Confederation of Indian Industry

India’s Outlook on Clean Energy Storage: A Roadmap to Net Zero

Comprehensive Analysis

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Foreword

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India is at a crucial juncture in its energy transition journey, with ambitious targets of achieving 500 GW of non-fossil energy capacity by 2030, expanding renewable energy, reducing carbon emissions, and achieving net zero by 2070. A cornerstone of this transition is the deployment of Energy Storage Systems (ESS) like Battery Energy Storage Systems (BESS) and Pumped Hydro Storage (PHS), which are indispensable for integrating renewable energy sources, stabilizing the grid, ensuring energy reliability. As India progresses towards its goals, the clean energy industry is both inspired by these ambitions and challenged by high initial costs, supply chain dependencies, and the need for localized manufacturing that we must overcome.

This report on Comprehensive Analysis of BESS and Pumped Hydro Storage in India (2024) by CII shares the challenges and immense opportunities within India's Energy Storage Systems (ESS) landscape, particularly Battery Energy Storage Systems (BESS) and Pumped Hydro Storage (PHS). Projections shown here indicate a monumental expansion of ESS capabilities, driven by government initiatives such as the Production Linked Incentive (PLI) scheme, Viability Gap Funding (VGF), and policies supporting local manufacturing of advanced battery components.

Given these challenges, battery recycling emerges as a crucial factor for the overall sustainability and resilience of the clean energy ecosystem. Recycling can significantly mitigate the environmental impact of battery disposal while recovering valuable raw materials, reducing dependency on imports, and closing the material loop for a circular economy. With India projected to reach 600 GWh in cumulative lithium-ion battery stock by 2030, a comprehensive recycling infrastructure is essential to recover critical resources like lithium, cobalt, and nickel, ensuring resource availability and cost efficiency in the long term.

As the report highlights, overcoming these challenges will require sustained commitment, innovation, and collaboration across industry and government. The path ahead is complex but promising, and as stakeholders, we have a unique opportunity to build a clean energy ecosystem that is both resilient and responsible. This report serves as a guide for navigating the evolving ESS landscape, offering insights that will drive India's journey toward a sustainable energy future.

The sector's expansion will pave the way for cleaner, smarter energy systems, not just for India but globally. The global and domestic momentum towards electrification and decarbonization is driving innovation, policy shifts, and investments in energy storage and Epsilon Group is excited to be of this mission of clean energy transition to a greener & sustainable future.

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CHAPTER 1: Executive Summary

In alignment with its COP 26 commitments (*Panchamrit*) for climate action, India has set ambitious targets:

- Attain 500 GW of non-fossil energy capacity by 2030.
- Accomplish 50% of its energy requirements from renewable energy by 2030.
- Reduce projected total CO2 emissions by 1 billion tons by 2030.
- Achieve net zero emissions by 2070.
- Reduce the carbon intensity of the economy by 45% by 2030, which is over 2005 levels.

To achieve these targets, the country is focusing on enhancing its energy security and emerging as a global leader in technology, innovation, and manufacturing. A critical component of this strategy is the development and integration of Energy Storage Systems (ESS), including Battery Energy Storage Systems (BESS) and Pumped Hydro Storage (PHS).

India's Battery Energy Storage Systems (BESS) are poised for substantial growth according to the projections indicating an increase to 8.68 GW/34.72 GWh from 2022 to 2027, and further expansion to 47.24 GW/236.22 GWh from 2027 to 2032.

As per the National Electricity Plan, 2023, India's Battery Energy Storage System (BESS) is poised for substantial growth, wherein the projections indicate an increase to 8.68 GW/34.72 GWh from 2022 to 2027 and further expansion to 47.24 GW/236.22 GWh from 2027 to 2032. Key government initiatives like the Production Linked Incentive (PLI) scheme and Viability Gap Funding (VGF) are designed to support this growth. However, challenges such as high costs, limited domestic manufacturing capabilities, and dependence on imports for critical raw materials need to be addressed to ensure successful implementation.

Pumped Hydro Storage (PHS) is also a critical component of India's energy strategy. As per the **Central Electricity Authority (CEA),** the current installed capacity of 4.75 GW is projected to increase to 18.8 GW by 2031-32. The government is promoting PHS development through waivers for Inter-State Transmission System (ISTS) charges and financial incentives. Despite these efforts, PHS projects face challenges such as long gestation periods and regulatory hurdles, which must be managed to achieve the desired expansion and integration into the energy grid.

India's commitment to developing such storage systems is crucial for achieving its renewable energy goals and ensuring a stable and reliable power supply in upcoming years. The government's supportive policies, technological advancements, and significant investments are driving this progress. However, overcoming challenges related to high costs, raw material dependencies, and regulatory hurdles is essential for the successful deployment and integration of these systems.

This report highlights the current state, challenges, and prospects of Energy Storage Systems in India's renewable energy landscape, providing insights and recommendations for stakeholders.

CHAPTER 2: Introduction

India is advancing rapidly towards its renewable energy goals, driven by commitments under the Paris Agreement and COP26. Central to this effort is the development of Energy Storage Systems (ESS), particularly Battery Energy Storage Systems (BESS) and Pumped Hydro Storage (PHS), which are crucial for enhancing grid stability, ensuring a reliable power supply, and facilitating the integration of variable renewable energy sources like solar and wind power. As of May 2024, India's renewable energy capacity reached 193.57 GW, with significant contributions from solar and wind power. The country aims to achieve 500 GW of non-fossil fuel energy capacity by 2030, highlighting its commitment to reducing carbon emissions and bolstering energy efficiency.

Despite this progress, several challenges need to be addressed for the successful deployment of ESS. High initial capital costs with limited domestic manufacturing capabilities for key components, and dependence on imports for critical raw materials are significant obstacles. To mitigate these issues, the Indian government has introduced various policies, including the Production Linked Incentive (PLI) scheme for advanced chemistry cell batteries and Viability Gap Funding (VGF) for BESS projects. Additionally, strategic partnerships and investments are being made to secure raw materials and develop a robust supply chain for battery manufacturing.

Government initiatives are indeed pivotal in advancing energy storage systems (ESS) in India. The *National Green Hydrogen Mission*, launched to make India a global hub for green hydrogen, aims to integrate renewable energy sources and promote ESS technology. This initiative is designed to support both decarbonization and energy independence through hydrogen-based energy solutions, making ESS critical for balancing grid fluctuations caused by renewable energy variability.

Moreover, the *PM-Surya Ghar: Muft Bijli Yojana*, approved in February 2024, focuses on increasing the share of solar energy in the national grid by providing significant financial incentives for rooftop solar installations. It offers up to 60% subsidy for systems up to 2kW, promoting solar energy generation at the residential level, which indirectly boosts the integration of energy storage solutions for managing surplus solar power. The scheme aims to strengthen the adoption of solar power across India, contributing to reduced reliance on conventional energy sources.

These programs are supported by additional policies, including waivers for Inter-State Transmission System (ISTS) charges, encouraging financial investments in domestic energy storage manufacturing and further enhancing renewable energy adoption. With these efforts, India is poised to achieve substantial progress in ESS technology, which will be crucial for maintaining a sustainable and resilient energy infrastructure.

CHAPTER 3: India Renewable Energy Landscape

India, recognized as the world's third-largest carbon emitter, has embarked on an ambitious journey toward sustainable energy. With a commitment to achieving net-zero emissions by 2070, India has made remarkable progress in expanding its renewable energy capacity and reducing its carbon intensity. Despite high initial capital expenditures, long gestation periods for projects, and a lack of domestic manufacturing capabilities for key components, the renewable energy landscape has evolved significantly. This section provides a detailed examination of the historical and current landscape of India's renewable energy sector, the government's policies and commitments driving this transformation, and the crucial role of Energy Storage Systems (ESS) in achieving these goals.

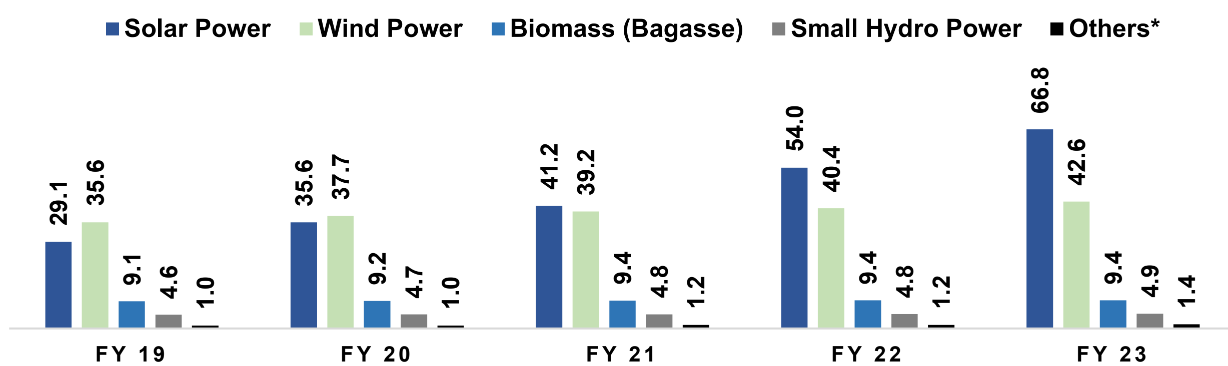
3.1 Historical Evolution & Current Landscape

India's journey towards renewable energy has been marked by significant milestones and a strong commitment to sustainable development. Post-independence, the country's energy landscape was dominated by fossil fuels, primarily coal, which accounted for a substantial portion of electricity generation. The shift towards renewable energy began in earnest in the early 2000s, driven by various government initiatives aimed at promoting cleaner energy sources. A pivotal moment was the launch of the National Solar Mission in 2010, which set targets for solar energy capacity. This initiative not only spurred extensive investments and technological advancements in the solar sector but also laid the groundwork for India's broader renewable energy strategy.

In 2015, as a signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and its Paris Agreement, India submitted its first Nationally Determined Contribution (NDC). This included targets to reduce the emissions intensity of its GDP by 33-35% by 2030 from 2005 levels, and to achieve 40% cumulative electric power installed capacity from non-fossil fuel sources by 2030.

By October 2023, India had surpassed these targets, with non-fossil fuel sources accounting for 43.81% of the total installed capacity. Additionally, the emission intensity of GDP was reduced by 33% between 2005 and 2019. In August 2022, India updated its NDC, setting more ambitious goals: a 45% reduction in GDP emissions intensity by 2030 from 2005 levels, and increasing the share of cumulative electric power installed capacity from non-fossil fuel sources to 50% by 2030.

Figure 1: India Installed Renewable Energy Capacity, By Source, FY20 – FY23 (In GW)



**Others include Biomass (Non-bagasse), Waste to Power & Waste to Energy (Off-grid)* *Source: Ministry of New & Renewable Energy & CEA*

As of May 2024, India's renewable energy capacity reached 193.57 GW including 84.27 GW from solar power and 46.42 GW from wind power. **The Ministry of New and Renewable Energy (MNRE)** reported that the country is on track to meet its ambitious goals, driven by extensive investments and supportive policies. The Power Ministry estimates a more than 83% increase in investments in renewable energy projects to around $16.5 billion in 2024, underscoring the nation's focus on energy transition to reduce carbon emissions. This aligns with the broader goal of having 500 GW of renewable energy by 2030 and reducing the overall power generation capacity from fossil fuels to less than 50%. Additionally, India's leadership in promoting solar energy is exemplified by its spearheading role in the International Solar Alliance (ISA), which aims to increase solar technology deployment and reduce dependence on fossil fuels among its 107 member countries.

Figure 2: India Installed Renewable Energy Capacity, By Source, 2023-2030 (In %)

Source: Ministry of New & Renewable Energy & CEA

As per forecasts by **the Central Electricity Authority (CEA),** achieving the milestone of 500 GW in non-fossil fuel energy, as announced at COP26, could potentially be attained by aggregating around 435 GW from wind, solar, and other renewable energy sources, 61 GW from large hydro, and 19 GW from nuclear energy. The **CEA's 'Optimal Generation Mix 2030'** report projects a substantial rise in peak power demand, expected to reach 366 GW by 2030, a significant increase from the current 243 GW. Consequently, India aims to nearly double its power capacity to approximately 900 GW by 2030, up from the current 427 GW, with 50% of this energy requirement expected to be fulfilled by renewable sources.

Furthermore, the country has outlined its goals at the **26th Conference of the Parties (COP26)** to the United Nations Framework Convention on Climate Change (UNFCCC) in Glasgow through the "*Panchamrit*", comprising five key elements:

- Achieving 500 GW of Non-Fossil Energy Capacity by 2030: India aims to install 500 GW of renewable energy capacity, including solar, wind, and other renewable sources, by 2030.

- Meeting 50% of Energy Requirements from Renewable Sources by 2030: India plans to meet half of its energy needs from renewable sources, significantly reducing dependence on fossil fuels.

- Reducing Total Projected Carbon Emissions by One Billion Tonnes by 2030: This ambitious target aims to cut India's carbon emissions by one billion tonnes, contributing substantially to global efforts to combat climate change.

- Reducing Carbon Intensity by 45% by 2030: Over 2005 levels, India seeks to enhance energy efficiency and promote low-carbon growth.

- Achieving Net Zero Emissions by 2070: Aligning with global climate goals, India has committed to achieving net-zero emissions by 2070.

3.2 Government Policies

India's renewable energy landscape has undergone a remarkable transformation over the past decade, driven by a series of ambitious government policies and strategic initiatives. The country has set an enhanced target of 500 GW of non-fossil fuel-based energy by 2030, a key pledge under the *Panchamrit* initiative at COP26, marking the world's largest expansion plan in renewable energy. The Indian government has implemented a comprehensive array of policies and commitments to support its renewable energy goals, driving significant investments and technological advancements across the sector.

PM-Surya Ghar: Muft Bijli Yojana (2024)

Launched in February 2024, the PM-Surya Ghar: Muft Bijli Yojana aims to install rooftop solar systems in one crore households, providing up to 300 units of free electricity per month. The scheme includes Central Financial Assistance (CFA) covering up to 60% of the system cost for 2 kW systems and additional assistance for systems up to 3 kW. The initiative also supports collateral-free low-interest loans for installations up to 3 kW, the development of model solar villages in each district, and incentives for urban local bodies and Panchayati Raj Institutions to promote rooftop solar installations. This program is expected to add 30 GW of solar capacity, create around 17 lakh direct jobs, and significantly reduce CO_2 emissions over the lifetime of the rooftop systems.

National Green Hydrogen Mission (2023)

With an initial budget of INR 19,744 crore, the National Green Hydrogen Mission focuses on establishing India as a global hub for green hydrogen production, utilization, and export. The mission includes the production of 5 million metric tonnes of green hydrogen per year by 2030 and is supported by investments in Electrolyzer manufacturing. It aims to enhance energy security, reduce dependence on fossil fuels, and create export opportunities. The mission also includes incentives under the Strategic Interventions for Green Hydrogen Transition (SIGHT) programme, with significant funds allocated for pilot projects, research and development, and other mission components.

Green Energy Corridors (GEC) (2024)

The Green Energy Corridors project is designed to enhance the grid infrastructure for renewable energy integration. Phase I and II of the projects aim to create an intra-state transmission system for renewable energy projects across ten states. This initiative includes Central Financial Assistance (CFA) to establish transmission infrastructure for the evacuation of power from renewable energy projects, ensuring efficient and reliable delivery of renewable energy to the grid.

