Smart Grid and Energy Storage in India

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Contents

Acronyms

ACC	Advanced Chemistry Cell
ACS	Average cost of supply
AMI	Advanced Metering Infrastructure
APDRP	Accelerated Power Development and Reform Program
ARR	Average Revenue Requirement
AT&C	Aggregate Technical & Commercial
BEE	Bureau of Energy Efficiency
BESS	Battery Energy Storage Systems
BIS	Bureau of Indian Standards
CAES	Compressed Air Energy Storage
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CoE	Centre of Excellence
CSIR	Council of Scientific and Industrial Research
CTU	Central Transmission Utility
DDUGJY	Deendayal Upadhyaya Gram Jyoti Yojana
DPR	Detailed Project Report
DMS	Distribution Management System
DRES	Distributed Renewable Energy Sources
DSM	Deviation Settlement Mechanism
EMS	Energy Management System
EPR	Extended Producer Responsibility
ESS	Energy Storage System
EV	Electric Vehicle
FACTS	Flexible alternating current transmission system
GBS	Government Budgetary Support
GoI	Government of India
GIS	Gas Insulated Substation
GW	Gigawatt
HVDC	High-voltage direct current
InSTS	Intra State Transmission System - InSTS
ICRA	Investment Information and Credit Rating Agency of India Limited
IoT	Internet of things
IPDS	Integrated Power Development Scheme
ISTS	Inter-State Transmission system
IEEMA	Indian Electrical and Electronics Manufacturers Association
JERC	Joint Electricity Regulatory Commission

Acronyms

LCOS	levelized cost of storage
LMP	Locational marginal price
MECSP	Materials for Energy Conservation and Storage Platform
MoP	Ministry of Power
NDC	Nationally Determined Contribution
NEF	National Electricity Fund
NLDC	National Load Dispatch Centre
NSGM	National Smart Grid Mission
OMS	Outage Management System
PFR	Pre feasibility report
PHESP	Pump hydro energy storage plant
PHS	Pumped Hydro Storage
PLI	Production linked incentive
PMU	Phasor Management Unit
PPA	Power Purchase Agreement
PQM	Power Quality Meter
PV	Photovoltaic
R-APDRP	Restructured Accelerated Power Development and Reforms Program
RAS	Remedial Action Services
RDSS	Revamped Distribution Sector Scheme
RGGVY	Rajiv Gandhi Grameen Vidyutikaran Yojana
RE	Renewable Energy
SCADA	Supervisory Control and Data Acquisition
SDS	Sustainable Development Scenario
SERC	State Electricity Regulatory Commission
SGKC	Smart Grid Knowledge Centre
SIPS	System integrated protection scheme
STATCOM	Static synchronous Compensator
STEPS	Stated Policies Scenario
STU	State Transmission Utility
SVC	Static VAR compensator
UDAY	Ujwal Discom Assurance Yojana
UI	Unscheduled Interchange
UI-ASSIST	US-India Collaborative For Smart Distribution System With Storage
UNFCCC	UN Framework Convention on Climate Change
VPP	Virtual Power Plants
WAM	Wide Area Measurement
WAMS	Wide Area Measurement Systems

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Executive Summary

1 Executive Summary

India announced the target of achieving net zero emissions by 2070 along with a long-term low emissions growth strategy, indicating low carbon transition pathways in key economic sectors. The critical commitments under India's updated 'Nationally Determined Contributions' submitted to the UN Framework Convention on Climate Change (UNFCCC) are:

- 50% of the installed cumulative electric power will come from Renewable Energy (RE) resources by 2030
- Reduce carbon intensity by 45%
- Reduce carbon emissions by 1 billion tons

Robust energy demand driven by electrification backs these targets. Renewable energy generation capacity has increased fourfold in less than eight years. Energy storage is in a nascent stage with a growing pipeline of projects in battery and pumped storage segments for short and long-duration applications, respectively. Self-reliance in the technology supply chain is central to the government's ambition to create jobs and value from this transition. This can be an opportunity for Danish companies to provide the technical know-how for manufacturing battery cell components and develop niche chemistry battery designs beyond lithium-ion for long-duration applications. The Danish companies can also join hands with Indian players in providing grid-scale energy storage services.

Besides energy storage, smart grids with Advanced Metering Infrastructure (AMI) and Internet of things (IoT) enabled devices are key digital initiatives shaping the electricity distribution landscape. The Revamped Distribution Sector Scheme (RDSS) has consolidated the smart grid markets and investments under one umbrella initiative driven at national and subnational levels with significant financial incentives for large-scale implementation of smart meters at the consumer premises and metering of distribution transformers. According to the smart meter dashboard on the NSGM's website, the government has sanctioned about 10.7 million smart meters for deployment, of which nearly 5 million are already installed.

Denmark has demonstrated experience in integrating large shares of renewable electricity into a smart grid. Indian stakeholders can benefit from the Danish industry's knowledge and competence in providing the right solutions for the integration of renewable energy. This report provides an outlook on smart grid and energy storage sectors in India, key stakeholders involved, regulatory and policy scenarios, government initiatives, technology landscape, and current opportunities. Key highlights of the report are:

GROWING SIGNIFICANCE

- Energy storage will be critical in meeting the country's ambition to integrate high shares of renewable energy in the power system
- Clean, reliable and resilient electricity systems need smart grids more than ever

APPLICATION AREAS

- Energy arbitrage by storing surplus renewable energy to reduce curtailment, diurnal and seasonal storage
- Smart metering, energy accounting and managing Renewable Energy (RE) intermittency

KEY TECHNOLOGIES

- Pumped storage and battery systems are adopted for long and short duration applications respectively
- Smart meters, AMI, PQM, DMS are key technologies from smart grid perspective

