRENA report predictions indicate that the cost of Vanadium flow batteries will reduce to around INR 8,700/kWh by 2030.

LiB and VRFB are promising candidates for energy storage required at grid scale. Localized manufacturing of the key components of the battery and BESS, should be promoted for self-reliance and low-cost end products. Emphasis should be given to exploring local resources and international trading to strengthen the supply chain. Incentive schemes such as PLI also enhance the wide-scale commercialization and development of localized infrastructure for manufacturing batteries and other components. Another round of the PLI scheme can be initiated, considering the specific requirements of batteries for stationary energy storage. Besides the development of gigafactories for manufacturing batteries, there is a need to establish infrastructure for recycling these batteries, as recycling could serve as a substantial source of raw materials for a country like India.

IV-6. PEM Fuel cell and Electrolyser

Hydrogen has the potential to decarbonize energy generation when coupled with renewable energy sources (RES). Fuel cell technology is developed and at the commercial stage. Polymer electrolyte membrane electrolysis (PEMEC) technology is at the engineering scale, while alkaline electrolysers (AECs) are already in the plant operation stage. The contribution of these technologies at the grid level can be realized via two modes, power to power, where the hydrogen generated during off-peak hours using RES coupled with electrolysis can be used to generate electricity during peak hours to increase reliability. However, the current capacity of modern-day fuel cells (kW-MW) limits the adaptation of this mode. On the other hand, power to gas presents itself as a likely alternative where the hydrogen generated through water electrolysis using unbalanced renewable energy can be used for the industries such as cement, ammonia etc.

Processing of raw materials, production of components, and end-of-life recovery are crucial elements of the supply chain of these technologies. Manufacturers such as 3M, DuPont, Cummins, and Ballard Power are major PEMFC producers and make the bipolar plates, gas diffusion layer, and electrolyte membrane in-house. However, around 80% of the cost components of PEMEC and AEC can be made indigenously in the country with only import dependence on electrolytes and catalysts. The current capital expenditure of electrolyser is INR 78,375/kW with the cost of hydrogen as INR 330-453/kg. With the large-scale adoption (capacities above 50 GW), these values can go down to INR 14,025/kW, and hydrogen production cost could be less than INR 82.5/kg.

To ensure the development of these technologies, policy interventions are needed. Given the significance of the National Solar Mission and the National Hydrogen Mission, the said missions can very well be brought under an umbrella to produce green hydrogen through water electrolysis, for which the country is bestowed with both solar energy and water. The produced hydrogen can even be exported, thereby making the country world’s supplier of green hydrogen. Furthermore, the growth of green hydrogen may be realized when small and medium industries are well encouraged by the established industries and the Government in possible capacities. Moreover, the gap between industries and academic/research institutes needs to be bridged as well.

IV-7. Thermal Energy Storage Technology

A total of eight concentrated solar power (CSP) plants without thermal energy storage (TES) have been commissioned in India with a total installed capacity of approximately 500 MW. Moreover, only three CSP plant with two-tank molten salt thermal energy storage is deployed in India with a total installed capacity of approximately 150 MW. Further, in order to develop innovative technologies (ex. High melting PCM, supercritical CO_2 power cycle), various research institutions conducted research on a lab scale to integrate TES for grid-integrated applications.

About eight companies are there in India for manufacturing the components of CSP plants. The LCOE of CSP without TES is found to be in the range of INR 11.20 to 19.03/kWh. An efficient TES system reduces the LCOE of the CSP plant. As determined by the techno-economic analysis (TEA), the present estimated CAPEX of a central tower receiver with a nominal capacity of 150 MW and TES ranging from 0 to 18 hours is between INR15 – 37 crores per MW. However, the LCOS (Tariff) of the TES system decreases from INR 9.39 – 8.5/kWh with increasing the storage duration from 3 to 18 hrs. As per the future roadmap of CSIRO Australia, the cost in 2050 should be slightly over A$100/MWh (INR 5,551/MWh) for 8-hour storage and A$99/MWh (INR 5,495/MWh) for 24-hour storage.

V. Selected Grid-scale Energy Storage Technologies

The summary of energy storage technologies in the previous section reveals that some technologies are more suited for grid-scale deployment in India than others. This was due to several factors including the availability of competing technologies, high costs, and lack of a suitable market case. For example, flywheel energy storage can be used for traction applications and in isolated grids to provide synthetic inertia. However, in larger grids, the availability of rotating machines, including synchronous condensers, can be much better alternatives because they can provide high power (both real and reactive), natural inertia, and short circuit strength to the grid. Their costs are also very high because of the use of composite materials for rotor manufacturing and the magnetic bearing system. Moreover, these materials are not manufactured in India at present.