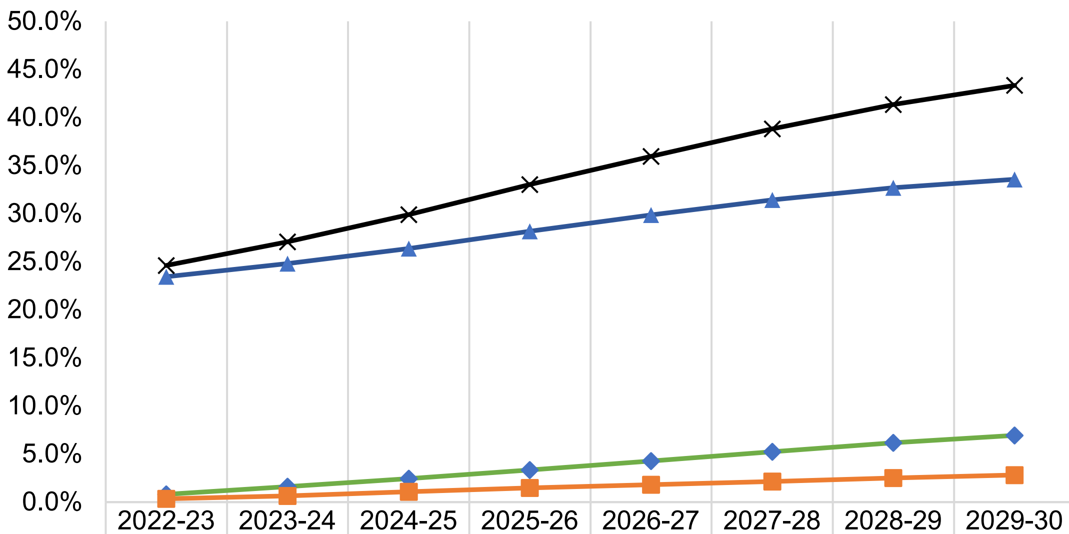
Production Linked Incentive (PLI) Scheme for Solar PV Modules (2022)

The second tranche of the National Programme on High-Efficiency Solar PV Modules, with an outlay of INR 19,500 crore, aims to build significant manufacturing capacity for high-efficiency solar PV modules. The PLI scheme provides financial incentives linked to the sale of domestically manufactured solar modules, encouraging the use of advanced technologies, and reducing dependence on imports. This initiative is crucial for enhancing India's renewable energy infrastructure and supporting the country's goal of achieving 500 GW of non-fossil fuel-based energy capacity by 2030.

Renewable Purchase Obligation (RPO) (2024)

The Renewable Purchase Obligation (RPO) targets, **notified under the Indian Electricity Act, 2003**, have recently mandated that 29.91% of total energy must come from renewable sources by 2024-25, increasing to 43.33% by 2029-30. The RPO also introduces separate targets for distributed renewable energy (DRE). This policy ensures a consistent increase in renewable energy adoption across various sectors, aiding in long-term energy planning and contributing to India's climate goals.

Figure 3: Renewable Purchase Obligation, By Source, 2023-2030



	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
Wind RPO	0.8%	1.6%	2.5%	3.4%	4.3%	5.2%	6.2%	6.9%
HPO	0.4%	0.7%	1.1%	1.5%	1.8%	2.2%	2.5%	2.8%
Other RPO	23.4%	24.8%	26.4%	28.2%	29.9%	31.4%	32.7%	33.6%
Total	24.6%	27.1%	29.9%	33.0%	36.0%	38.8%	41.4%	43.3%

Source: Ministry of Power, 6Wresearch

Furthermore, schemes such as the ***Pradhan Mantri Kisan Urja Suraksha evam Utthan Mahabhiyan*** **(PM-KUSUM)** scheme, launched in 2019, which focuses on promoting decentralized solar energy through the solarization of agricultural pumps and small-scale solar power plants, and the **Rooftop Solar Programme Phase II** which aims to promote the installation of grid-connected rooftop solar power plants across residential sectors, has also been supporting the renewable energy landscape in India.

India's proactive and strategic approach to renewable energy development is reflected in the various schemes and policies aimed at boosting sustainable energy sources. The government's initiatives, from rooftop solar programs to green hydrogen missions, showcase its commitment to reducing carbon emissions and enhancing energy security.

3.3 Role of Energy Storage Systems in India's Renewable Energy Goals

Energy Storage Systems (ESS) are pivotal in achieving India's ambitious renewable energy targets. With the goal of reaching 50% cumulative installed capacity from non-fossil fuel sources by 2030, ESS addresses the challenges associated with the integration of variable renewable energy sources like solar and wind.

Energy Storage Systems contribute significantly to grid stability and flexibility. They balance supply and demand by storing excess energy generated during periods of high renewable output and releasing it during peak demand. This capability is crucial for maintaining a stable and reliable grid, particularly with the intermittent nature of solar and wind energy. Additionally, ESS provides essential services such as frequency and voltage regulation, which are vital for the operational integrity of the power system. ESS also plays a critical role in peak shaving and load shifting, thereby reducing the need for additional generation capacity, and lowering overall energy costs. By storing energy during low-demand periods and discharging it during peak hours, ESS ensures the efficient utilization of renewable energy and decreases reliance on fossil fuels. Furthermore, ESS minimizes renewable energy curtailment by storing surplus generation, ensuring maximum utilization of resources.

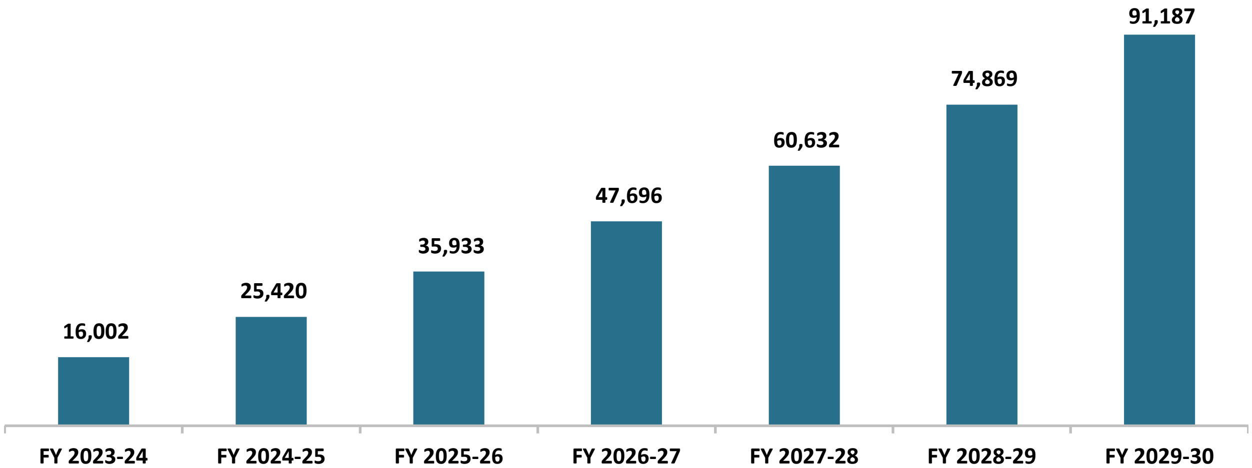
For instance, as highlighted by **the National Electricity Plan**, pumped storage plants, with their long-life spans of around 40 years and efficiency ranges of 70-80%, provide significant peaking power and grid stability benefits by storing and releasing energy as needed. This storage capacity is critical for maintaining a consistent power supply during non-solar hours, thereby enhancing the overall reliability of renewable energy sources. The plan also emphasizes the role of BESS, particularly lithium-ion batteries, which offer high energy density and efficiency of around 88-90%. BESS is instrumental in providing ancillary services such as frequency regulation, voltage support, and energy arbitrage.

At the transmission and distribution levels, ESS optimizes infrastructure by maximizing the use of transmission assets, reducing congestion, and deferring the need for upgrades. ESS enhances grid resilience and flexibility, particularly in load centers, improving power supply reliability. Standalone ESS applications, such as those providing energy for electric vehicles or operating in V2X scenarios, highlight their versatility and importance. Looking forward, the projected increase in ESS demand to 320 GW by 2047 underscores its growing importance. Advanced technologies like liquid metal batteries, gravity storage, and green hydrogen storage promise to further enhance efficiency and reduce costs. Sustainable practices, including battery recycling and the promotion of a circular economy, ensure minimal environmental impact and maximum resource recovery, reinforcing the essential role of ESS in India's renewable energy landscape.

The government's policies, including the **Energy Storage Obligations (ESO)** that mandate increasing storage requirements from 1% in FY2023-24 to 4% in FY2029-30, are designed to promote the widespread adoption of BESS. Additionally, the Viability Gap Funding (VGF) scheme approved in September 2023 supports the development of 4,000 MWh of BESS capacity by providing financial assistance up to 40% of the capital cost scheme aims to achieve a levelized cost of storage between

Rs 5.50 and Rs 6.60 per kilowatt-hour, making stored renewable energy a viable option for managing peak power demand. Storage would also be necessary for reliable supply and grid stability as the share of variable renewable energy (VRE) would go up sharply from the existing level of around 10%.

Figure 4: Growth in Storage Obligations by FY2029-30 (In GWh)



Source: 6Wresearch, CEEW Study based on CEA 2022 and MoP 2022

CHAPTER 4: Energy Storage Systems

Energy Storage Systems (ESS) have emerged as a fundamental element in India's energy landscape, especially given the country's progressive renewable energy goals Energy Storage Systems (ESS) encompass a range of technologies designed to store electrical energy for future use. These systems store energy during periods of low demand and release it during peak demand, thus balancing the supply and demand dynamics of the power grid. ESS ensure a stable and reliable power supply, particularly critical when integrating intermittent renewable energy sources such as solar and wind. The technologies span battery-based systems, mechanical storage solutions, and thermal storage, each offering unique benefits suited to different energy storage needs.

4.1 Types of Energy Storage Systems

Battery Energy Storage Systems (BESS)

- **Lithium-ion Batteries**: Lithium-ion batteries represent the forefront of energy storage technology due to their superior energy density, high efficiency, and rapidly declining costs. These batteries are predominantly utilized in grid-scale storage projects, electric vehicles (EVs), and various consumer electronics. Their role in India's energy landscape is expected to expand significantly as the country advances towards its renewable energy goals and electric mobility initiatives. Lithium-ion batteries are critical for stabilizing the grid by storing excess energy generated during peak renewable production periods and discharging it during times of high demand, thus ensuring a reliable and efficient power supply.

- **Flow Batteries**: Flow batteries, including vanadium redox and zinc-bromine variants, offer distinct advantages in scalability and longevity. These batteries operate by circulating liquid electrolytes through a system of pumps and tanks, allowing for flexible scaling to meet large energy storage requirements. Flow batteries are particularly suitable for applications requiring long-duration storage and frequent cycling, such as renewable energy integration and grid stabilization. Their ability to separate power and energy capacities provides a tailored solution for diverse energy storage needs.

- **Lead-acid Batteries**: Although older than lithium-ion and flow batteries, lead-acid batteries remain relevant due to their cost-effectiveness and robustness. They are extensively used in backup power systems, off-grid energy solutions, and various industrial applications. Advanced configurations, such as lead-carbon and bipolar lead-acid batteries, have enhanced their performance, making them viable for frequency regulation and other grid services. Lead-acid batteries provide a reliable and economically feasible option for short-term energy storage and backup power.

Pumped Hydro Storage (PHS)

Pumped Hydro Storage (PHS) is a technically mature and widely adopted energy storage technology that utilizes gravitational potential energy. During periods of low electricity demand, surplus energy is used to pump water from a lower reservoir to an upper reservoir. During peak demand, the stored water is released to flow back down through turbines, generating electricity. PHS is particularly advantageous due to its large-scale energy storage capacity and long operational life. It plays a pivotal role in balancing supply and demand, providing grid stability, and integrating renewable energy sources by offering significant storage capabilities and quick response times.

Compressed Air Energy Storage (CAES)

Compressed Air Energy Storage (CAES) systems function by compressing air and storing it in underground caverns or high-pressure containers. When electricity demand is high, the compressed air is heated and expanded to drive turbines and generate electricity. CAES offers an efficient solution for long-duration energy storage, capable of providing large-scale energy storage with minimal environmental impact. The integration of advanced heat storage techniques can further enhance the efficiency and sustainability of CAES systems. This technology is particularly suited for grid-scale applications where long-term storage and high energy output are required.

Flywheel Energy Storage (FES)

Flywheel Energy Storage (FES) systems store kinetic energy in a rotating mass. The flywheel is accelerated to high speeds, and the energy is stored as rotational energy. When needed, the kinetic energy is converted back into electrical energy through a generator. FES systems are characterized by their high-power density, rapid response times, and long cycle life. They are particularly effective for applications requiring frequent and rapid energy discharge, such as frequency regulation, uninterruptible power supply (UPS), and other high-power grid services. The robust design and minimal maintenance requirements make FES an attractive option for enhancing grid stability and reliability.

Thermal Energy Storage (TES)

Thermal Energy Storage (TES) systems capture and store energy in the form of heat or cold for later use. These systems are commonly employed in Concentrated Solar Power (CSP) plants, where solar energy is used to heat a medium such as molten salts. The stored thermal energy can be used to generate electricity during non-sunny periods, ensuring a continuous power supply. TES systems offer high efficiency and long-duration storage capabilities, making them ideal for balancing intermittent renewable energy sources. They also have applications in industrial processes, district heating and cooling, and enhancing the overall efficiency of energy systems.

Table 1: Comparison Of ESS, By Technologies

Factors	Pumped Hydro Storage	Compressed Air Energy Storage	Flywheel	Thermal Energy Storage	Lead Acid Batteries	Li-ion Batteries	Flow Batteries
High Round Trip Efficiency							
Fast Response Time							
Long Lifetime							
Technology Readiness							
Low Capital Cost							
High Energy Density							
High Power Rating							
Indigenous Capability in India							
Less space Required							
Short construction period							
Applications	Bulk Power Management	Bulk Power Management	Grid Support, UPS	Grid Support	Grid Support, UPS	Grid Support, UPS	Grid Support

Source: CEEW, CEA 2022 and Ministry of Power Report, 2022

4.2 Functions of Energy Storage Systems

Energy Storage Systems (ESS) are pivotal in enhancing the stability and reliability of the power grid in India. They provide essential services such as frequency regulation, voltage support, and spinning reserves, maintaining real-time grid balance. ESS facilitates the integration of renewable energy sources by storing excess energy during peak production and releasing it during high-demand periods, ensuring a steady and reliable power supply. Additionally, ESS contributes to peak shaving and load levelling, reducing the need for peaking power plants and lowering overall energy costs. By enabling energy arbitrage, ESS allows utilities and consumers to benefit from price differentials in electricity markets, charging during low-price periods and discharging when prices are high. They also enhance system resilience by providing backup power during grid outages, ensuring continuous power supply to critical services.

India's Energy Storage Systems (ESS) are integral to large-scale renewable energy projects such as the Solar Energy Corporation of India's (SECI) solar-plus-storage tenders and the National Thermal Power Corporation's (NTPC) standalone ESS initiatives. SECI's tenders, designed to facilitate solar energy storage, provide a model for incorporating significant renewable capacity into the national grid. NTPC's standalone ESS projects, such as the 100MW/400MWh battery storage project in Telangana, further exemplify the country's commitment to grid stability and renewable integration. These projects highlight how ESS can smooth variable renewable energy sources like solar and wind, ensuring more reliable and resilient energy infrastructure.

In commercial and industrial settings, ESS is widely used for demand charge management and uninterruptible power supply (UPS). By reducing peak demand from the grid, ESS helps commercial and industrial users lower their demand charges, resulting in significant cost savings. In residential applications, ESS are increasingly paired with rooftop solar installations to store excess solar energy generated during the day for use during night-time or cloudy periods. This not only enhances energy independence but also reduces reliance on the grid, leading to lower electricity bills

Energy Storage Systems are indispensable to India's journey towards a sustainable and resilient energy future. By addressing the challenges of renewable energy integration, grid stability, and energy security, ESS supports the nation's ambitious renewable energy targets and paves the way for a cleaner, more efficient power system. With ongoing advancements in technology and supportive policy frameworks, the deployment of diverse ESS technologies will continue to play a crucial role in shaping India's energy landscape in the coming decades.

CHAPTER 5: Battery Energy Storage Systems

5.1 Overview

Battery Energy Storage Systems (BESS) are transformative in modern energy management, ensuring stable and reliable power supply by balancing the intermittency of renewable sources like solar and wind. By storing excess energy during low demand and discharging it during peak periods, BESS enhance grid stability and reduce reliance on fossil fuel-based plants. Furthermore, recent technological advancements such as vanadium redox flow batteries and sodium-ion batteries have made batteries more efficient and cost-effective, while regulatory support has spurred their adoption. BESS provides economic benefits through peak shaving and demand charge management, and they offer new revenue opportunities in energy markets. They also enhance grid resilience by providing backup power during outages and supporting microgrids in remote areas. Environmentally, BESS facilitates greater use of renewable energy and reduces greenhouse gas emissions. Overall, BESS is crucial for modernizing the power grid, improving reliability and efficiency, and advancing sustainable energy solutions.

5.2 Understanding Cell Chemistries

Different types of batteries have unique features and suitability. The most important feature of batteries is their rapid response time, which makes them suitable for enhanced frequency regulation and voltage support, enabling the integration of VRE into electricity grids. They have high reliability and low self-discharge rates. They can provide almost all electricity services, except seasonal storage. Their main drawbacks include relatively short lifetimes and the use of hazardous or costly materials in some variants.