MARKET ASSESSMENT

- 9.3 GW of energy storage projects under pipeline with a potential for 70 GW by 2032
- Projects worth US$19.6b have been approved for smart metering and infra upgradation under the RDSS scheme

2

Smart Grid — Revolutionizing Energy Management

2 Smart Grid — Revolutionizing Energy Management

2.1. Introduction and overview

The Indian power system is one of the largest in the world, with ~406 GW of installed capacity and close to 315 million customers as on 31 March 2021. So far, the system has been successful in electrifying 99.9% of households in India. Urban consumers of electricity are about 12.48 crores (39.55%), and rural consumers are approximately 19.07 crores (60.45%). Out of the total consumers, about 90.57% of the consumers are metered in the country. India has already set a goal of achieving 50% of the cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030 and is investing in strengthening the electrical network at the consumption end through initiatives such as Reform Linked Distribution Sector Scheme (RDSS).

The Government of India's initiative for improving the electricity distribution sector

Electricity distribution companies in India have proved to be an Achilles heel for the Indian power sector. This is due to the poor operational and financial condition of most electricity distribution companies (Discoms). India increasingly views smart grid technology as a strategic infrastructural investment that will sustain its long-term economic prosperity and help achieve its carbon emission reduction targets. It can provide ample opportunities to the companies involved in the smart grid network market in the near future. To address problems in the distribution sector, the Government of India (GoI) has implemented various schemes in the past (like the APDRP launched in 2002-03; the R-APDRP; the RGGVY launched in 2009; the IPDS launched in 2004 ; the DDUGJY launched in 2015) to improve the sub-transmission and distribution network separating agricultural feeders and rural electrification. The GoI has established a National Electricity Fund (NEF) to promote investment in the distribution sector. NEF Scheme has a provision to provide interest subsidy and other charges aggregating to US$1.02b for a period of 14 years on loans availed by the distribution utilities in the public and private sectors. Along with the above-mentioned schemes, the GoI also launched the Ujwal Discom Assurance Yojana (UDAY) scheme in November 2015 to ensure the economic revival of electricity distribution companies by taking over 75% of their debts and issuing bonds (by the Discoms) for the remaining 25% of the debt. It also envisaged reducing AT&C losses in the distribution sector, reducing the gap between the average cost of supply (ACS) and the average revenue requirement (ARR), and installing smart meters. UDAY scheme is credited for the commencement of the large-scale rollout of smart meters.

Revamped Distribution Sector Scheme (RDSS)

GoI launched the RDSS scheme in July 2022, subsuming earlier ongoing schemes such as IPDS, DDUGJY, and UDAY. The scheme provides financial assistance to Discoms to strengthen supply infrastructure based on meeting pre-qualifying criteria and achieving basic minimum benchmarks. The scheme has an outlay of $36.7b over five years, i.e., FY22 to FY26. The outlay includes an estimated Government Budgetary Support (GBS) of US$11.79b.

The objectives of the scheme are:

- Improved quality and reliability of power supply to consumers
- Financially and operationally efficient distribution sector, reduce AT&C losses to 12% to 15% by 2024-25, reduce ACS-ARR gaps to zero by 2024-25 and developing institutional capabilities

Components under the scheme

The scheme is divided into two parts. Part A is related to financial support for prepaid smart metering, system metering, and up-gradation of the distribution infrastructure. Part B has training and capacity-building provisions and other enabling and supporting activities. Components under Part A, Part B, and the associated details are mentioned in Figure 1.

Figure 1: Structure of RDSS scheme

Part A Component 1 (Budget – US$18.22b)

Metering

- 100% consumer metering through prepaid or smart prepaid mode and 100% communicable DT and feeder metering with AMI to enable energy accounting
- Metering of unmetered feeders and bringing all feeder meters (new and old) online
- Replacement or fresh DT meter installation in TOTEX (Capital expenditure + operational expenditure) mode

Part A Component 2 (Budget – US$18.30b)

Distribution Infra Work Targeted at loss reduction

- Armored / Aerial bunched Cables, HVDS system in high loss areas, segregation of feeders and new feeders for loss reduction
- Targeted at network strengthening
- Augmentation of Substations, additional HT lines to improve quality of supply, IT/OT enablement works, SCADA, DMS in urban areas

Part A Component 3 (Budget – 1% of project cost)

Project Management

- Scope for PMA to include:
  - Project Management Agency (PMA) shall be appointed by each Discom
  - DPR preparation, Tender documents and Project awarding, Monitoring, Quality assurance, Results evaluation, Other aspect as decided by Discoms

Part B - Training, capacity building and other enabling and supporting activities (Budget – $0.17b)