Therefore, six energy storage technologies were selected and reviewed in more details with respect to technical attributes, supply chain, deployment, policy, and market readiness level. A comprehensive literature survey, market survey, and industry interaction was performed for these technologies. However techno-economic analysis (TEA) and life cycle assessment (LCA) has been carried out for five prospective grid-scale storage technologies, viz. pumped storage, Li-ion batteries, vanadium redox flow batteries, compressed air energy storage, and thermal energy storage. Although the level of detail is limited to keep the model manageable and the complexity understandable, the analysis contains sufficient detail for a meaningful assessment of the different storage options.

In the techno-economic analysis, the LCOS for all five storage technologies has been compared for three different scenarios, (a) only storage cost is considered without including the power purchase tariff, (b) a constant power purchase tariff is considered at INR 3/kWh, and (c) Power purchase tariff is considered at INR 3/kWh with an annual escalation of 3%. Based on the model, pumped storage, compressed air storage, and thermal energy storage are expected to be more economically appealing. The sensitivity analysis highlights the importance of round-trip efficiency and electricity buy price when comparing the different options. Further, business models following Central Electricity Regulatory Commission (CERC) guidelines have also been prepared, and the net present value (NPV) and internal rate of return (IRR) of different storage options have been presented.

An India-specific cradle-to-grave LCA has also been carried out for the different storage options. Different scenarios have been modeled in SimaPro 9.4.0.2 software utilizing the Ecoinvent database. The inclusion of charging electricity as well as the source of charging electricity in the analysis has a significant impact on the LCA results. The emission hotspots during the lifecycle of different storage options have been highlighted. The analysis concludes that the pumped storage performs the best both in terms of environmental impacts (least impacts) at 0.12 kg CO_2 /kWh discharged as well as in terms of levelized cost of storage (least cost/unit of electricity) at INR 3.91/kWh without cost of pumping power.

The table ES-1 summarizes the key attributes of the six selected energy storage technologies.

Table ES–1. Energy storage parametric matrix

Energy storage technology		**Pumped hydro storage**	**Li-ion BESS**	**Vanadium Flow batteries**	**Thermal energy storage**	**Compressed air energy storage**	**Hydrogen energy storage**
General attributes	Technology readiness level	9	9	8	5-9	9 (globally) India (1-2)	PEMEL:7, Alkaline EL: 9
	Capacity (MWh)	Purulia 900 MW (largest in India); 50 MW to 1000+ MW globally	upto 400MW/1600 MWh	upto 100MW/400MWh	1010 MWh (India) 200 to 1010 MWh (Global)	320 MW (in Germany	60,000-100,000
	Discharge time (hours)	ranges from hours to days.	4-8	4-12	16 h (India) Global (2 to 7.5 h at full load)	290 MW peak power provided for 2 hours	9 to 10
	Life time (number of cycles)	18,000 – 27,000 in 50 years	2,000–4,000+	7,000-10,000+	20 to 25 Years	1000 – 10,000	PEMEL:5 years, Alkaline EL: 7 years
	Power density	0.1-0.2 W/l (2015 source)	40-60 (W/kg)	3.33-10 (W/kg)	1 MW/m^3	-	1.4-5 W/cm^2
	Energy density	0.2-2 Wh/l (2015 source)	At cell level, 160-350 (Wh/kg) and 250-670 Wh/l	25 – 35 (W/kg)	0.05 to 0.55 MWh/m^3	-	0.4370 (W/kg)
	Round-trip efficiency (%)	80%	85-95% (cell level), 60-75% (system level)	60-65	70-90 %	65-75%	NA
	CAPEX (₹)	35,000 -55,000 / kW	13,600 – 20,000 /kWh	24,000 – 32,000 /kWh	240,000 /kW	88,000 – 112,000 /kW	PEMEL: 56,000– 112,000 /kW Alkaline EL: 40,000 – 80,000 /kW
	LCOS* (₹/kWh)	3.91	10.16	11.52	8.65	3.58	-
	GWP** (kg CO_2 eq/MWh)	120	162	190	185	160	-
Supply chain related attributes	India's manufacturing capacity	*70% cost were civil works and are done by indigenous technologies and Domestically produced materials*	Imported as of now; PLI scheme live to promote indigenous manufacturing	Only 1-2 manufacturers with small production capacities	In lab scale (India) 250 GWh (Installed capacity) (Global)	No local manufacturer, some global manufacturers have India operations but unclear if CAES equipment manufactured here	5 MMT/year (Targeted for the year 2030)
	Raw material availability	For civil works Yes.	Imported	Imported	Yes	Yes	PGM and rare earth metals