Lithium-Ion (Li-ion) Batteries

Lithium-ion batteries are the most prevalent type used in battery storage systems due to their high energy density, long cycle life, and decreasing costs. These batteries are suitable for a broad range of applications, from consumer electronics to grid-scale storage. Within this category, Lithium Iron Phosphate (LFP) batteries are favoured for their safety and long cycle life, while Nickel Manganese Cobalt (NMC) and Nickel Cobalt Aluminium (NCA) chemistries are preferred in applications requiring high energy density, such as electric vehicles and home energy storage. Their efficiency, relatively low maintenance, and scalability make lithium-ion batteries ideal for both stationary and mobile applications.

Lead-Acid Batteries

Despite being an older technology, lead-acid batteries are still in use due to their low cost and reliability. They are primarily deployed in backup power supplies and off-grid settings. Lead-acid batteries are valued for their proven technology and low initial cost, making them a practical choice for certain applications despite their lower energy density and shorter lifespan compared to lithium-ion batteries.

Nickel-Cadmium (Ni-Cd) Batteries

Nickel-cadmium batteries are known for their robustness and ability to perform in extreme temperatures. These batteries are used in industrial applications and aviation, where durability and long service life are critical. However, their use is limited by environmental concerns due to the toxicity of cadmium.

Flow Batteries

Flow batteries, such as vanadium redox batteries, offer the advantage of long operational life and scalability. They are particularly suitable for large-scale energy storage systems due to their ability to handle extensive cycling without significant degradation. Flow batteries do not exhibit performance degradation over time, making them a promising technology for stationary storage applications.

Table 2: Battery Technologies and Their Characteristics

Energy Storage System Attributes	Lead Acid	Li-Ion	NaS	Flow Batteries
Round Trip Energy Efficiency (Dc-Dc)	70-85%	85-95%	70-80%	60-75%
Range of Discharge Duration	2-6 Hours	0.25–4+ Hours	0.25–4+ Hours	4-12 Hours
C Rate	C/6 to C/2	C/6 to 4C	C/8 to C/6	C/12 to C/4
Cost Range Per Energy Available at Full Discharge ($/kWh)	100-300	250-800	400-600	400-1000
Development & Construction Period	6 months - 1 year	6 months - 1 year	6 months - 1.5 year	6 months - 1.5 year
Operating Cost	High	Low	Moderate	Moderate
Estimated Space Required	Large	Small	Moderate	Moderate
Cycle Life: f Discharges of Stored Energy	500-2000	2000 -10,000+	3000-5000	5000 - 8000+
Maturity Of Technology	Mature	Commercial	Commercial	Early to moderate

Source: CEA 2022 and Ministry of Power Report, 2022

5.3 Current Capacity of BESS in India

India's Battery energy storage landscape is witnessing substantial growth. As of March 2023, the installed capacity for BESS in India stood at over 33 MW/37 MWh. The Central Electricity Authority (CEA) projects this capacity to escalate significantly, targeting 41.7 GW/208 GWh by 2030. However, the deployment of grid-scale BESS has been relatively slow, with the first such system being commissioned in 2019 by Tata Power in Rohini, Delhi. Noteworthy projects include a 1 MW/0.5 MWh pilot project in Puducherry by PGCIL, which combines Advanced Lead-acid and Li-ion (LFP) technologies, a 16 MW/8 MWh BESS project in the Andaman & Nicobar Islands by NLC, and a 510 kWh Advanced Lead-acid & Li-ion project in Sahibabad by CEL. These initial projects reflect the diverse technological strategies being adopted in India's nascent BESS market.

The recent surge in BESS projects highlights a growing commitment to energy storage as an integral part of India's energy infrastructure. In 2024, the Solar Energy

Corporation of India Limited (SECI) commissioned the country's largest BESS in Rajnandgaon, Chhattisgarh. This system, integrated with a solar photovoltaic (PV) plant, has an installed capacity of 152.325 MWh and a dispatchable capacity of 100 MW AC. The 40 MW/120 MWh BESS, which stores energy using solar power, marks a significant milestone in India's renewable energy initiatives. The energy produced is purchased by the state of Chhattisgarh, contributing to meeting peak energy demands with green energy and supporting its renewable purchase obligations. Such large-scale projects exemplify the growing scale and ambition within India's BESS sector.

Table 3: Status of Key BESS Projects

Project	Location	Capacity	Status	Completion
SECI Rajnandgaon Solar + BESS Project	Chhattisgarh	152.325 MWh (100 MW AC)	Operational	February 2024
Larsen & Toubro Solar + BESS Project	Bihar	254 MWh (185 MW solar)	Under Construction	--
BRPL Kilokari Standalone BESS	Delhi	40 MWh (20 MW)	Under Construction	End of 2024
IndiGrid BESS Project	Gujarat	360 MWh (180 MW)	Under Construction	--
IndiGrid BESS Project	Delhi	40 MWh (20 MW)	Under Construction	2026

Source: 6Wresearch, Ministry of Power, CEA

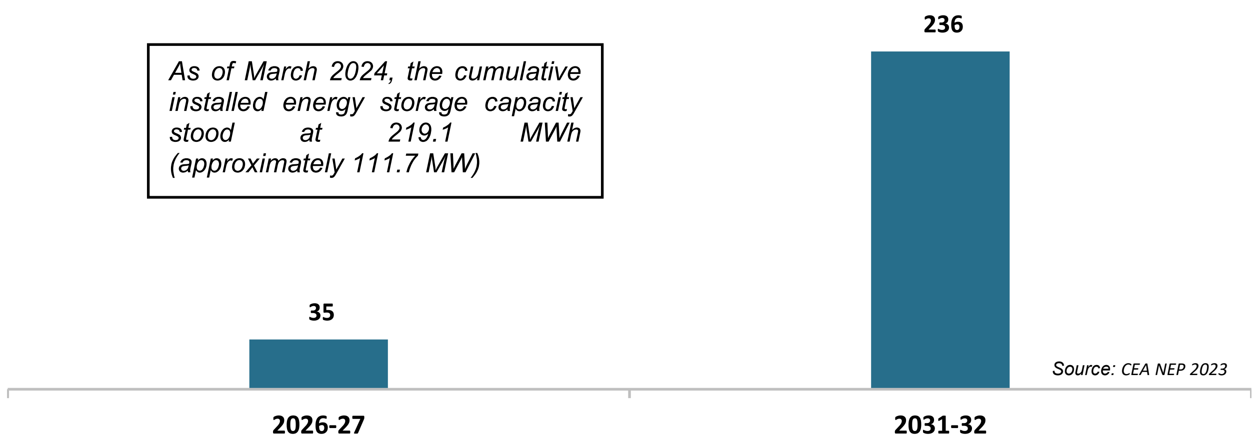
Table 4: BESS to be set under the Transmission Schemes for 500 GW RE, By States, 2022

Location	BESS Capacity (GW)
Rajasthan	22.5
Maharashtra	1.1
Andhra Pradesh	14
Karnataka	3
Telangana	3

Source: CEA, Ministry of Power Report

Looking ahead, numerous BESS projects are in development, poised to further expand India's energy storage capabilities. For example, Sun Source Energy is planning a 2.15 MWh system in Lakshadweep, Tata Power is working on systems with capacities of 60.56 MWh and 120 MWh in Ladakh and Chhattisgarh, respectively, and JSW Renew Energy is planning two standalone battery energy systems, each with a capacity of 500 MWh. While lead-acid batteries are primarily confined to behind-the-meter applications, commercial grid-scale flow battery pilots, such as vanadium redox batteries in Bangalore and Hyderabad, suggest future potential. The continued development of these projects, along with supportive policies and significant investments, positions India to make substantial advancements in energy storage, which is critical for its transition to renewable energy.

Figure 5: BESS Projected Requirement (In GWh)



5.4 Demand Forecast in Upcoming Years

India's goal of achieving 500 GW of non-fossil energy capacity necessitates the development of a robust Battery Energy Storage Systems (BESS) ecosystem, expected to exceed 238 GWh in capacity by 2032. Additionally, the **National Renewable Energy Laboratory (NREL)** forecasts that BESS will significantly contribute to the capacity mix by 2047, with an estimated 237 GW or 13% of the total installed capacity. This anticipated increase in BESS capacity after 2030 is driven by falling capital costs and the accelerated deployment of renewable energy (RE) sources. These projections highlight the need for India to be prepared to integrate a substantial volume of renewables into its power grid to ensure a stable and reliable energy supply.

The Central Electricity Authority's (CEA) National Electricity Plan (NEP) 2023 provides a detailed forecast of energy storage capacity requirements, indicating a clear growth trajectory. By 2026-27, the projected requirement stands at 34.72 GWh from BESS. This requirement is expected to increase significantly to 236.22 GWh by 2031-32. Further projections by the CEA indicate that by 2047, the energy storage requirement will soar to 1840 GWh from BESS, thereby reflecting the growing necessity for energy storage solutions to support the large-scale integration of renewable energy, particularly considering India's commitment to achieving net-zero emissions by 2070. Additionally, the funds requirement for BESS is projected to be Rs. 566.47 billion for the period 2022-2027, supporting a capacity of 8.68 GW/34.72 GWh. For the subsequent period of 2027-2032, the required investment jumps significantly to Rs. 2926.37 billion to achieve a capacity of 47.24 GW/236.22 GWh. By 2047, the installed capacity is projected to reach 230 GW/1840 GWh, although the exact funding requirements for this period have yet to be detailed.

Table 5: Projected Capacity and Funds Requirement for BESS

Year	Capacity (GW/GWh)	Funds Requirement (Rs. Billion)
2022-2027	8.68/34.72	566.47
2027-2032	47.24/236.22	2926.37

Moreover, to ensure adequate storage capacity, the Ministry of Power has established a long-term trajectory for Energy Storage Obligations (ESO). This trajectory mandates a gradual increase in storage capacity requirements from 1% in FY 2023-24 to 4% by FY 2029-30, with an annual increment of 0.5%. Compliance with these obligations requires that at least 85% of the total energy stored annually be sourced from renewable energy. These regulatory measures aim to foster the development of a strong energy storage infrastructure, enabling India to meet its renewable energy targets and maintain grid stability. The ongoing expansion of BESS capacity underscores the strategic importance of energy storage in India's transition to a sustainable energy future.

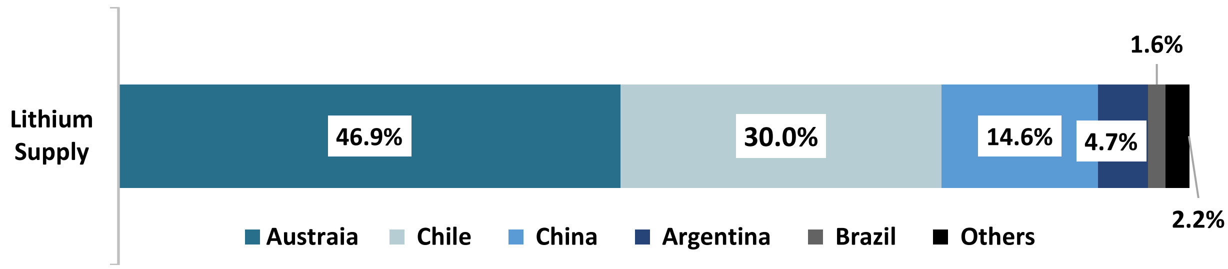
5.5 Value Chain Analysis

India's battery supply chain is evolving rapidly, driven by the burgeoning demand for electric vehicles (EVs) and renewable energy storage solutions. The value chain encompasses several critical stages, including the extraction of raw materials, processing, cell component production, and the integration of these components into complete battery packs. Presently in India, either the cells are imported and are assembled into battery packs or the entire battery packs are imported. The Indian Ministry of Heavy Industries has come up with a new Production-Linked Incentive (PLI) scheme to encourage domestic manufacturing of ACCs, which includes LIBs. Through this scheme, the Government of India (GoI) envisages reducing the dependency on imports for LIB cells.

5.5.1 Raw Material Extraction and Processing

Raw material sourcing for cell manufacturing is not well established, with limited resources in the country. As such, India is expected to continue depending on imports of the raw materials required for LIB cell manufacturing.

Figure 6: Global Lithium Supply % Share, By Countries, 2022

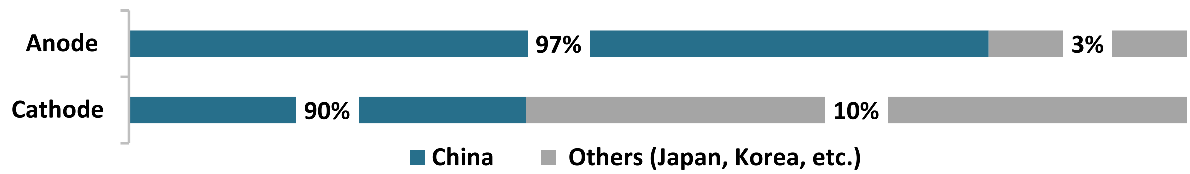


Source: US Geological Survey and US Department of the Interior, 2023; JRC, 2020; USGS, 2023b

This involves mining raw materials such as lithium, cobalt, and nickel, essential for battery production. India currently lacks significant domestic lithium extraction capabilities. Most of the lithium used in India is imported from countries such as Australia, Chile, and China, which dominate the global lithium supply. Efforts are being made to identify and develop local lithium reserves, such as those in Jammu, but these initiatives are still in the exploration and early development stages. Government-to-government collaborations and joint ventures, like Khanij Bidesh India Ltd. (KABIL), aim to secure lithium supplies from international sources, reflecting India's heavy reliance on imports for raw lithium. Once extracted, raw materials are refined and processed into battery-grade materials. The processing of lithium and other essential materials for battery production is another area where India is highly dependent on imports, particularly from China. The country currently lacks the infrastructure and technological capabilities to refine and process lithium domestically. Most of the processed lithium and other materials like cobalt and nickel are imported, adding to the overall cost and complexity of the supply chain.

5.5.2 Cell Components Production

Figure 7: Global Anode & Cathode Supply % Share, By Countries, 2022



Source: IEA

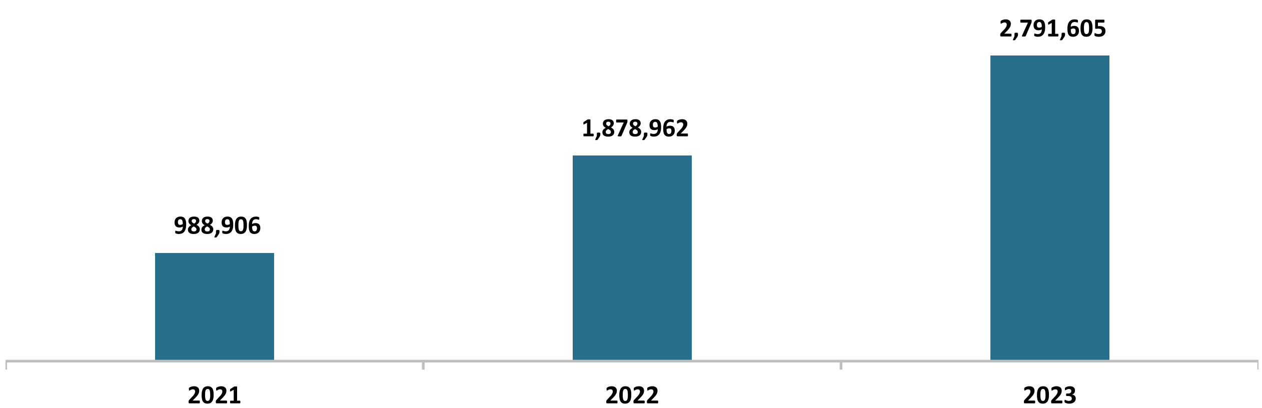
This stage includes manufacturing key components like anodes, cathodes, electrolytes, and separators. India is progressively enhancing its capabilities in producing key battery cell components. Companies like Epsilon Carbon and Himadri Chemicals are making significant investments in anode production. In contrast, cathode manufacturing remains at a nascent stage, primarily due to challenges related to raw material availability and high investment costs. The production of electrolytes and separators is also emerging, with firms like Neogen Chemicals entering the market. Furthermore, domestically manufactured anodes are anticipated to be competitively priced, making them attractive to battery manufacturers looking to diversify their supply chains, aligning with the "China+1" strategy. This approach encourages businesses to reduce their dependency on China by investing in alternative markets like India.

5.5.3 Battery Packs Assembling and Integration

The process of assembling and integrating battery packs involves combining battery cells into modules and packs, incorporating necessary electronics, and implementing thermal management systems to ensure optimal performance and safety. India, recognized as one of the top five global battery producers, excels in battery pack assembly, particularly in the manufacturing of advanced lithium-ion batteries. Prominent players such as Tata Chemicals and Bharat Heavy Electricals Limited (BHEL) spearhead this market, leveraging their robust infrastructure and technical expertise.