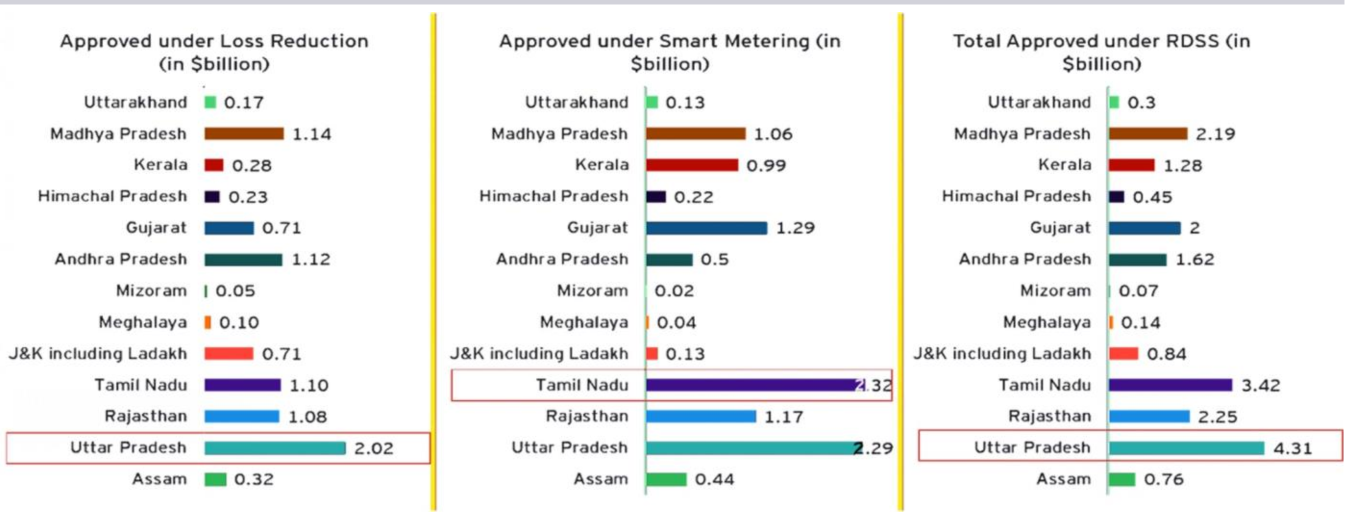
- Upgradation of personnel skills involved in execution of the scheme at field level, process map improvements, augmentation of Smart Grid Knowledge Center, awards and recognitions, etc.

Source: EY Analysis

Current status of the scheme

The government has approved sanction of $19.57b worth of proposals from 13 states under the scheme (till April 2022), out of which $10.63b has been earmarked for smart–metering and $9.06b for infrastructure upgradation toward loss reduction efforts. The state-wise segregation shows that Uttar Pradesh, Tamil Nadu, Rajasthan, Madhya Pradesh and Gujarat are the states where much work must be done. The state wise breakup has been shown below in figure 2:

Figure 2: Outlay under RDSS scheme, state wise breakup



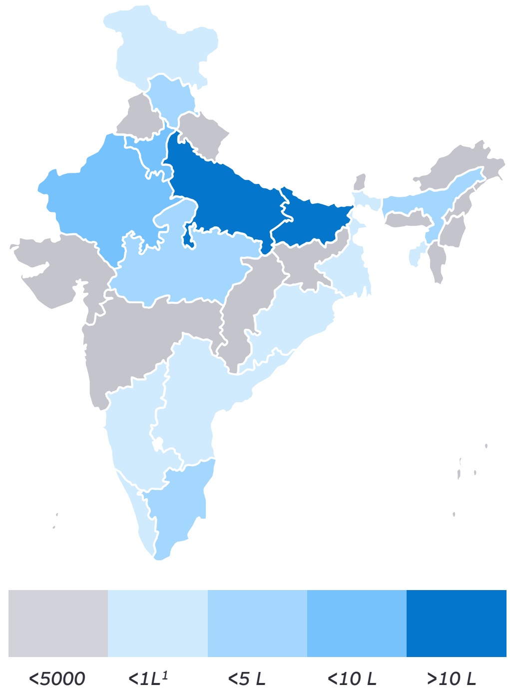
Source: EY Analysis

Status of Smart Metering in India

~50% of the sanctioned 10.7 million smart meters have been installed under various schemes with many populous states yet to start their smart metering drive

A total of 10,705,751 smart meters have been sanctioned (as of November 2022), out of which 4,976,506 smart meters have been installed. These smart metering projects were sanctioned under DDUGYJ, IPDS, NSGM, SG Pilot, PMDP, and under the utility ownership model. State wise breakup is shown in table 1:

Table 1: Agency and scheme wise summary		
All India Status		
Agency	**Sanctioned (million)**	**Installed (million)**
EESL	7.8	3.07
PFCCL	0.15	1.5
RECPDCL	0.71	0.15
Utility	2.59	1.71
Grand Total	**11.27**	**5.09**
Scheme wise	**Sanctioned** (million)	**Installed** (million)
DDUGJY	0.039	0.038
IPDS	1.26	0.81
NSGM	0.18	0.14
PMDP	0.68	0.13
SG Pilot	0.16	0.16
Utility owned	8.95	3.81
Grand Total	**11.27**	**5.09**



Source: Smart Meter Dashboard, NSGM Website

Smart grid developments in India

National Smart Grid Mission (NSGM): National Smart grid Mission was formed in 2008 as one of the eight missions under the National Action Plan on Climate change. NSGM was created to accelerate Smart Grid deployment in India and has been operational since 2016, housed under the MoP. NSGM has its own resources, authority, functional and financial autonomy to plan and monitor the implementation of the country's policies and programs related to Smart Grids. There are 12 Smart Grid pilot projects approved under NSGM so far, adopting the functionalities as mentioned below in figure 3. Apart from NSGM, a few private utilities have also demonstrated smart grid projects covering extra functionalities such SCADA/EMS, SCADA/DMS, and battery energy storage systems.

Advanced metering infrastructure	Peak Load Management	Cybersecurity
Distributed generation	Micro grid	Power quality measurement
Smart City Control Center	Smart homes	Advanced IT infrastructure
Renewable Energy Integration	EV with charging infra	Home energy management center
AMI (Smart Metering)	Outage management system	Customer engagement social media for utility

Source: EY Analysis

Smart Cities Mission

The purpose of the Smart Cities Mission is to drive economic growth and improve the quality of life of people by enabling local area development and harnessing technology, especially technology that leads to smart grid. One hundred cities have been selected for the mission with an outlay of US$24.77 billion. The Smart City program also promotes "smart grids for smart cities". The activities focused upon under Smart City initiative for Smart Grids is mentioned in the adjoining figure 4.