Energy storage technology		Pumped hydro storage	Li-ion BESS	Vanadium Flow batteries	Thermal energy storage	Compressed air energy storage	Hydrogen energy storage
		Only up to 30% components of E&M works may be imported from reputed manufacturers.					are not available
	Source of import (if not available in India)	Manufacturers in Europe and Japan	China, Hong Kong, Vietnam, Singapore, Korea, Japan	South Africa, Brazil	Manufacture in Europe	NA	South Africa, Germany, Switzerland and Others

*without cost of input electricity **results based on solar grid

VI. Policy and Regulatory Recommendations for Grid-Scale Energy Storage in India

VI-1. Legislative Framework

The definition and details of Energy Storage & Technologies should be explicitly covered in Electricity Act 2003.

VI-2. Policies

The National Tariff Policy and the National Electricity Policy provide vision & directions for the power sector. Further, there is another provision in the Electricity Act that covers Rural Electrification Policy. However, all the above policy documents do not explicitly cover Energy storage and therefore, the Electricity Act 2003 may be amended to cover the following:

a. These documents need now to define energy storage and the way it may be promoted and what technologies are most suitable for India, be laid down.

b. A comprehensive energy policy should be made which should provide a roadmap to develop the energy sector more sustainably and increase the stake of renewable energy sources and energy storage targets for each licensee.

c. Tariff Policy must include measures to promote energy storage technology through regulated and competitive tariffs.

d. There should be explicit and specific policy changes in the form of National Policies, including allowing storage with attractive tariff to provide ancillary services and frequency regulation and adding a storage purchase obligation for appropriate utilities.

e. The policy should make provisions for regulatory compliance so that the appropriate Regulatory Commission make necessary changes in their Regulation in consultation with CERC & State Utilities as being done for existing Renewable Purchase Obligation and proposed Hydropower Purchase Obligation

f. The government of India and state government should support R&D in developing grid-scale technology, including indigenous manufacturing of emerging technology and their integration with the grid.

VI-3. Regulations

a. CERC & SERC to review their respective Grid Codes for promoting greater flexibility in the generation plants so as to facilitate the integration of renewable energy in the electricity grid. CERC has already amended the electricity grid code to lower the minimum generation threshold for thermal generators from 70% to 55%. This change is expected to reduce renewable curtailment nationwide and reduce operating costs.

b. Similar action is required at the state level so as to promote flexibility at State Generation plants. CERC has already started action for introducing tertiary-level ancillary services which should go further.

c. Studies should be made by all State Stakeholders to review present thermal plants which may go further beyond 55% Minimum-technical.

d. CERC needs to frame an appropriate regulatory framework/market expansion for greater operational flexibility through requirements for fast-responding assets to improve system reliability. Expanding the range of storage technologies eligible to meet flexibility needs beyond PSH can increase the total amount of fast-responding assets available for balancing.

e. Need to formalize the roles and ownership models for energy storage investments from different segments of the power sector through CERC/SERC regulations which can reduce uncertainty for investors of the power sector.

f. Energy storage ownership remuneration rules are not clearly defined by CERC or SERC in India like it is defined for transmission, generation, and distribution companies, all for different purposes. There should be clear rules for claiming of storage fixed charges and energy charges for each utility. For example, the generator could sell power in the market as an energy arbitrage resource. Distribution companies would be allowed to own storage for the purposes of reliability, sale of power to other generators, or demand management.

g. CERC has asserted that establishing proper “safety standards and procedures” is necessary for storage to be deployed in one of its papers. The Bureau of Indian Standards is now pursuing this task through its Energy Storage Sectional Committee. to create an Energy Storage Standards Taskforce. This needs to be done in a timely manner.

The present study will support the policymakers and all stakeholders in the power sector to make the policy conducive for grid-scale energy storage technology to meet the national commitment of net zero carbon by encouraging indigenous manufacturing and adoption of cost-effective energy storage technologies.

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13. Mr Siddhartha Arora, Associate Director – Clean Power, Shakti Foundation.

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