To enhance domestic manufacturing and reduce reliance on imports, the Indian government has introduced several key policies. The Production Linked Incentive (PLI) Scheme for Advanced Chemistry Cell (ACC) Battery Storage aims to establish 50 GWh of manufacturing capacity by offering financial incentives to encourage local production. Additionally, the Viability Gap Funding (VGF) scheme supports the development of Battery Energy Storage Systems (BESS) by covering up to 40% of the capital cost, thereby improving the economic feasibility of these storage solutions. Moreover, the differential Goods and Services Tax (GST) rates, with an 18% rate for lithium-ion batteries, create a more favourable tax environment compared to other battery types, further promoting the adoption and manufacturing of advanced battery technologies in India.

Figure 8: Lithium- Ion Accumulators (HS Code-850760), Imports from China, 2021-2023



Source: 6Wresearch, Trademap

Table 6: Funding Instrument for Domestic Manufacturing of Advanced Chemistry Cells

Timeline	Scheme	Focus	Budget
2023-2029	Production Linked Incentive (PLI) Scheme **'National Programme on Advanced Chemistry Cell (ACC) Battery Storage'**	Setting up domestic production capacities of advanced chemistry cells for **at least 5 GWh and totalling up to 50 GWh battery capacity**	**$2.5 Bn**

Source: 6Wresearch, Ministry of Heavy Industries

5.6 Government Policy

The Government of India has undertaken significant policy measures to promote the development and integration of Battery Energy Storage Systems (BESS) in the energy sector. These initiatives are aimed at facilitating the integration of renewable energy (RE) into the grid and creating a supportive environment for energy storage solutions, thereby supporting India's transition towards a sustainable and resilient energy future.

One of the key policies supporting BESS is the waiver of Inter-State Transmission System (ISTS) charges for energy storage systems, including BESS and Pumped Storage Plants (PSPs). According to the Ministry of Power's order dated November 23, 2021, a complete waiver of ISTS charges is available for BESS and PSP projects commissioned up to June 30, 2025. For projects commissioned after this date, transmission charges will be gradually introduced, increasing by 25% annually from July 1, 2025, to June 30, 2028. This policy aims to reduce the initial cost burden on energy storage projects and promote their early adoption.

The government has also recognized the high costs associated with establishing BESS projects in their initial stages due to low volumes. To address this challenge, Viability Gap Funding (VGF) has been proposed to support the initial uptake of BESS by consumers. The VGF can cover up to 40% of the capital cost of a project, provided the projects are commissioned within 18 to 24 months. This financial support is expected to lower the Levelized Cost of Storage (LCoS) to affordable levels, making BESS a viable option for peak power management. This scheme aims to develop 4 GWh of BESS projects by FY 2030–32, with an initial outlay of ₹9,400 crore (approximately US$1.13 billion). The VGF scheme targets achieving an LCOS of ₹5.50–6.60 per kilowatt-hour (kWh) and mandates that at least 85% of the project capacity be made available to distribution companies (Discoms). The selection of projects will be through a competitive bidding process, ensuring transparency and efficiency in fund allocation.

In addition to financial aid, the government has launched several strategic initiatives to foster the growth of the BESS sector. For instance, the National Framework for Promoting Energy Storage Systems, released by the Ministry of Power in August 2023, lays out comprehensive policies to accelerate storage development. This framework includes extending benefits previously reserved for renewable energy generators to energy storage assets, providing subsidies, supporting market development, and setting procurement targets.

Furthermore, the Production-Linked Incentive (PLI) scheme for advanced chemistry cell batteries, launched in 2021, provided ₹18,100 crore (approximately US$2.5 billion) to establish a domestic battery manufacturing sector. This scheme has secured bids from 10 companies totalling 128 GWh of capacity in 2022, far exceeding the targeted tender. Further, as of April 2024, the scheme has secured additional bids from seven companies namely ACME Cleantech Solutions Private Limited, Amara Raja Advanced Cell Technologies Private Limited, Anvi Power Industries Private Limited, JSW Neo Energy Limited, Reliance Industries Limited, Lucas TVS Limited, and Waaree Energies Limited for a cumulative capacity of 70 GWh.

Such government initiatives are crucial in overcoming initial cost barriers, promoting domestic manufacturing, and ensuring the integration of renewable energy into India's national grid. The ongoing expansion of BESS capacity underscores the strategic importance of energy storage in India's transition towards a sustainable and resilient energy future.

5.7 Challenges

The integration of Battery Energy Storage Systems (BESS) into India's energy grid is essential for enhancing grid stability and supporting the country's ambitious renewable energy targets. However, several significant challenges must be addressed to achieve this goal.

1. Financial and Investment Barriers

Securing sufficient financing for BESS projects in India presents a significant challenge due to the high initial capital costs and extended return on investment periods. The banking sector, burdened by the non-performing asset (NPA) crisis, has limited lending capacity, complicating funding efforts. While the domestic bond market offers potential for long-term borrowing, it remains underutilized due to the need for established project performance records and high credit ratings. Additionally, non-banking financial companies (NBFCs) face liquidity constraints, further complicating the funding landscape.

The Indian government's Viability Gap Funding (VGF) scheme, providing up to 40% of the capital cost for BESS projects, aims to alleviate some financial barriers. However, the substantial upfront investment required remains a significant hurdle for many potential investors.

2. Technological and Market Challenges

The BESS sector in India encounters various technological and market-related obstacles. The relatively nascent stage of battery storage technologies leads to limited familiarity with different storage solutions, such as lithium-ion, sodium-ion, and solid-state batteries. This unfamiliarity, combined with the rapid pace of technological advancements, complicates the establishment of comprehensive standards and guidelines for BESS deployment.

Additionally, India's dependence on imported raw materials like lithium, cobalt, and nickel poses a significant challenge. Global supply chain disruptions and price volatility can impact the availability and cost of these critical materials, affecting the production and deployment of battery storage systems. This import dependency increases the vulnerability of the BESS sector to international market fluctuations, further complicating efforts to stabilize and expand the industry.

3. Infrastructure and Implementation Delays

The construction and integration of large-scale battery storage facilities involves substantial civil works and coordination across multiple stakeholders, leading to delays. Regulatory approvals and clearances further extend project timelines, delaying the realization of benefits and returns on investment. These delays make BESS projects less attractive compared to other energy storage solutions.

By overcoming these barriers, India can fully leverage the potential of BESS to support its renewable energy targets and enhance grid stability. The successful deployment of BESS will play a vital role in balancing supply and demand, ensuring a reliable and sustainable energy future for the country.

CHAPTER 6: Pumped Hydro Storage Systems

6.1 Overview

Pumped Hydro Storage (PHS) stores electrical energy as the potential energy of water. Generally, this involves pumping water into a large reservoir at a high elevation—usually located on the top of a mountain or hill. When energy is required, the water in the reservoir is guided through a hydroelectric turbine, which converts the energy of flowing water to electricity. The pumped storage plants are of two types: ‘open loop’, which has an associated natural water source (like a river) for one or both the reservoirs; and ‘closed loop’ (or off-river PSH), which does not have a connected natural-water source, and the same water is cycled between the two reservoirs for pumping and generation4. PHS is often used to store energy for long durations for future use.

The transformation of India's energy sector is marked by an increasing focus on renewable energy sources. Within this evolving landscape, Pumped Hydro Storage (PHS) has become a critical component for grid stability and energy storage solutions. The **Central Electricity Authority (CEA)** estimates that by 2031-32, India will need 26.69 GW of PHS capacity to accommodate its renewable energy growth.

PSPs are generally designed for a longer duration of discharge of more than 6 hours to meet the peak demand or for compensating the variability in the grid due to VRES. Currently, Battery Energy Storage Systems are designed for up to 4 hours of discharge generally. The firm capacity of PSPS during peak hours is guaranteed and relatively immune to grid conditions. These features enable PSP to provide multiple services to the power grid. The high ramping capability helps it deal with the sudden increase of load in the power system. Furthermore, it can smoothen the sudden fluctuations in RE generation and can also provide frequency and voltage support ancillary services.

Table 7: Flexibility Capabilities of Thermal and Pumped Storage Plants

Plant Type	Pumped Hydro Storage	Coal Fired Plants
Start-up time (cold start)	75 – 120 sec.	300-600 mins
Minimum load (% of P)	35 – 45%*	25-40%
Average ramp rate (% of P/min)	80 – 100%*	1-4%

Notes: Minimum load and avg. ramp rate considered the same as hydropower plants as no separate data for PSH is available, P = power output

Source: Ministry of Power, CEA

6.2 Current Capacity of PHS In India

Figure 8: PHS Capacity in India, Operational and Under Development (MW), 2023

As of 2023, India had an installed PHS capacity of around 4.75 GW, with 3.3 GW operational in pumping mode. Significant operational plants include Nagarjuna Sagar and Srisailam in Telangana, Kadamparai in Tamil Nadu, Bhira and Ghatgar in Maharashtra, and Purulia in West Bengal. Currently, there are 2.8 GW of PHS projects under construction and an additional 24 GW in various stages of development.

Table 8: Status of Pumped Storage Development in India, 2023

Schemes	Number of Projects	Installed Capacity
Existing Schemes		
A. Working in Pumping Mode	6	3,306
B. Presently not working in Pumping Mode	2	1,440
Sub-total	8	4,746
Schemes under Construction	4	2,780
DPRs Concurred by CEA	1	1,000
Under Examination	1	1,350
Schemes under Survey & Investigation	33	42,150
Schemes under Survey & Investigation held up	5	5,320
Total	52	57,346

Source: Ministry of Power, CEA

The country has upcoming plans for expanding its PHS capacity, with about 44.5 GW of projects under various stages of development. This includes a notable 34 GW of off-river pumped storage hydro plants. Recent initiatives highlight the proactive measures being taken to advance PHS infrastructure. For instance, in March 2023, the Power Company of Karnataka (PCKL) awarded contracts to JSW Neo Energy and Greenko KA 01 IREP for providing 1 GW of electricity from PHS projects. These projects are designed to offer a continuous 5-hour discharge, with JSW Neo Energy securing 300 MW and Greenko securing the remaining 700 MW. Similarly, In August 2023, Tata Power and the Government of Maharashtra signed a Memorandum of Understanding (MoU) to develop two significant PHS projects with a combined capacity of 2,800 MW. These projects, located in Shirawata, Pune (1,800 MW) and Bhivpuri, Raigad (1,000 MW), are expected to involve an investment of approximately Rs.13,000 crore.

Table 9: Upcoming Pumped Hydro Storage Projects

Name of Project Capacity Agency	Capacity (MW)	Actual/Expected Commissioning	Cost of Project (Rs. Crore)	Cost of Project (Rs. Cr./MW)
Tehri PSH Project, Uttarakhand	1000	2024	4825.6	4.83
Turga PSH Project, West Bengal	1000	2028-29	4800.69	4.80

Source: Media Reports, 6Wresearch

The critical need to accelerate the deployment of energy storage solutions in India aligns well with the capabilities of PHS. The recent MoU between NHPC Ltd. and the Government of Maharashtra for developing four pumped storage projects aggregating 7,350 MW further exemplifies the strategic focus on PHS. These projects, including Kalu (1,150 MW), Savitri (2,250 MW), Jalond (2,400 MW), and Kengadi (1,550 MW), are expected to bolster India's energy storage capacity significantly.

6.3 Demand Forecast in Upcoming Years

Table 10: Projected Demand Forecast for Pumped Hydro Storage System

Year	Capacity (GW/GWh)	Funds Requirement (Rs. Billion)
2026-27	7.45/47.6	54,203
2029-30	18.98/128.15	75,240
2031-32	26.69/175.18	N/A

Source: CEA

India's demand for pumped hydro storage (PHS) is set to grow significantly, driven by the increasing integration of renewable energy sources into the national grid. The Central Electricity Authority (CEA) estimates that India will require 74 GW of storage capacity by 2032. This expansion is crucial for balancing the intermittent nature of renewable energy sources like wind and solar, ensuring grid stability and reliability.

The Kurukutti Pumped Storage Hydropower (PSH) project in Andhra Pradesh and the MP30 Gandhi Sagar Pumped Storage Project (PSP) in Madhya Pradesh are notable examples of large-scale PHS initiatives. The Kurukutti PSH, developed by M/S Adani Green Energy, has a capacity of 1200 MW and an estimated project cost of Rs. 4766 crores, which includes interest during construction (IDC) and financing charges (FC). The levelized cost of generation is projected at Rs. 7.85/kWh, considering a pumping cost of Rs. 3.0/kWh. This project is expected to be commissioned by December 2028. Similarly, the MP30 Gandhi Sagar PSP, developed by M/s Greenko Energies Pvt. Ltd., boasts a capacity of 1440 MW, with an estimated cost of Rs. 6991.25 crore and is anticipated to be operational by December 2024.

Advancements in technology and innovative project designs are influencing the future of PHS in India. Off-river PHS systems, which do not depend on natural water bodies, offer greater site selection flexibility, and reduce environmental impacts. The use of reversible turbines and advanced control systems is enhancing the efficiency and cost-effectiveness of these projects. These innovations are essential for PHS to stay competitive with other energy storage solutions, especially as battery storage technologies become more cost-effective.

6.4 On-river Vs Off-river

India's commitment to renewable energy has led to the development of various energy storage solutions, with pumped hydro storage (PHS) being a significant technology. PHS systems are essential for grid stability and managing the intermittent nature of renewable energy sources like solar and wind. The pumped storage plants are of two types: ‘open loop’, which has an associated natural-water source (like a river) for one or both the reservoirs; and ‘closed loop’ (or off-river PSH), which does not have a connected natural-water source, and the same water is cycled between the two reservoirs for pumping and generation.

On-river pumped hydro storage systems involve the construction of reservoirs on existing rivers, making use of natural water flows. During periods of low electricity demand, water is pumped from a lower elevation reservoir to a higher elevation reservoir. This water is then released back through turbines during peak demand periods to generate electricity. The Central Electricity Authority (CEA) estimates that India has an on-river PHS potential of approximately 103 GW. NHPC is currently developing several on-river PSPs in states such as Gujarat, Andhra Pradesh, and Maharashtra, with capacities ranging from 750 MW to over 7,000 MW . Additionally, Madhya Pradesh is advancing the 1,440 MW Neemuch PSP, which will integrate over 7,000 MW of renewable capacity.

Off-river PHS, also known as closed-loop systems, do not rely on natural water bodies. Instead, they utilize man-made reservoirs situated away from rivers, cycling the same water between two reservoirs. This setup reduces environmental impacts and offers more flexibility in site selection. A prominent example is the Pinnapuram Integrated Renewable Energy Project in Andhra Pradesh, which combines solar, wind, and PHS. Off-river PSPs are also undergoing significant development. Greenko is constructing a 1,200 MW off-river project at Pinnapuram in Andhra

Pradesh, part of an integrated renewable energy project combining solar, wind, and PHS. Torrent Power is developing three off-river PSPs in Maharashtra, with a combined capacity of 5,700 MW.

Table 11: PHS Capacity in India, Operational and Under Development (MW)

Region/State	On river		Off river	
	No. of Projects	Installed Capacity (MW)	No. of Projects	Installed Capacity (MW)
In Operation	8	4745.60		
Under Construction	3	1580	1	1200
DPR Concurred By CEA	1	1000		
Under Examination	1	1350		
Schemes under Survey & Investigation	6	8200	27	33950
Schemes under Survey & Investigation held up	3	4500	2	820
Total	22	21375.60	30	35970

Source: Ministry of Power

Pumped hydro storage (PHS) systems in India, both on-river and off-river, encounter significant challenges in regulatory and environmental domains. The regulatory approval processes for these projects are complex and time-consuming, requiring coordination across multiple governmental agencies. Although the Indian government has implemented guidelines to streamline environmental clearances and incentivize the development of PHS projects, the regulatory landscape remains convoluted, often resulting in delays and increased administrative burdens for developers.

Additionally, on-river PHS projects face considerable environmental challenges, including potential disruptions to local ecosystems, impacts on biodiversity, and alterations to natural water flows. These projects necessitate thorough environmental impact assessments (EIAs) to address issues such as land submergence and the implications for water availability. Conversely, off-river PHS projects generally have a lower environmental impact as they avoid major disruptions to natural water bodies. However, they still require meticulous planning to minimize ecological disturbances during construction and operation. Despite the higher infrastructure costs, off-river systems offer greater flexibility and are more environmentally friendly compared to on-river systems. Both types of PHS are essential for India's energy transition but addressing these regulatory and environmental challenges is crucial for their successful implementation and operation.