Figure 4: Activities under Smart Cities Initiative

- Effective outage management
- Waste and energy reduction
- Reduced equipment failures
- Improved revenue cycle
- Reduced OPEX
- Affordable power
- Effective load management

Source: EY Analysis

Drivers for smart grid for different stakeholders in India

The drivers for the smart grid for different key stakeholders such as utilities, consumers, and government bodies are mentioned in figure 5.

Figure 5: Drivers for smart grid for different stakeholders

Utilities	Customer	Government and regulators
▶ Reduction of T&D losses ▶ Peak load management and increasing grid visibility ▶ Reduction in power purchase cost ▶ Better asset management and self-healing grid ▶ RE Integration	▶ Expand access to electricity and emergence of “Prosumer” ▶ Improve reliability of supply and Increased choices ▶ Beneficial tariffs and improved quality of supply ▶ User-friendly and transparent interface with utilities	▶ Satisfied customers ▶ Financially sound utilities ▶ Tariff neutral system upgrade and modernization ▶ Reduction in emission intensity

2.2. Policy regulations

India follows the US model of a Central Electricity Regulatory Commission (CERC) and separates electricity regulatory commissions (SERCs) in each state. There are 27 SERCs, two joint electricity regulatory commissions, and one CERC. The chairpersons of all the 30 commissions form a statutory body called the Forum of Regulators (FOR), which the chairperson of CERC chairs.

Table 2: Key policies and regulations related to / affecting smart Grid

Regulations	Key highlights
Indian Electricity Grid Code, 2010	Lays down the rules, guidelines and standards to be followed to plan, develop, maintain and operate the power system, in an efficient, reliable, economic and secure manner
Model Smart Grid Regulations	Model regulation has been formulated by FoR in November 2015 regarding forecasting, scheduling and imbalance handling of RE generators at intra-state level for adoption by SERCs.
Ancillary Services Regulations	The regulations aim to maintain the grid frequency close to 50 Hz, and restore the grid frequency within the allowable band as specified in the Grid Code and for relieving congestion in the transmission network, to ensure smooth operation of the power system, and safety and security of the grid
Regulatory Framework for Intra-State Balancing, Accounting and Settlement System	Model regulations have been formulated by FoR in March 2017, regarding imbalance handling (Deviation Settlement Mechanism) at intra-state level for adoption by respective SERCs
Imbalance Handling Mechanism	CERC has introduced a Deviation Settlement Mechanism (DSM) for imbalance pricing in India since February, 2014, replacing erstwhile Unscheduled Mechanism (Unscheduled Interchange/UI)) in vogue since 2002, with amendments in Nov 2015/May 2016 for renewables
Regulatory Framework for Communication in Power Sector	The users, including RE generators, shall be responsible for provision of compatible equipment along with appropriate interface for uninterrupted communication with the concerned control centres

Source: EY Analysis

2.3. Stakeholders for engagement

An inter-ministerial group, i.e., the India Smart Grid Task Force, provides directions to the Smart Grid initiatives in the country. The Central Technical Authority is the key technical body, and its chairperson heads the technical committee of NSGM, whereas the state smart grid mission units are formed to implement smart grid initiatives at the state level. All the critical stakeholders for engagement from the public and private sectors have been mapped in Appendix 1.

2.4. Research and Development

The Smart Grid Knowledge Centre (SGKC), established at Manesar, is the key Centre of Excellence focusing on fostering partnerships, innovation and entrepreneurship in smart grid technologies. A few of the inter-governmental collaborations for research in areas related to smart grid are the US-India Collaborative for Smart Distribution System with Storage (UI-ASSIST), the Indo-Sweden Collaborative Industrial Research and Collaborative Programme, the India EU Integrated Local Energy Systems program etc. Indian universities, with support of NSGM and the Department of Science and Technology, are leading several research activities. Details about all the key R&D activities in India related to smart grid have been tabulated in Appendix 2.

2.5. Civil society actors and industry associations in the domain of smart grid

The India Smart Grid Forum, established as a Public Private Partnership, is the major body spearheading the mission to accelerate electric grid modernization in India. The Indian Electrical and Electronics Manufacturers Association (IEEMA) through its smart grid division is a crucial industry association involved in smart grid dialogues. The description roles and significance of key organizations are tabulated in Appendix 3.

2.6. Technological landscape

Smart grid components in the transmission system

In the Inter State Transmission System (ISTS) at 220 kV or above, the CEA has already termed the power system 'Quite Smart' in its rollout plan. The latest technology has been greatly deployed in the form of state-of-the-art SCADA systems, FACTs devices, HVDC, Wide Area Measurement Systems (WAMS), Gas Insulated Substation (GIS) and substation automation. However, to meet future energy requirements, strengthening / upgradation of existing state transmission system (i.e., Intra State Transmission System - InSTS) with smart technologies is essential. To strengthen the InSTS, sub-station automation / remote operation, real time power system monitoring and measurement systems (SCADA and WAMS for Steady state and dynamic monitoring respectively), must be deployed by all STUs. Further, the following intelligent technologies are essential for deployment in the transmission sector at InSTS level:

a) Robust, reliable, and high-capacity backbone communication system using fiber optic

b) Supervisory Control and Data Acquisition (SCADA) system at state transmission

c) Synchro Phasor Measurement System using phasor measurement units

d) Digital substation using process bus technologies

e) FACTS devices (STATCOM / SVC)

f) Battery Energy Storage Systems (BESS)

Smart grid at the distribution level

As per ICRA report, the consolidated debt of state-owned distribution companies is estimated at US$72.78b in FY 2022. The average AT&C losses of Indian Discoms is 17.47%. Improving the operational and billing efficiencies can help plug these losses. The distribution grid comprises medium and low-voltage networks that have historically lacked automation. The distribution grids of big utilities span hundreds of thousands of kilometers, making it prohibitively costly to construct a reliable communication system between all endpoints and the control center. As a result, there needs to be more insight into the low-voltage network's power flows. Additionally, most faults are not recognized automatically. Only when consumers report an outage, a staff is assigned to identify and fix the issue. As a result, the primary objective of the smart grid effort is to modernize the distribution grid with the addition of sophisticated automation and control capabilities.