6.5 Government Policies

India is dedicated to advancing its clean energy transition with ambitious targets to reduce the emission intensity of its GDP by 45% by 2030, achieve 50% of its installed capacity from non-fossil fuel sources by the same year, and reach net-zero carbon emissions by 2070. Pumped hydro storage projects (PSPs) are essential in this transition, providing necessary grid stability and balancing the intermittent nature of renewable energy sources like wind and solar.

In April 2023, the **Ministry of Power** released detailed guidelines to streamline the development of PSPs. These guidelines outline key provisions designed to facilitate project execution and attract investment. They establish competitive bidding processes to ensure transparency and efficiency, encouraging participation from both public and private sectors. The guidelines also identify exhaust mines as potential sites for PSPs, promoting the reuse of existing infrastructure. Additionally, they provide financial incentives such as tax benefits and concessional climate financing through government green bonds. To expedite development, certain off-river PSPs may be exempt from environmental impact assessments. The guidelines further encourage early development by allowing states to award projects to hydro central public sector undertakings (CPSUs) or state public sector undertakings (PSUs) on a nomination basis, while also permitting competitive private sector participation.

The Indian government has introduced several additional incentives to enhance the attractiveness and feasibility of PSP projects. Among these is the waiver of inter-state transmission system (ISTS) charges for projects awarded until June 2025, which significantly reduces operational costs. Furthermore, there is a relaxation of land stamp duty and registration fees, lowering initial financial barriers for developers. The provision of government land at concessional rates for PSP projects is another critical incentive, making land acquisition more affordable. The policy also includes PSPs in the Energy Storage Obligation (ESO), mandating a certain portion of energy storage to further boost PSP development.

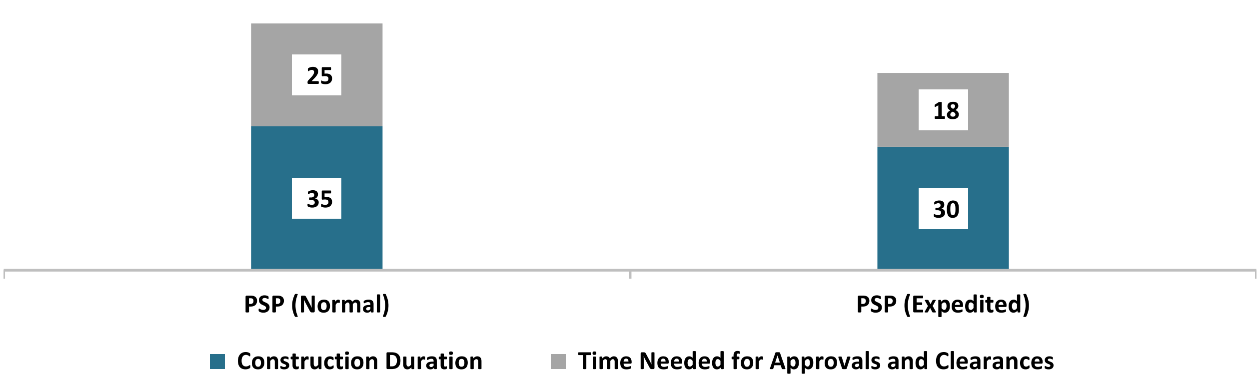
These comprehensive measures and incentives reflect the Indian government's commitment to promoting PSPs as a pivotal element of the country's clean energy transition. By addressing financial, regulatory, and environmental challenges, these policies aim to fully leverage the potential of PSPs to stabilize the grid and support India's sustainable energy goals.

6.6 Challenges

1. **Long Gestation Period and Environmental Clearances**

   The development of Pumped Hydro Storage (PHS) projects in India is significantly hampered by extended gestation periods, largely due to the cumbersome process of obtaining environmental and forest clearances. PHS construction necessitates complex civil works, including the building of dams, tunnels, and reservoirs, leading to prolonged timelines. Typically, PHS projects require 5-8 years from inception to commissioning, with environmental and forest clearance procedures potentially adding 2-3 years. Despite the relatively lower environmental impact of PHS projects, especially those utilizing existing reservoirs or off-the-river sites, these projects are subjected to stringent clearance procedures similar to those for conventional hydroelectric projects.

Figure 9: Construction Duration and Approval Times for Normal and Expedited PHS Projects in Months



Source: Goldman Sachs

2. Taxation and Financial Challenges

PHS projects in India face significant taxation and financial challenges. Although recognized as renewable sources by the Union Cabinet, PHS projects do not benefit from the same tax incentives as other renewable energy technologies, such as solar and wind. Components for PHS projects are subjected to a higher Goods and Services Tax (GST) rate of 18-28%, compared to the 12% rate applied to other renewable energy components. This disparity increases overall project costs and reduces the competitiveness of PHS projects. Furthermore, PHS projects encounter double taxation, with power taxed both upon storage and final supply, further escalating costs.

The high upfront capital requirements and extended gestation periods associated with PHS projects exacerbate financial burdens. While mechanisms such as concessional climate finance and green bonds have been proposed to alleviate these issues, their implementation remains in the early stages. Additionally, leveraging innovative sites like exhausted coal mines for PHS could attract more investment, but this requires clear regulatory support and guidelines.

3. Dormant Pumped Hydro Storage Capacity

A significant portion of India's PHS capacity remains dormant due to operational issues or topographical challenges. Out of the 4.7 GW PHS capacity, only 3.3 GW is operational. This underutilization of existing capacity poses a considerable challenge as it reflects inefficiencies and technical difficulties that need to be addressed. Ensuring that the existing capacity is fully operational is crucial for maximizing the efficiency and reliability of PHS projects in India. Dormant capacity also represents a lost opportunity for energy storage, which could otherwise contribute to stabilizing the grid and supporting renewable energy integration.

CHAPTERs 7: Peer Country Analysis

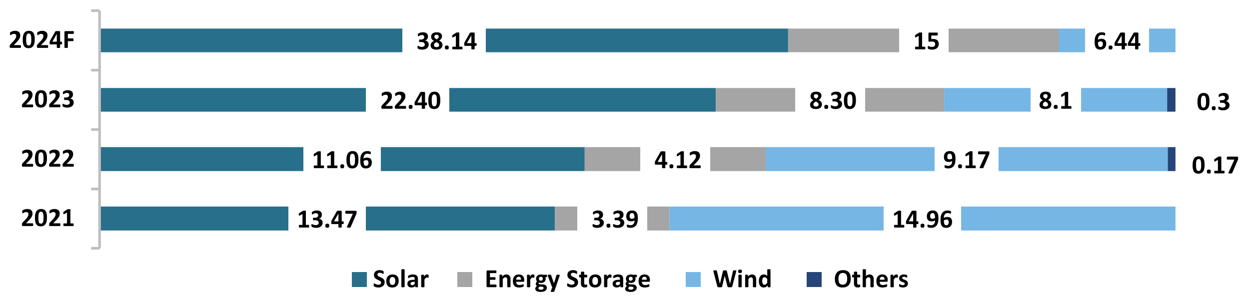
Over the past decade, the global renewable energy landscape has significantly advanced, primarily led by China, the USA, and European countries. These advancements are driven by the imperative to mitigate the environmental impacts of fossil fuels and enhance the resilience of energy grids. Energy storage systems have emerged as critical solutions to manage the intermittency of renewable energy sources such as solar and wind power. In 2023, global battery energy storage capacity nearly doubled to over 90 GWh, with China, the EU, and the USA contributing 90% of the new capacity. Projections indicate a 27% annual growth rate in energy storage, reaching 110 GW/372 GWh by 2030, with significant contributions from the Asia Pacific region and EMEA. To meet climate goals, energy storage must increase sixfold by 2030, with battery storage expected to rise 14-fold to 1,200 GW, supported by policies and technological innovations in leading countries.

7.1 Renewable Energy Landscape

The global renewable energy landscape is undergoing a transformative shift as nations worldwide increasingly prioritize sustainability and carbon reduction. In 2022, renewable electricity accounted for 30% of total electricity generation globally. Investment in renewable energy sectors witnessed strong growth in the Americas and Asia-Pacific region, with 36.7 GW of clean power committed through corporate power purchase agreements (PPAs) in 2022 alone, making an 18% increase from 2021. However, this progress is accompanied by challenges such as supply chain disruptions, inflation, and regulatory obstacles. These challenges highlight the critical need for ongoing innovation and global cooperation to sustain momentum and achieve long-term energy and climate targets.

The U.S. renewable energy sector is experiencing substantial growth, with renewable sources projected to become the leading source of electricity generation by the mid-2030s and providing 42% of the nation's electricity by 2050, up from approximately 20% today. The decline in costs of renewable technologies continues to drive this expansion. For instance, the average construction cost for solar generators has decreased by 51.5% since 2013, making them increasingly competitive with traditional fossil fuels. Furthermore, new renewable capacity, primarily from solar and wind, is expected to significantly reduce coal and natural gas generation over the next few years. In 2023, 96% of newly installed utility-scale solar PV and onshore wind capacity had lower generation costs than new coal and natural gas plants, emphasizing the economic shift towards renewables.

Figure 10: Utility-scale Energy Capacity Additions in the US, 2021-2024

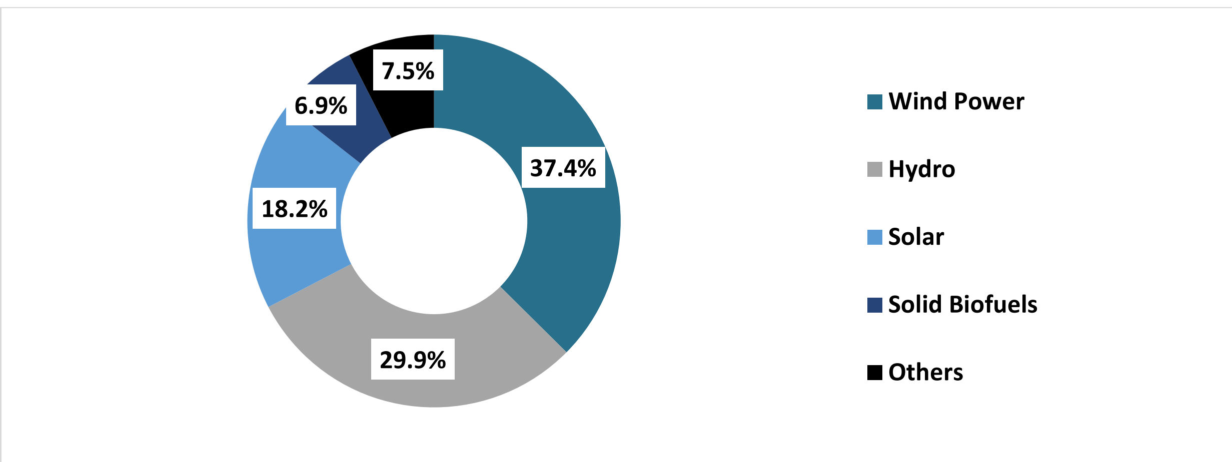


Source: WRI, US EIA

China has maintained a dominant position in global green manufacturing, especially through the breakthrough of key clean energy technologies such as electric vehicles (EVs), lithium-ion batteries, and solar panels. The country has invested over US$50 billion in solar photovoltaics (PV) supply chains since 2011, creating 300,000 green manufacturing jobs and establishing dominance in every segment of the solar PV supply chain. According to the DNV Energy Transition Outlook 2024, China's share of global energy-related CO2 emissions is projected to decrease from one-third in 2023 to one-fifth by 2050, with a 70% reduction in absolute emissions. This shift is primarily facilitated by replacing coal with renewable energy sources and the electrification of end-use demand. In 2022, China contributed 35% of global solar and 40% of wind power capacity additions, and by 2050, renewables are expected to account for 88% of the country's power mix. Policy initiatives, including the 14th Five-Year Plan, emphasize energy efficiency and the reduction of fossil fuel reliance, aiming for CO2 emissions to peak before 2030 and achieve carbon neutrality by 2060. The landscape is further shaped by China's efforts to attain energy independence, reducing reliance on imported fossil fuels by boosting domestic renewable energy production. According to UNFCCC, under the Paris Agreement, China aims to reduce carbon intensity (CO2/unit of GDP) to 65% below 2005 levels and increase the share of non-fossil fuels in primary energy consumption to around 25% by 2030.

The EU aims for climate neutrality by 2050 and has revised its Renewable Energy Directive to require that at least 42.5% of energy consumption come from renewable sources by 2030, to reach 45%. As of 2022, renewable energy accounted for approximately 23% of the EU's energy consumption. The European Green Deal and REPowerEU plan have significantly accelerated the transition to renewables, especially in response to the energy crisis triggered by geopolitical events such as Russia's invasion of Ukraine. This situation has intensified the push to reduce reliance on fossil fuels and increase the adoption of renewable energy. There has been notable growth in solar PV and wind energy installations, with substantial increases in rooftop solar PV systems in Germany, Italy, and the Netherlands. In 2023, Europe installed a record 18.3 GW of new wind power capacity. Despite these advances, challenges like permitting delays and the need for grid improvements persist. Nevertheless, the EU's renewable energy outlook remains positive, supported by strong policy frameworks aimed at reducing greenhouse gas emissions.

Figure 11: Sources of Renewable Energy in EU Electricity Consumption, 2022

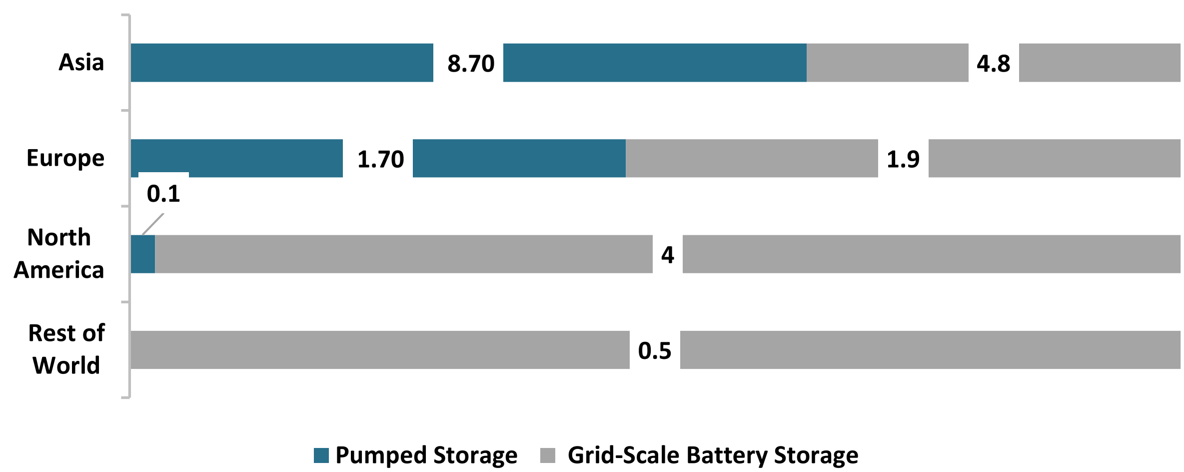


Source: European Parliament Report

7.2 Energy Storage Outlook

The global energy storage landscape is experiencing a significant transformation, fuelled by technological advancements, supportive policies, and substantial investments in renewable energy. In 2022, the total global pumped storage capacity increased by 10.5 GW, reaching 175 GW, with China at the forefront, contributing 26% of the global capacity. The WEO 2022's long-term projections of the development of the global energy system foresee a dramatic increase in the relevance of battery storage for the energy system.

Figure 12: Capacity Additions of Pumped Storage and Utility-Scale Battery Storage, By Region, 2022, GW



Source: IEA

United States of America

The U.S. energy storage market set new records in the third quarter of 2023, adding 7,322 megawatt-hours (MWh) of capacity. This rapid expansion is expected to continue, with 63 gigawatts (GW) projected to be installed from 2023 to 2027. As of 2023, the U.S. had approximately 8.8 GW of operational utility-scale battery storage. Installations are mainly concentrated in California and Texas, driven by favourable state policies and significant solar and wind capacities. By the end of 2023, Texas had 7.3 GW of storage capacity, and California had 3.2 GW. Other states, particularly those in CAISO, ERCOT, NYISO, PJM, and ISO-NE regions, also made significant progress, with a collective 4.3 GW of standalone storage capacity as of 2022 and an additional 24 GW expected between 2024 and 2025.

As of 2023, 16 states have implemented various forms of energy storage policies, categorized into procurement targets, regulatory adaptations, demonstration programs, financial incentives, and consumer protections.