The Indian smart grid sector requires urgent digital initiatives enabling a fast-paced digital transformation which can future-proof the utility to face more changes and challenges. The COVID-19 pandemic has further compelled utilities to accelerate this shift. The catalyst of digital transformation (technology) and its impact is depicted in figure 6:

Figure 6: Catalyst of digital transformation and its impact in the smart grid market in India

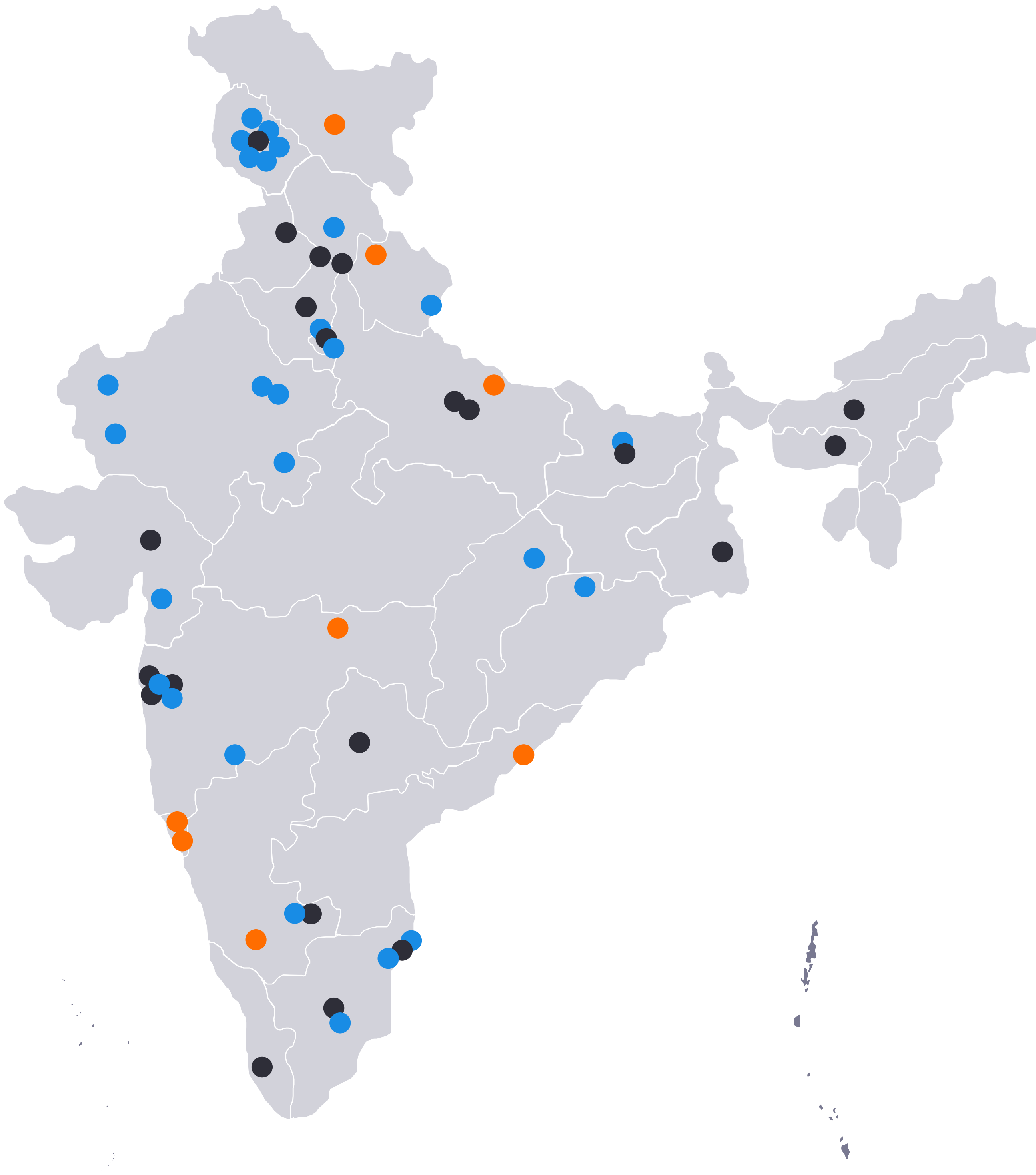
Catalyst	Impact
AMI	▶ By adopting AMI Solution, Discoms can improve their billing efficiency, that may lead to a decrease in commercial losses. Smart meter data help Discoms to perform analytics on consumption pattern, assets performance and load profiling which can lead to enhanced operational efficiency and consumer satisfaction.
Blockchain	▶ Blockchain-based solutions assist businesses in swiftly, securely and accurately obtaining the appropriate information required to make quick and effective decisions. It can be leveraged in the execution of trade agreements by enforcing terms of the agreement through smart contracts deployed on blockchain
Power Purchase Optimisation	▶ The usage of advanced analytics and sophisticated weather forecasting models improves demand and supply side forecasting, especially from variable RE sources. Corelating with historical data, Discoms can accurately predict short-, medium- or long-term power purchase trends, thereby optimizing power purchase portfolios.
Internet of Things	▶ The growing need to improve resiliency through improvements in reliability and reduction in operational costs with the goal of enhancing customer satisfaction, IOT will be a game changer.
Unified revenue management system	▶ Discoms can move to a Unified Revenue Management System to have a bird eye view of revenue operations of their entire consumer base. Some other significant advantages are easier accounts consolidation, seamless integration with digital payment avenues and greater insights into end point electricity consumption.
Enterprise asset management	▶ EAM has features such as work management, asset management, planning and scheduling, supply chain and health and safety. When integrated with SCADA, ERP and GIS can help utilities maximize the value of their assets.
Virtual Augmented Reality	▶ AR/VR in combination of edge devices can provide rich insights on assets, operations and maintenance management.
Unmanned Aerial Vehicles	▶ An integrated solution encompassing efficient drone operations, a robust data management platform and advanced analytics will help power and utility companies realize the true value.
Virtual Power Plants	▶ VPP is an aggregated portfolio of distributed energy resources including storage and rooftop solar systems that mimic an actual power plant to provide grid services such as peak load management, grid balancing and fast frequency response.
Cybersecurity	▶ Cybersecurity governance and technical safeguards deployed for infrastructure and operations would be key elements of a resilient power sector and will help in mitigating the risk of cyber attacks.
Scada – EMS and ADMS	▶ With growing impetus on smart grids, ADMS (unification of SCADA, DMS and OMS implementation is picking up momentum. It will help in dynamic monitoring of grid, using Phasor Management Unit (PMU) and Wide Area Measurement (WAM) enabling features such as Remedial Action Services (RAS), System integrated protection scheme (SIPS), adaptive islanding and self-healing grid.