I. Procurement Targets

Eleven states, including California, Oregon, Nevada, Illinois, Virginia, New Jersey, New York, Connecticut, Massachusetts, Maine, and Maryland, have established procurement targets requiring utilities to acquire a specified amount of energy storage by set deadlines. Below are the top five states with the most ambitious targets.

Table 13: Energy Storage Procurement Targets, By States, 2023

State	Targets
New York	6,000 MW by 2030
Virginia	3,100 MW by 2035
Maryland	3,000 MW by 2033
New Jersey	2,000 MW by 2030
Nevada	1,000 MW by 2030
Connecticut	300 MW by 2024, 650 MW by 2027, 1,000 MW by 2030
Illinois	Illinois Commerce Commission to establish storage procurement targets for all utilities serving more than 200,000 customers to achieve by 2032.

Source: Morgan Lewis, Wood Mackenzie

II. Regulatory Adaptation

Regulatory adaptations involve changes to state energy regulations to create opportunities for storage. States with storage policies generally have a Renewable Portfolio Standard (RPS) or a non-binding renewable energy goal. Recent mandates in states such as Arizona, California, Colorado, Connecticut, Florida, Hawaii, Indiana, Kentucky, Massachusetts, Michigan, New Mexico, North Carolina, Oregon, Utah, Virginia, Washington, Missouri, Minnesota, Maryland, and Maine require utility resource plans to include energy storage.

III. Demonstration and Financial Incentive

State demonstration programs and financial incentives are vital for advancing energy storage technologies. These initiatives support incremental studies on the benefits and logistics of energy storage solutions and provide economic signals to encourage adoption. The table below summarizes key initiatives by various states, highlighting their objectives, funding mechanisms, and policy tools to support energy storage development.

Table 14: Key Financial Incentives

State	Financial Incentives
Washington State	*Recently awarded 14 grants through the Clean Energy Fund for energy storage projects, including $149,534 to Energy Northwest for a long-duration energy storage project study and $2 million to Willapa Bay Enterprises for a battery energy storage system.*
California	*The Self Generation Incentive Program (SGIP) allocates 88% of funds to energy storage technologies, with 7% of the energy storage category carved out for small residential projects less than or equal to 10 kW.*

Source: 6Wresearch, State Departments

As states continue to implement and refine policies such as procurement targets, regulatory adaptations, demonstration programs, and financial incentives, the deployment of diverse storage technologies is expected to accelerate. This momentum is evident in the increasing capacity of various storage systems, each contributing uniquely to the energy mix.

Table 15: U.S Utility-Scale Energy Storage Systems for Electricity Generation, 2022

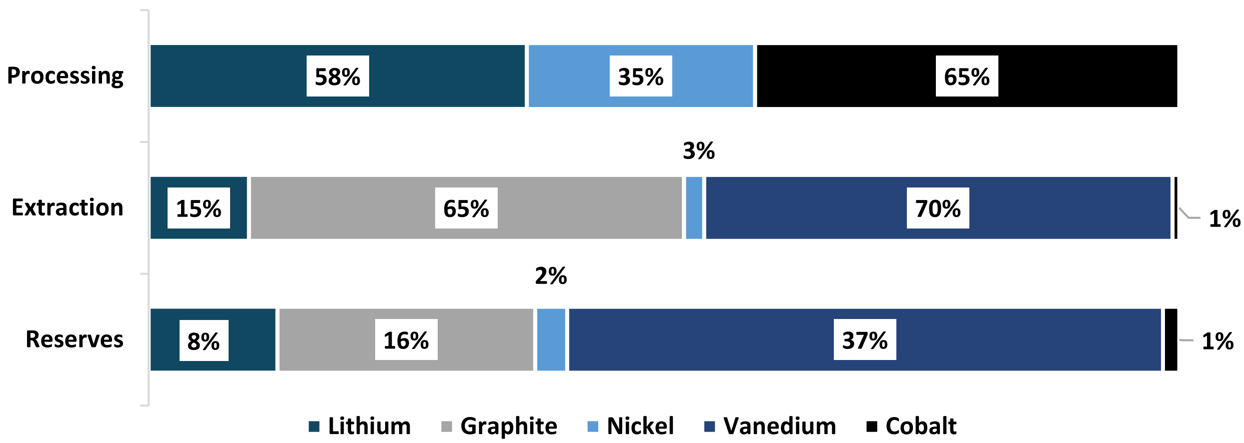
System	Number Of Plants/ Generators	Power Capacity (MW)	Energy Capacity (MWh)	Gross Generation (MWh)	Net Generation (MWh)
Pumped Hydro Storage	40/152	22,008	NA	22,459,700	-6,033,905
Batteries	403/429	8,842	11,105	2,913,805	-539,294
Solar-Thermal	2/3	405	NA	NA	NA
Compressed Air	1/2	110	110h	NA	57
Flywheels	4/5	47	17	NA	0

Source: U.S. Energy Information Administration

China

China is making significant strides in the development of its energy storage systems, particularly in battery energy storage (BESS) and pumped hydro storage. By the end of 2023, China had achieved a cumulative energy storage capacity of nearly 83.7 GW, with battery energy storage reaching approximately 32.2 GW and pumped hydro storage accounting for around 50.6 GW. This rapid expansion is driven by the need to stabilize the grid as the country integrates more renewable energy sources. The country aims to achieve a total of 1,200 GW of solar and wind generation capacity by 2030. Key projects, such as the world's largest 300 MW compressed air energy storage station in Shandong, which supports up to 300,000 households during peak hours, exemplify this growth.

Figure 13: China's Share (%) of Critical Mineral in the Supply Chain, 2023



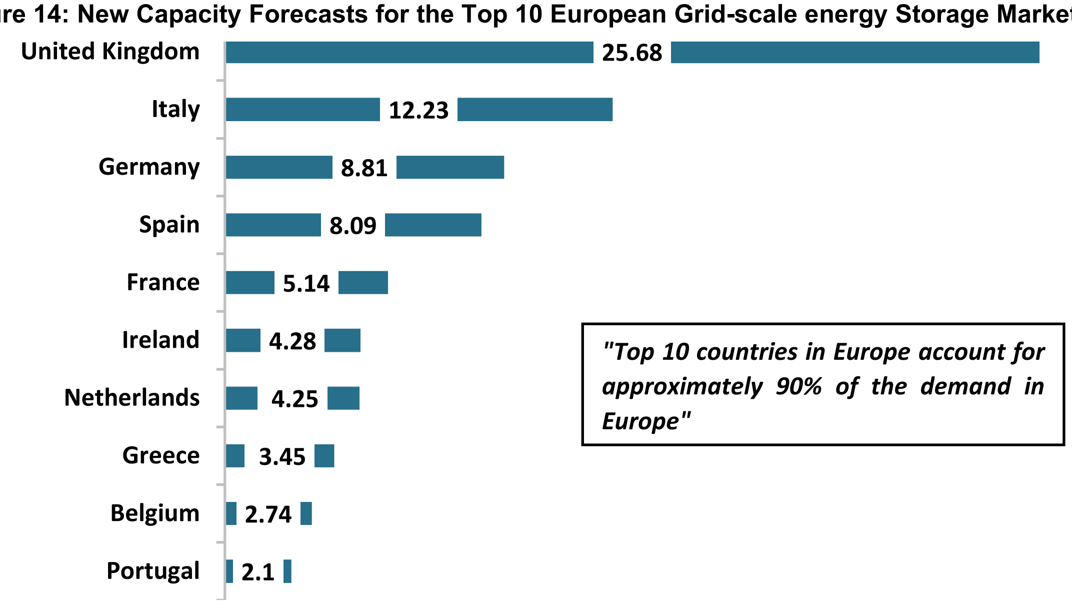
Source: United States Geological Survey, IEA

China's progress in energy storage is largely policy-driven, with strategic initiatives at both the national and local levels. Key policies include the National Development and Reform Commission's (NDRC) directives to enhance new energy storage and the National Energy Administration's (NEA) guidelines for grid-connected energy storage rules. The "New Energy Storage Development Implementation Plan (2021-2030)" aims for significant technological advancements and deployment, targeting 30 GW to 40 GW of new energy storage capacity by 2024. Local governments, such as those in Anhui and Jiangsu, are also actively promoting industrial and commercial energy storage solutions through supportive pricing mechanisms and large-scale project implementations. Additionally, the Chinese government has set ambitious targets, aiming to achieve over 30 million kW of installed capacity by 2025 and full market-oriented development by 2030. The northwestern regions have been pivotal in this expansion, with 10.3 GW of new-type energy storage already operational. Further, since the beginning of 2024, major power generation enterprises have invested 136.5 billion yuan ($18.84 billion) in power projects and 76.6 billion yuan in power grid projects.

Despite the progress, China faces several challenges in scaling up its energy storage systems. The high initial costs and technological complexities of advanced energy storage solutions, such as lithium-ion and sodium-ion batteries, pose significant barriers. Moreover, the regulatory environment is still evolving, and there is a need for more comprehensive policies to support the commercial viability of new energy storage technologies. Ensuring a stable supply chain for critical materials like lithium and addressing environmental concerns associated with battery production and disposal are also critical issues. This coupled with low utilization rates—38% for grid-side and 65% for user-side storage— poses a significant barrier towards the development of energy storage systems. However, with continuous policy support and technological advancements, China is well-positioned to overcome these challenges and further enhance its energy storage capacity, contributing to a more resilient and sustainable energy future.

Europe

Figure 14: New Capacity Forecasts for the Top 10 European Grid-scale energy Storage Markets



Source: Wood Mackenzie

In 2023, Europe installed 17.2 GWh of new BESS capacity, a 94% increase from the previous year, bringing the total capacity to approximately 36 GWh. Germany, Italy, and the United Kingdom are leading this surge, with Germany accounting for 34% of the market share. Major projects like the 600 MW/2,400 MWh GIGA Green Turtle in Belgium and the 880 MW Tâmega Complex in Portugal exemplify the expansion and potential of energy storage in stabilizing grids and integrating renewable energy sources.

The growth of energy storage systems in Europe has been significantly accelerated by a robust framework of policies and financial assistance. These policies aim to support the integration of renewable energy, stabilize energy markets, and reduce dependency on fossil fuels. The European Union has implemented comprehensive measures, including the Electricity Market Design Reform, the Net-Zero Industry Act, and the Critical Raw Materials Act, among others.

Table 16: Key Policies Focused on Energy Storage Systems

Policy Name	Year	Description
Batteries Regulation	2023	*This regulation focuses on reducing the carbon footprint of batteries, minimizing harmful substances, ensuring the recycling of batteries within the EU, and introducing a digital passport for detailed information on each battery. It aims to decrease reliance on raw materials from third countries and promote a circular economy within the battery industry.*
State Aid for Energy Storage	2023	*The European Commission revised the Temporary Crisis and Transition Framework to allow member states to grant state aid for covering investment costs of energy storage projects. This revision enhances the economic viability of energy storage projects, making it easier for member states to support the development of these technologies.*
Strategic Technologies for Europe Platform (STEP)	2024	*This proposal aims to boost critical strategic technologies, including energy storage, to enable the EU's industry to achieve digital and net-zero transitions. STEP introduces the Sovereignty Seal and Sovereignty Portal, providing investment and funding opportunities to support the development and deployment of key technologies.*
Innovation Fund	2024	*Supports large-scale energy storage projects through significant grants, aiming to finance a diverse range of innovative technologies. In addition to the traditional calls with a total budget of €4 billion for 2024, the Innovation Fund offers a second form of funding: sustainable hydrogen auctions with a total budget of around €800 million for 2024.*

Source: European Union, Media Reports

CHAPTER 8: Sectoral Demand Analysis

By the end of 2022, China had amassed over 14.1 GWh of electrochemical storage capacity across 472 stations, marking a 127% year-on-year increase. The sector is dominated by applications for generators/grids (87%), followed by residential, industrial, and commercial consumers making up 13% of the installed capacity. Government policies, including directives from the **National Energy Administration** such as "Notice on Encouraging Renewable Power Generation Enterprises to Build or Purchase Peak Shaving Capacity", incentivize industrial and commercial sectors to adopt energy storage. This is especially welcome given the high electricity costs and the implementation of time-of-use pricing, which makes peak load shifting economically advantageous. By 2031, industrial and commercial energy storage is expected to comprise 10% of the market, reaching a total installed capacity of 442 GWh, underscoring China's strategic focus on enhancing energy reliability and economic efficiency through storage solutions.

In the United States, the energy storage market is characterized by significant growth across utility-scale grids and residential sectors, while the industrial and commercial sectors are experiencing a decline. Utility-scale storage is pivotal for balancing renewable energy output and providing essential services such as frequency regulation and peak shaving. Federal and state policies promoting renewable energy and grid modernization are key drivers of this growth. The decline in the industrial and commercial sectors is attributed to several factors, including high upfront costs, regulatory uncertainties, and the complexity of integrating storage with existing operations. Conversely, the residential storage market is expanding rapidly, propelled by declining battery costs and increasing adoption of solar PV systems. Homeowners are increasingly investing in storage systems to achieve energy independence and cost savings, with residential storage expected to double between 2023 and 2025.

Europe leads in integrating energy storage with renewable energy projects, particularly in Germany, the UK, and Italy. The region has a well-developed residential storage market, driven by high energy costs and substantial government support. In 2022, Europe witnessed significant investments in battery energy storage systems, with Germany alone installing over 1.1 GWh of residential storage.

The demand from generators and grids is set to rise as Europe advances towards its 2050 carbon neutrality targets, with utility-scale storage playing a crucial role in supporting grid stability and renewable integration. Unlike the USA, the industrial and commercial sectors in Europe are seeing robust demand, driven by high energy costs and comprehensive regulatory frameworks. This growth is supported by policies that promote energy efficiency and sustainability within the industrial sector.

In India, the demand for stationary energy storage systems (ESS) is anticipated to grow significantly from 2022 to 2032, driven by the need to support the increasing penetration of renewable energy into the grid and ensure reliable power supply across various sectors. One of the primary drivers is the declining cost of lithium-ion batteries, which are becoming more cost-effective and efficient for long-duration storage applications. Additionally, India's ambitious renewable energy targets, aiming for around 500 GW of renewable capacity by 2030, necessitate substantial energy storage solutions to manage intermittency and integrate renewable energy smoothly into the grid. This project is expected to significantly improve power quality and reliability for over 12,000 low-income consumers, showcasing the critical role of ESS in urban energy management. Furthermore, large-scale initiatives like the Tata Power Solar project in Chhattisgarh, integrating a 100 MW solar plant with a 120 MWh BESS, highlight the expanding role of ESS in stationary storage solutions.

The demand for energy storage systems in the electric vehicle (EV) sector is also expected to surge dramatically between 2022 and 2027. Government initiatives like the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme and the Production Linked Incentive (PLI) scheme are central to this growth. These policies aim to boost EV adoption and establish local manufacturing capacities for advanced chemistry cells (ACC), targeting 50 GWh of annual ACC manufacturing capacity by 2025. The annual capacity addition for lithium-ion batteries (LiBs) for automotive applications is projected to rise from 2.3 GWh in FY2021 to 104 GWh by FY2030, driven by the increasing popularity of electric wheelers. Additionally, the expected drop in lithium-ion battery prices to under $100/kWh by 2027, making EVs more affordable and attractive to consumers, thereby boosting demand.

Table 17: Sectoral Demand of Energy Storage (GWh) till 2032

	Application	Energy Storage (GWh)			
		2019-22	2022-27	2027-32	Total By 2032
Stationary Storage	Grid Support (MV/LV)	10	24	33	67
	Grid Support (EHV)	7	38	97	142
	Telecom Towers	25	51	78	154
	Data Centres, UPS and Inverters	80	160	234	474
	Miscellaneous Applications (Railways, Rural Electrification, HVAC application)	16	45	90	151
	DG Usage Minimization	-	4	11	14
	Total Stationary (GWh)	138	322	543	1,002
Electric Vehicles	E2W	4	51	441	496
	E3W	26	43	67	136
	E4W	8	102	615	725
	Electric Prices	2	11	44	57
	Total Electric Vehicles (GWh)	40	207	1,167	1,414
Total Energy Storage Demand		178	529	1710	2416

Source: Niti.gov, ISGF Report

CHAPTER 9: Battery Recycling

9.1 Introduction

Amidst India's ambitious transition towards sustainable practices, the burgeoning adoption of electric vehicles (EVs) and battery energy storage systems (BESS) is highlighting the critical need for effective battery recycling. The exponential growth in the adoption of lithium-ion batteries, primarily driven by EVs and renewable energy storage, presents both challenges and opportunities. According to a NITI Aayog report, the cumulative stock of lithium-ion batteries in India is projected to reach 600 GWh by 2030, with an estimated recycling potential of 128 GWh. To address this, India is implementing robust policies like the Battery Waste Management Rules, promoting extended producer responsibility (EPR), and fostering collaborations for technological advancements in recycling processes. These measures aim to mitigate environmental impacts, recover valuable materials such as lithium, cobalt, and nickel, and support a circular economy, ensuring the sustainable growth of the battery sector in India.