Source: EY Analysis

Figure 7: Upcoming opportunities in smart grid space for India

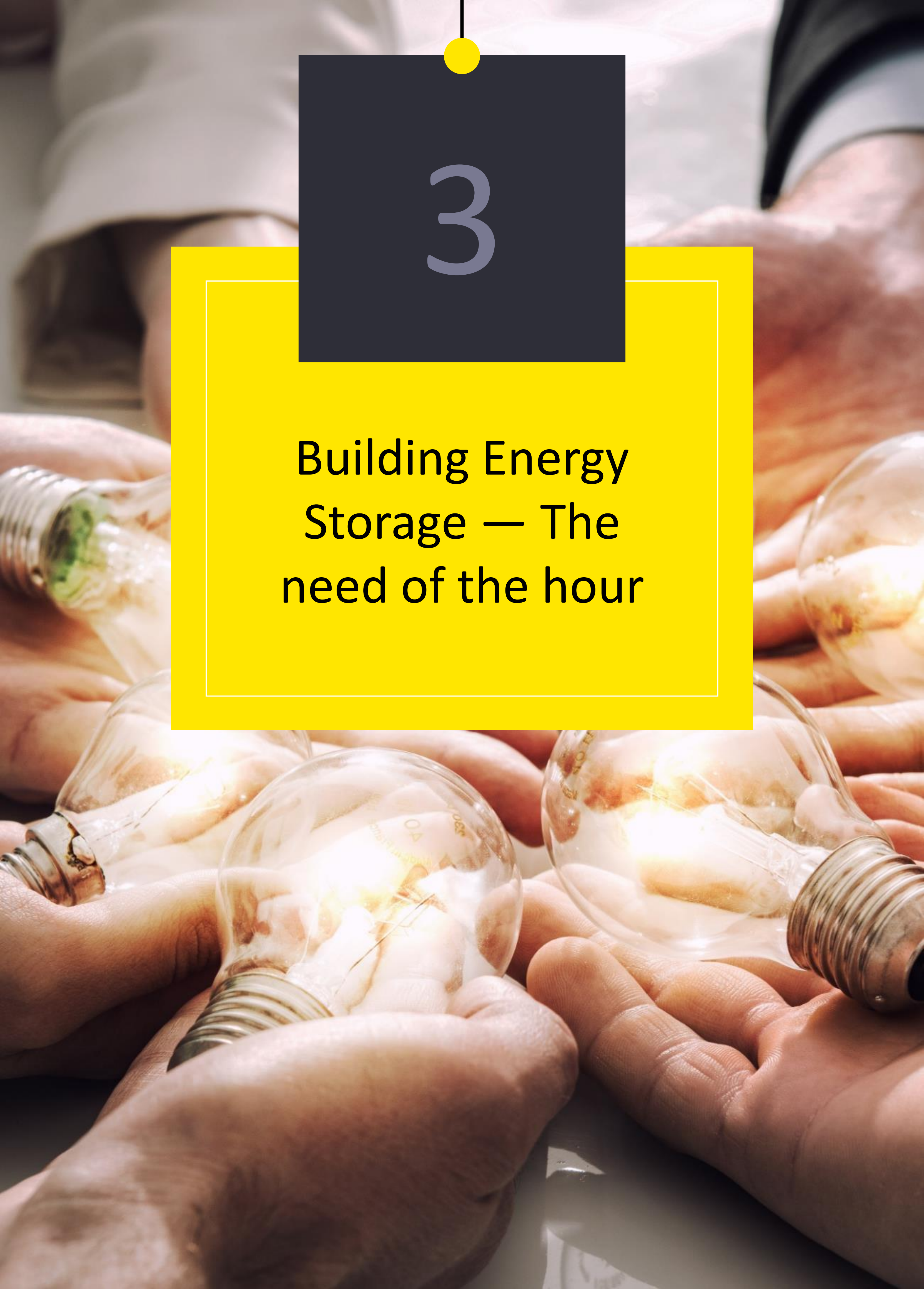
2.7. Upcoming opportunities

The upcoming opportunities in smart grid space for India including that of smart meters are indicated below.