9.2 Current Policies and Regulations

The Government of India introduced the "Lithium-ion Battery Waste Management Rules, 2022" to regulate the recycling of lithium-ion batteries in the country. These rules apply to all types of lithium-ion batteries, including those used in electric vehicles, laptops, and mobile phones. Some key provisions of the Lithium-ion Battery Waste Management Rules, 2022 include:

- *Collection and Recycling: The rules mandate that manufacturers or importers of lithium-ion batteries must collect and recycle the batteries at the end of their life cycle. The collection target is set at 25% in the first year, gradually increasing to 70% by the fifth year of implementation.*

- *Battery Disposal: The rules require the disposal of spent batteries to be done in an environmentally sound manner and in compliance with the guidelines issued by the Central Pollution Control Board.*

- *Record Keeping: The manufacturers or importers of lithium-ion batteries must maintain records of the quantity and type of batteries they produce or import, as well as their collection and recycling activities.*

- *Extended Producer Responsibility: The rules establish Extended Producer Responsibility (EPR) for the manufacturers or importers of lithium-ion batteries. They are required to bear the financial and/or physical responsibility for the proper management of the batteries they produce or import.*

- *Penalties: The rules provide for penalties for non-compliance, including fines and imprisonment.*

Furthermore, in April 2024, the European Union (EU) and India launched an Expression of Interest (EoI) aimed at startups specializing in battery recycling technologies for electric vehicles (EVs). This initiative, part of the India-EU Trade & Technology Council (TTC) established in April 2022, seeks to foster collaboration between European and Indian SMEs and startups in clean technology. The matchmaking event planned for June 2024 will see twelve innovators selected to pitch their solutions, with six finalists getting opportunities to visit India and the EU for further collaboration. This program underscores the commitment to advancing the circularity of rare materials and achieving carbon neutrality, providing a platform for startups to engage with venture capitalists and industry leaders, thereby accelerating the development of sustainable battery recycling technologies.

9.3 Recycling Technologies

Battery recycling technologies in India are diverse and continuously evolving to address environmental and economic challenges. The primary methods used include hydrometallurgical and pyrometallurgical processes, integrated carbothermal reduction (ICR), and mechanical processing.

Hydrometallurgical Process: This involves the use of aqueous solutions to extract metals from spent batteries. This process includes leaching, where acids such as sulfuric acid dissolve the metals, followed by solvent extraction and precipitation to separate, and purify valuable metals like lithium, cobalt, and nickel. In contrast, pyrometallurgical processing uses high temperatures to smelt batteries and recover metals. Although effective, this method is energy-intensive and produces significant emissions, making it less environmentally friendly.

Pyrometallurgical Processes: This involves heating batteries to high temperatures to extract metals such as cobalt, nickel, and copper. These metals can then be refined and reused in new batteries. Pyrometallurgical processes are typically employed for large-scale battery recycling due to their effectiveness in handling substantial volumes of waste.

Direct Recycling: This technique reuses recovered electrode materials in new battery manufacturing without further refining or processing. Direct recycling is more energy-efficient and cost-effective compared to traditional methods.
An innovative approach employed in India is the Integrated Carbothermal Reduction (ICR) process, developed by Metastable Materials. This chemical-free process achieves over 90% recovery of metals from lithium-ion batteries, offering an eco-friendly solution that preserves the quality of critical elements. Mechanical processing, which includes crushing and shredding batteries to reduce their size and separate materials based on physical properties, is also widely used.

Economically, lithium-ion battery recycling offers substantial benefits. The global market for this recycling sector is expected to reach several billion dollars by 2030, fueled by the rising demand for EVs and other battery-powered devices. Efficient recycling processes can recover between 50-95% of the valuable materials in these batteries, making it a profitable venture. For instance, a European Commission study estimates that recycling 20% of Europe's lithium-ion batteries could save up to 40,000 tons of cobalt, 200,000 tons of nickel, and 20,000 tons of lithium per year by 2030, with a combined value of billions of euros.

9.4 Need for Recycling

The need for lithium-ion battery recycling in India is becoming increasingly critical due to several key factors.

Environmental Sustainability: As the adoption of electric vehicles (EVs) and renewable energy systems increases, managing the lifecycle of lithium-ion batteries becomes crucial to prevent environmental hazards. Improper disposal can lead to soil and water contamination from toxic substances like lithium, cobalt, and nickel. Recycling these batteries helps mitigate environmental damage and recover valuable materials, thus reducing the reliance on virgin resources.

Economic Benefits: The global market for lithium-ion battery recycling is projected to be worth several billion dollars by 2030, driven by the growing demand for EVs and other battery-powered devices. Efficient recycling processes can recover between 50-95% of valuable materials from these batteries, making it a lucrative industry. For example, the European Commission estimates that recycling 20% of Europe's lithium-ion batteries could save up to 40,000 tons of cobalt, 200,000 tons of nickel, and 20,000 tons of lithium annually by 2030, translating to a combined value of billions of euros.

Regulatory Compliance: The Indian government has introduced several initiatives to promote battery recycling. The Battery Waste Management Rules, 2022 enforce Extended Producer Responsibility (EPR), mandating manufacturers to collect and recycle used batteries. Additionally, initiatives like the National Electric Mobility Mission Plan (NEMMP) 2020 and the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme indirectly support the recycling industry by boosting EV adoption and, consequently, the demand for recycled battery materials.

9.5 Outlook of Present Recycling Facilities

With the integration of batteries into the expanding market for electric vehicles (EVs) and energy storage technologies, the influx of end-of-life batteries poses both challenges and opportunities. Establishing a robust battery recycling ecosystem is crucial for managing waste, recovering valuable materials, and reducing dependency on imports. Indian companies are stepping up to meet this demand, employing advanced technologies and scaling up their capacities to handle the expected surge in battery recycling needs.

Table 18: Major Battery Recycling Companies in India

Company	Location	Technology Used	Processing Capacity
Attero	Noida	Hydrometallurgical	700 tons/year, expanding to 20,000 tons/year
LICO Materials	Bengaluru	Mechanical Recycling	12,000 tons/year, 2.2 GWH
BatX Energies	Uttar Pradesh	Mechanical recycling (SPOKE and HUB model)	4,000 tons/year
Lohum	Delhi	NEETM recycling technology	2 GWh recycling, 300 MWh reuse
Rubamin	Gujarat	Hydro and Pyro-metallurgical	10,000 tons/year, expanding
Tata Chemicals	Near Mumbai	Mechanical shredding, Hydrometallurgical	Pilot scale, 500 tons/year

Source: Mercom India, 6Wresearch

9.6 Applications of Recycled Batteries

Recycled batteries, particularly those repurposed from electric vehicles (EVs), hold significant potential for various applications in India. As EV batteries degrade and their capacity falls below 70–80% of the initial rating, they can no longer meet the high-performance requirements for automotive use. However, these batteries still retain enough capacity for less demanding applications. Second-life batteries are thus increasingly being used for stationary energy storage solutions. These batteries can provide backup power, support grid stability, and store energy from renewable sources such as solar and wind, which is crucial for India's growing focus on sustainable energy solutions.

In addition to stationary storage, second-life batteries from EVs can also be used in smaller-scale applications such as powering residential energy systems and providing backup for telecom towers. This repurposing not only maximizes the utility of the batteries before they reach their end-of-life but also reduces the demand for new batteries and the raw materials needed to produce them. Encouraging the use of second-life batteries through supportive policies and market incentives can help offset the costs associated with repackaging, testing, and commissioning these systems. Effective regulatory frameworks and minimum standards are essential to ensure the safe and efficient deployment of these second-use batteries.

CHAPTER 10: Levelized Cost Analysis

The levelized cost of storage (LCOS) for battery energy storage systems (BESS) in India has seen substantial reductions over the past decade, making BESS an increasingly optimal venture for various stakeholders in the energy sector.

10.1 Key Terms

I. **Levelized Cost of Storage (LCOS):** The LCOS is a measure of the average cost per kilowatt-hour (kWh) of storing and discharging electricity over the lifetime of the storage system. It includes all capital, operational, and maintenance costs divided by the total energy discharged over the system's life.

II. **Levelized Cost of Electricity (LCOE):** The LCOE is the average cost per kWh of electricity generated over the lifetime of an energy generation system. It includes capital costs, fuel costs, operation and maintenance costs, and the cost of capital.

III. **Tariff Rates:** These are the rates at which electricity is sold to consumers. They vary based on the type of consumer (residential, commercial, industrial) and the amount of electricity consumed.

10.2 Current Scenario And Future Projections

As of 2023, the Levelized Cost of Storage (LCOS) for standalone Battery Energy Storage Systems (BESS) in India ranges from ₹7 to ₹8 per kWh. Solar plus BESS systems currently incur higher costs due to additional infrastructure and technology requirements but are becoming increasingly competitive with conventional power sources like coal. By 2030, the LCOS for standalone BESS is expected to decline to approximately ₹4.12 per kWh due to advancements in technology and economies of scale. The projected costs for solar plus BESS systems are expected to fall to 3.32 per kWh by 2025, and ₹2.83 per kWh by 2030. Standalone energy storage currently has an LCOS ranging from ₹7 to ₹8 per kWh, which is expected to drop to ₹4.12 per kWh by 2030 due to cost reductions in lithium-ion technology. In comparison, solar plus energy storage systems have higher initial costs but are projected to become highly competitive, reaching an LCOS of ₹2.83 per kWh by 2030. This cost reduction makes solar plus storage an attractive option for integrating renewable energy into the grid, providing reliability and cost savings.

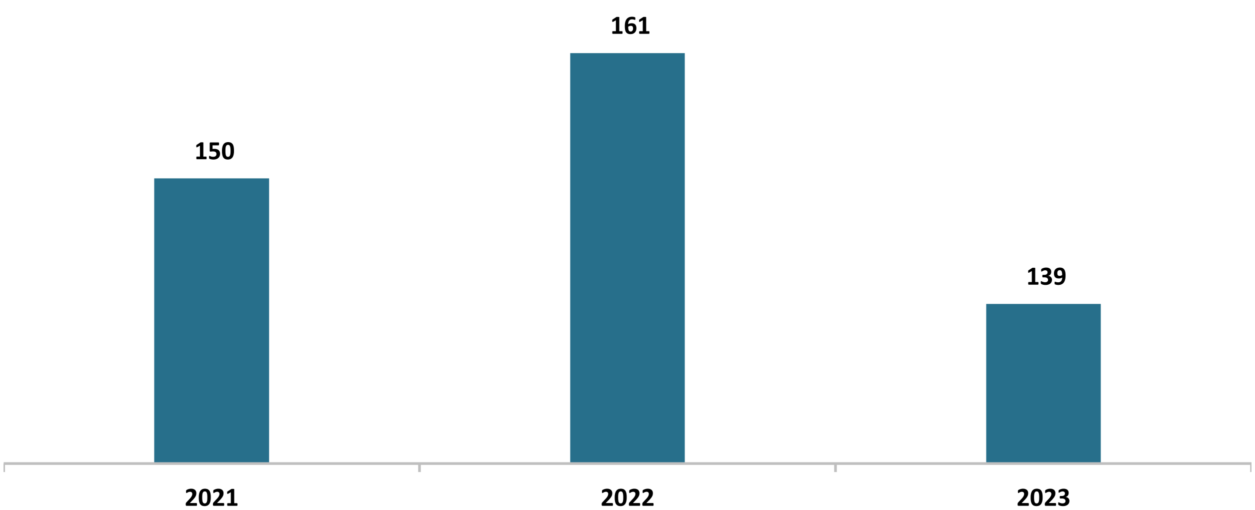
Table 19: LCOS Comparison Standalone BESS Vs Solar PV BESS (INR/kWh)

Year	Standalone BESS LCOS (INR/kWh)	Solar PV BESS LCOS (INR/kWh)
2020	7.5	3.94
2025	5.06	3.32
2030	4.12	2.83

Source: Mercom India

Additionally, lithium-ion battery prices have dropped dramatically from USD 1,400 per kWh in 2010 to less than USD 140 per kWh in 2023, representing a 90% reduction. This significant decline is driven by technological improvements, research and development, and economies of scale in manufacturing. Lithium-ion batteries dominate the market due to their high energy densities, longer lifetimes, and decreasing costs. These batteries are adaptable to various applications, including electric vehicles (EVs) and stationary storage, making them versatile and increasingly affordable.

Figure 15: Lithium-Ion Battery Price ($/kWh)



Source: Bloomberg NEF, 6Wresearch

10.3 Levelized Cost of Storage (LCOS) Methodology

Calculation Components:

1. *Capital Costs: Includes the cost of battery packs, enclosures, balance of system (BoS), inverters, installation, and taxes.*
2. *Operating Costs: Maintenance and energy costs for charging the batteries.*
3. *Energy Output: Total energy discharged over the battery's lifetime.*

The LCOS is calculated by considering all capital, operational, and maintenance costs associated with the BESS, divided by the total energy discharged over the system's life. This includes capital costs such as battery packs, enclosures, balance of system (BoS), inverters, installation, and taxes. Operating costs encompass maintenance and energy costs for charging the batteries. The total energy output over the battery's lifetime is then used to determine the average cost per kilowatt-hour (kWh).

10.4 Evaluating Optimal Solutions

The economic viability of BESS in India is influenced by current tariff rates, which range between ₹6 and ₹12 per kWh for high-end residential and commercial consumers. This makes BESS economically viable at the current LCOS. As the LCOS continues to decline, BESS will become viable for a broader range of consumers, including industrial users. The deploymet of BESS offers significant environmental and operational benefits, including reducing reliance on fossil fuels, lowering greenhouse gas emissions, and enhancing grid stability and reliability, particularly in areas with high renewable energy penetration.

10.5 Role of Different Stakeholders in Minimizing Cost of Storage

Government: The Indian government plays a crucial role in minimizing the cost of storage by providing financial incentives such as Viability Gap Funding (VGF) to reduce initial capital costs. For instance, the government has approved a VGF scheme with an initial outlay of ₹9,400 crore, aimed at supporting the development of 4,000 MWh of BESS projects by 2030-31. Additionally, policy measures like the energy storage obligation (ESO) and the National Energy Storage Policy are helping create a conducive environment for ESS projects (IEEFA).

Energy Companies: Energy companies are investing in research and development to improve battery technologies and reduce costs. For example, India's first commercial utility-scale BESS project, supported by The Global Energy Alliance for People and Planet (GEAPP), involves a 20 MW/40 MWh installation at BRPL's Kilokari substation. This project sets a new standard for BESS affordability with an annual levelized tariff nearly 55% lower than previous benchmarks. Companies like IndiGrid and BSES Rajdhani Power Limited (BRPL) are leading this initiative (Global Energy Alliance).

Investors and Financial Institutions: Investors and financial institutions offer funding and financial products tailored to renewable energy and storage projects. The concessional loan provided by GEAPP for the BRPL BESS project, covering 70% of the total project cost, is a prime example of how strategic financial support can drive down costs and attract further investments

The deployment of BESS in India is becoming increasingly optimal due to significant reductions in costs and supportive government policies. As the LCOS continues to decline, BESS will become more economically viable for a broader range of consumers, contributing to a sustainable and reliable energy future for India. Different stakeholders play crucial roles in driving this transition, from providing financial support to developing advanced technologies and fostering market adoption. Through collaborative efforts, India can achieve its ambitious renewable energy targets and ensure energy security for its growing population.

10.6 Peer Analysis

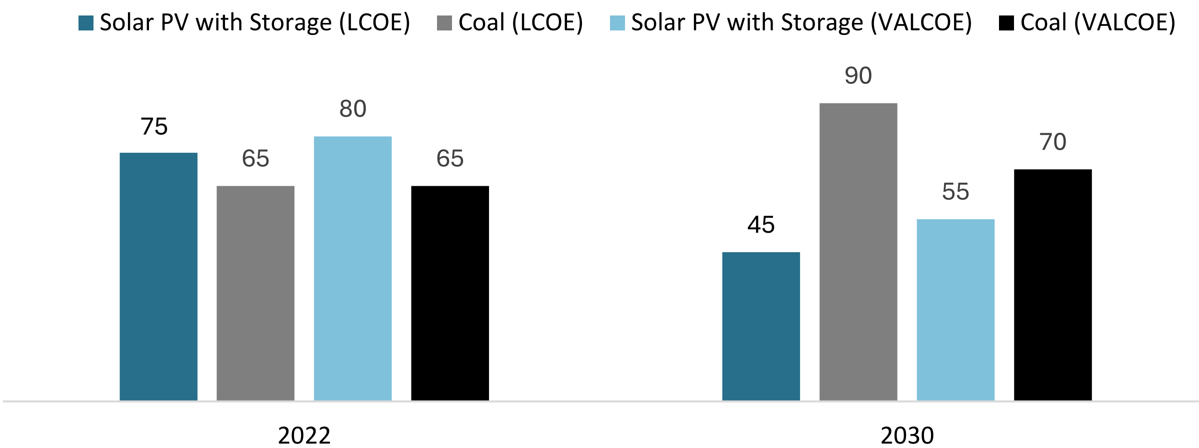
10.6.1 Methodology

The Levelized Cost of Electricity (LCOE) and Value-Adjusted Levelized Cost of Electricity (VALCOE) are critical metrics used to evaluate the economic viability and overall value of energy storage and generation systems. LCOE measures the average cost of generating electricity over the lifetime of a system, considering all associated expenses. VALCOE adjusts LCOE by accounting for the timing and location of electricity generation, providing a more comprehensive measure of its value to the grid. These metrics are essential in comparing the cost-effectiveness and value of energy storage solutions across different countries, such as India, China, and the USA, helping stakeholders make informed decisions about investments in renewable energy and storage technologies. This comparative analysis highlights how each country leverages technological advancements and policy support to optimize its energy storage strategies.

10.6.2 Current Scenario

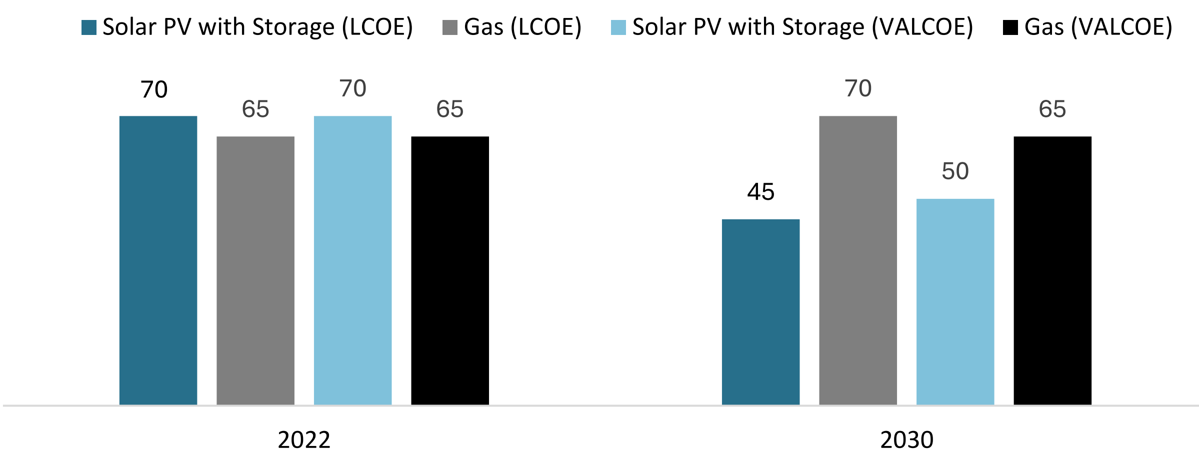
As of 2024, the Levelized Cost of Storage (LCOS) for Battery Energy Storage Systems (BESS) exhibits significant variability across major global players, namely India, China, and the USA. In the USA, the LCOS for solar PV with storage stands at approximately $70 per kWh, which is expected to decrease to $45 per kWh by 2030. This reduction is facilitated by advancements in battery technologies and substantial federal and state incentives, such as the Investment Tax Credit (ITC), which promotes the adoption of renewable energy and storage solutions. However, policy uncertainties and the ongoing competitiveness of natural gas pose challenges to further cost reductions. China, on the other hand, has a current LCOS for solar PV with storage at around $75 per kWh, which is projected to drop to $45 per kWh by 2030. China benefits from its dominant position in the global battery supply chain, significant R&D investments, and strong governmental support. Nevertheless, challenges such as the over-reliance on coal and the need for grid infrastructure upgrades persist. These trends highlight the global momentum towards cost-effective energy storage solutions driven by technological improvements and supportive policies.

Figure 16: Analysis of LCOE & VALCOE for China, 2022 & 2030F ($/kWh)



Source: IEA, 6Wresearch

Figure 17: Analysis of LCOE & VALCOE for USA, 2022 & 2030F ($/kWh)

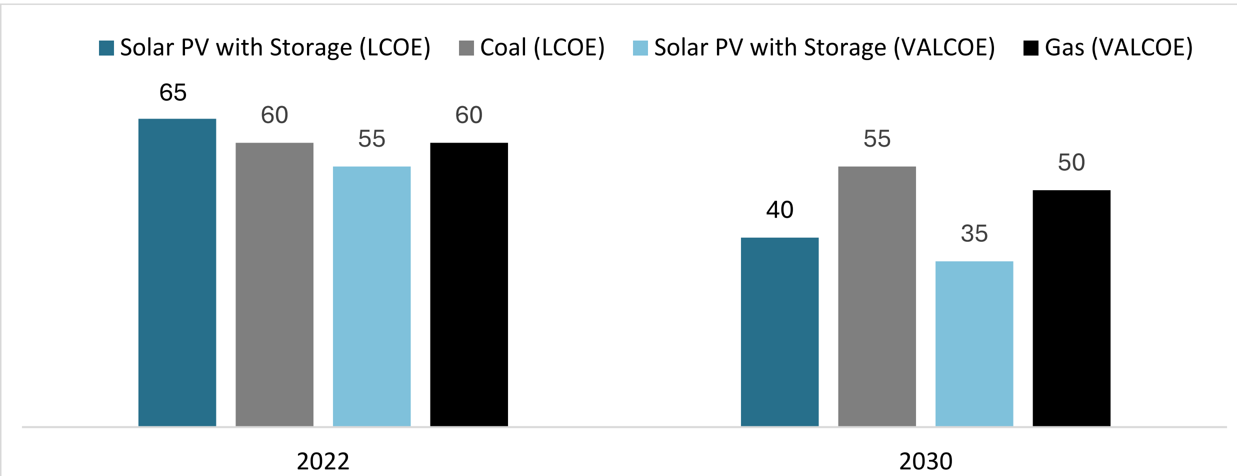


Source: IEA, 6Wresearch

10.6.3 India's Competitive Edge

India exhibits a notable competitive edge in the global BESS market, with its current LCOS for solar PV with storage at $65 per kWh, projected to decrease significantly to $35 per kWh by 2030. This rapid reduction is facilitated by comprehensive government initiatives like Viability Gap Funding (VGF) and energy storage obligations (ESO), which provide financial incentives and regulatory support. The Indian government has committed substantial funding and strategic partnerships, such as the project with BRPL's utility-scale BESS, supported by concessional loans from the Global Energy Alliance for People and Planet (GEAPP). Additionally, India focuses on local manufacturing and continuous technological advancements, further strengthening its market position. This proactive approach, combined with strategic international collaborations, positions India to achieve the lowest projected LCOS for solar PV with storage among major economies by 2030.

Figure 18: Analysis of LCOE & VALCOE for India, 2022 & 2030F ($/kWh)



Source: IEA, 6Wresearch

CHAPTER 11: Recommendations

11.1 Existing Gaps in Current Policies

India's energy storage system (ESS) ecosystem is grappling with several challenges and gaps that hinder its development and deployment. One of the primary issues is the high dependency on imported raw materials, such as lithium and cobalt, which are essential for lithium-ion battery manufacturing. The lack of a robust domestic supply chain for these critical minerals leads to increased production costs and vulnerability to global market fluctuations. Additionally, the absence of a well-established recycling infrastructure exacerbates the problem, as there are limited facilities for processing end-of-life batteries and recovering valuable materials.
Another major challenge is the inadequacy of domestic manufacturing capabilities for advanced battery technologies. Despite government initiatives like the Production Linked Incentive (PLI) scheme, the industry suffers from a lack of technical expertise and manufacturing infrastructure. This gap hinders the production of high-quality batteries at scale, essential for supporting the growing demand for electric vehicles (EVs) and renewable energy storage solutions. Moreover, existing policies and incentives are insufficient to attract significant investments, slowing progress toward achieving energy independence.

The regulatory landscape also presents substantial hurdles. The complex and lengthy processes for obtaining environmental and forest clearances delay project implementations, particularly for Pumped Hydro Storage (PHS). Furthermore, the current tax regime, which includes high GST rates and customs duties on ESS components, increases the overall cost of these systems. Additionally, the lack of clear standards and certification processes for batteries and related components hampers the industry's growth. This regulatory uncertainty discourages potential investors and developers from committing to large-scale projects, further stalling the development of a robust energy storage ecosystem.

11.2 Recommendations

To address these issues, several recommendations are proposed. The government authorities are suggested to implement additional financial incentives and clear policy frameworks. The reduction in cost would make BESS and PHS more accessible and attractive to investors, encouraging wider adoption across various sectors. By lowering GST and providing duty exemptions, the government can help alleviate financial pressures, making these technologies more competitive and viable in the market.

- **Extended Tax Holidays and Duty Exemptions:** It is recommended to implement a 5-year tax holiday for projects involving standalone Battery Energy Storage Systems (BESS) charged with renewable energy, storage coupled with transmission elements, and storage integrated with renewable plants. This measure will reduce the financial burden on investors and encourage more projects.

- **Reduction of GST Rates:** The current GST rates on lithium-ion batteries range between 18% to 28%. A uniform reduction to 5% across all advanced battery chemistries is recommended to facilitate large-scale deployment and reduce overall system costs.

- **Avoidance of Double Taxation:** Ensure that Electricity Duty (ED) and Cross Subsidy Surcharge (CSS) are not applied to the input power used for charging ESS, as these systems are merely facilitating energy conversion. These charges should only apply to the final consumption, aligning with the principles of double taxation avoidance.

Additionally, increasing Viability Gap Funding (VGF) to cover more than 40% of capital costs for BESS projects can make them more financially viable, accelerating the deployment of ESS infrastructure. Besides financial incentives, the exiting gaps in policy frameworks need to be mitigated. Significant investments are needed to upgrade the existing grid infrastructure, including the establishment of dedicated transmission lines for high-potential renewable energy zones and industrial clusters. These upgrades are essential for improving system reliability and integration, facilitating the seamless flow of electricity across the grid. Additionally, establishing expedited processes for obtaining environmental and forest clearances, particularly for PHS projects, will help reduce project lead times and associated costs. By pre-identifying project sites and securing necessary approvals before tendering, the government can mitigate risks and attract more investments, ensuring efficient and effective project implementation.

Alongside investment in localisation efforts for lithium-ion, additional focus on alternative battery technologies, such as sodium-ion, vanadium, and redox flow batteries, is crucial for diversifying India's energy storage landscape. By encouraging the development of these technologies, the country can reduce its reliance on specific raw materials and provide tailored solutions for its unique energy needs. This diversification will enhance the resilience and adaptability of the energy storage sector, supporting the country's long-term energy security goals. Following the example set by the US under the Inflation Reduction Act (IRA), India should provide generous subsidies and support for the localization of battery manufacturing. This includes fostering partnerships with international firms to build a robust domestic supply chain and reduce dependency on imports Furthermore, fostering innovation in these alternative technologies will contribute to the global competitiveness of India's energy storage industry, positioning the country as a leader in sustainable energy solutions.

As recommended by the Ministry of Power, the discarded mines including coal mines in different parts of the country could be used as Hydro Storage and thereby become natural enablers for the development of Hydro Pumped Storage Projects (PSPS). It is recommended to check the viability of such a suggestion and incentives should be given to coal-enriched states such as Jharkhand, Chhattisgarh and Orissa for identification of suitable sites to encourage pump storage. For instance, the government is targeting de-coaled mines in Jharkhand and Madhya Pradesh to set up these projects. Additionally, converting these sites into PHS facilities can address issues related to land use and environmental restoration, creating economic opportunities for local communities, and supporting the transition to a cleaner energy future.

Furthermore, BESS has significant potential in the ancillary service market, offering essential grid services such as frequency regulation and reserve power. To capitalize on this potential, it is recommended to develop a market mechanism for the procurement of Primary Reserve Ancillary Services (PRAS) and other ancillary services. This mechanism should include performance incentive structures for participating assets and the creation of a dedicated fast-response market. For the Secondary Response Ancillary Service (SRAS), providing a capacity/commitment charge will promote the business case for BESS and attract investment in grid-stabilizing services.

Moreover, the EU's emphasis on BTM solutions, including residential and commercial storage, has shown significant benefits. India could adopt similar policies to encourage the use of BTM systems, providing financial incentives and regulatory support to households and businesses investing in energy storage solutions. The EU's focus on research and innovation, particularly in long-term energy storage technologies, provides a model for India. Initiatives could include technology accelerator programs, dedicated support schemes for innovation, and funding for advanced R&D in energy storage systems.

CHAPTER 12: Conclusion

India's journey towards a sustainable and energy-secure future is intricately linked to the development and integration of Energy Storage Systems (ESS), particularly Battery Energy Storage Systems (BESS) and Pumped Hydro Storage (PHS). To reduce reliance on fuel-based energy and meet its net-zero carbon emission commitment by 2070, the integration of energy storage systems (ESS) is gaining momentum across various sectors. The development of a domestic battery manufacturing ecosystem, declining prices of battery technologies and growing shift towards clean energy are anticipated to enhance India's competitiveness and energy efficiency significantly.

BESS capacity is projected to grow from 8.68 GW/34.72 GWh by 2027 to 47.24 GW/236.22 GWh by 2032, driven by initiatives such as the Production Linked Incentive (PLI) scheme and Viability Gap Funding (VGF). Additionally, Pumped Hydro Storage (PHS) remains vital, with a current capacity of 4.75 GW and a projected increase to 18.8 GW by 2031-32. Government support through financial incentives and waivers for Inter-State Transmission System (ISTS) charges promotes PHS, with a growing shift towards off-river plants due to lower environmental impact. Notable PHS projects include the Tehri PSH Project in Uttarakhand and the Turga PSH Project in West Bengal, which exemplify the potential of expanding PHS capacity in India.

India's energy storage landscape shows a growing preference for BESS, particularly lithium-ion batteries, due to their high energy density, efficiency, and rapidly declining costs. The demand for advanced chemistry cell batteries is expected to rise sharply, driven by the expanding electric vehicle market and grid storage applications. Recycling used batteries will play a crucial role in securing raw materials and promoting a sustainable circular economy, thereby reducing dependency on imports. Efforts to lower the Levelized Cost of Storage (LCOS) through government incentives like VGF are essential to making BESS economically viable. Despite these promising trends, challenges such as high initial capital costs, limited domestic manufacturing capabilities, and reliance on imported raw materials must be addressed to achieve these targets. Overcoming these barriers by addressing high costs, enhancing domestic manufacturing, and streamlining regulatory frameworks are crucial steps toward achieving a stable and sustainable energy future.

References

- NITI Aayog: Advanced Chemistry Cell Battery Reuse and Recycling Market in India
- National Electricity Plan 2023 (Volume 1)
- NITI Aayog: Need for Advanced Chemistry Cell Energy Storage in India
- IISD Report: India's Potential in the Midstream of Battery Production
- ISGF Report: Energy Storage System Roadmap for India: 2019-2032
- CEA Report, 2022: Transmission system for RE capacity by 2030
- National Framework for Promoting Energy Storage Systems, August 2023
- European Association for Storage Of Energy: Activity Report 2023
- IEEFA Report: Achieving India's Renewable Energy Target by 2030
- NITI Aayog: Status quo analysis of various segments of electric mobility and low carbon passenger road transport in India
- U.S. Department of Energy Office of Electricity: Energy Storage Safety Plan
- Renewables 2023 Global Status Report – Global Overview
- IEEFA Energy Storage: Connecting India to Clean Power on Demand
- Industry Research Report on Renewable Energy, Green Technologies and Power-focused NBFCs
- IEA: World Energy Outlook 2023
- Global Energy Outlook 2024: Peaks or Plateaus
- Lazard's Levelized Cost of Energy Analysis—Version 16.0
- CEEW: How can India Indigenous Lithium-Ion Battery Manufacturing

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