- Grid Modernization project
- Advanced Metering Infrastructure project
- Microgrid project

Source: Various Secondary sources, EY Analysis



3

Building Energy Storage — The need of the hour

3 Building energy storage — The need of the hour

3.1. Introduction and overview

India is on the cusp of an energy transition. The share of electricity in total final energy consumption could increase from 17% in the base scenario to 23% in the more optimistic sustainable development scenario (SDS) by 2030. India expects annual electricity demand to grow at an average of 7.2% over five years ending March 2027, nearly double the growth rate of over 4% seen during FY 2018-22.

Fig 8: Share of electricity in total energy consumption

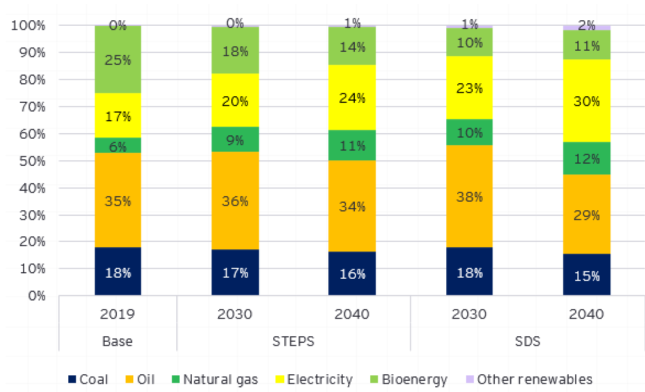
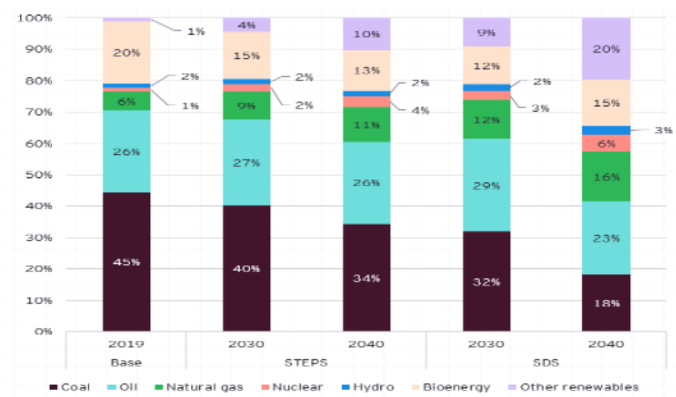


Fig 9: Scenarios depicting change in primary energy mix



Source: India Energy Outlook, 2021

The share of coal in India's primary energy mix could reduce from 45% in the base scenario to 32% in the more optimistic SDS scenario by 2030. It is accompanied by the increased share of other renewable energy from 1% in 2019 to 9% and 20% in 2030 and 2040, respectively. This twin effect of reducing the share of conventional sources and increasing the clean energy capacity is creating a case of a reduction in grid inertia. Due to renewable energy's intermittency nature, energy storage technologies are needed for grid security and reliability.

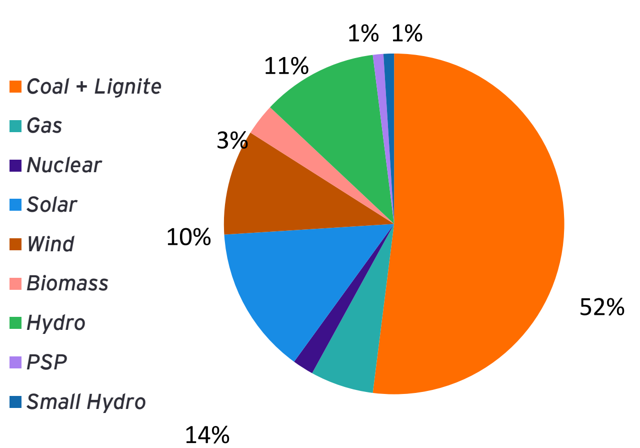
To boost battery energy storage systems, India in its annual budget has announced to offer viability gap funding (VGF) for a total capacity of 4,000 MWh

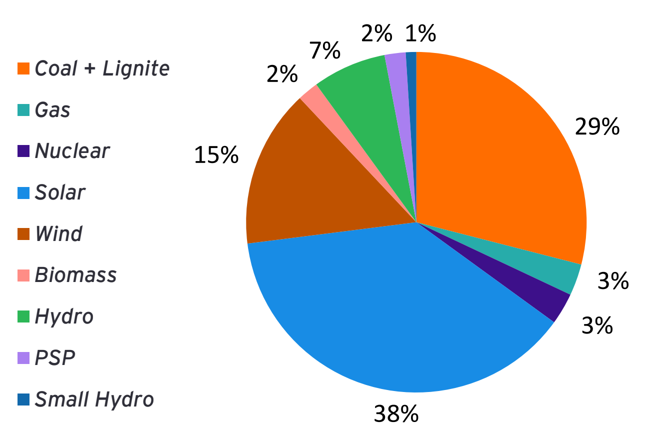
Future outlook

On the global front, Pumped Storage Plants (PSP) provided ~90% share of energy storage technology in 2020. As per CEA's draft report on optimal generation capacity mix report for 2031-32, electricity demand will likely increase to 363 GW (peak) and 2,538 billion units by FY32. The non-fossil fuel-based installed capacity by the end of 2031-32 is projected to be 592 GW, which covers 467.GW of variable renewable energy resources-based generation. CEA also expects the requirement of ~ 392.78 GWh of battery energy storage capacity by 2031-32, including 135 GWh from a pumped hydro storage systems.

Figure 10: Present installed capacity and forecasted values for FY 2031-32

Present	Future
Installed Capacity (as on May 2022)	CEA Projected likely installed capacity (MW) in 2031-32



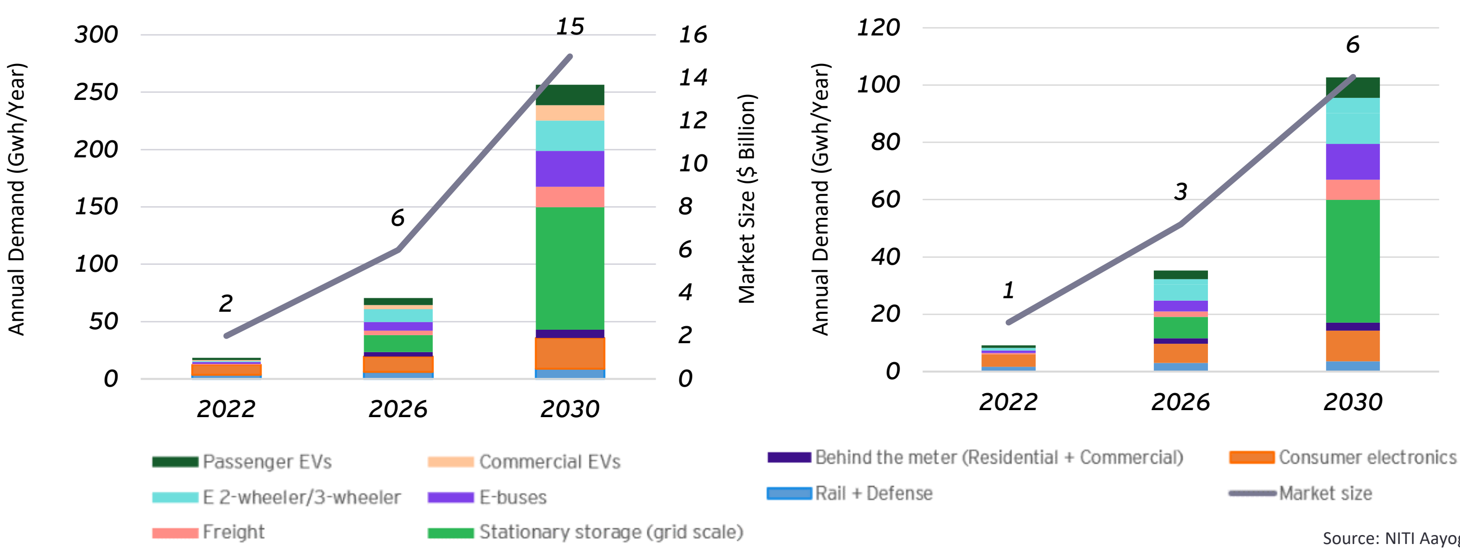


Source: CEA

3.2. Outlook — Battery demand

India has outlined an ambitious target of 50% cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030. To attain these targets, India needs a significant amount of grid storage. Two scenarios have been considered for accessing demand, i.e., an accelerated and conservative scenario. The accelerated scenario depicts the current policy momentum triggering the high penetration of these technologies, whereas conservative scenario means battery demand will align with the most conservative forecasts. The demand for batteries under the accelerated and the conservative scenario is depicted below.

Figure 11: Battery demand outlook



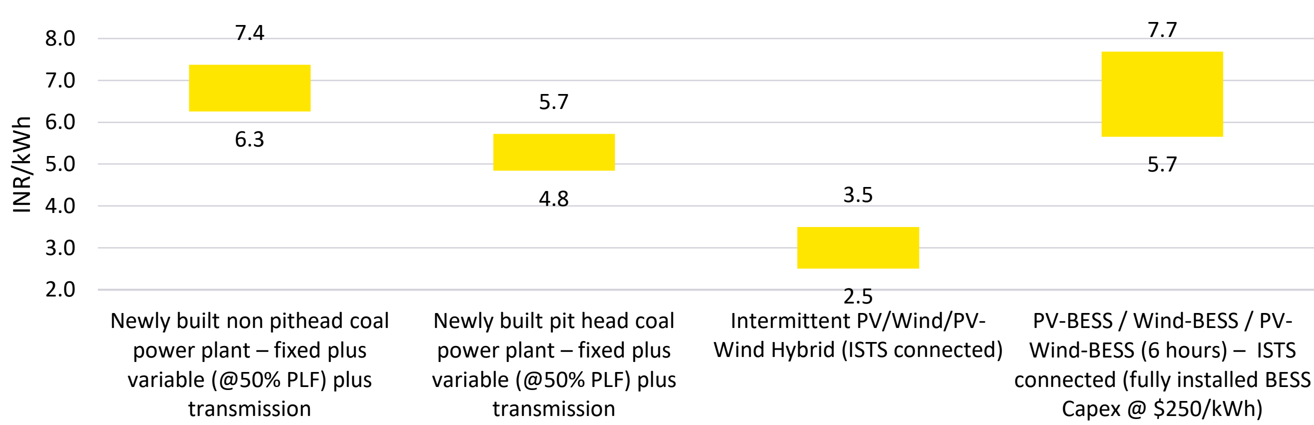
Source: NITI Aayog

The annual market for stationary and mobile batteries in India could surpass US$15 billion by 2030, with almost US$12 billion from cells and US$3 billion from pack assembly and integration.

Competitiveness of stationary battery energy storage applications in the Indian power sector

The cost of energy storage as a service, when integrated with intermittent PV/Wind/PV-Wind hybrid systems, will need to reach parity with the levelized cost of procurement from conventional baseload generation. This will determine the speed and scale of energy transition in the power sector going forward. A comparison of per unit cost of electricity in different scenarios is mentioned below:

Figure 12: Competitiveness of stationary battery energy storage



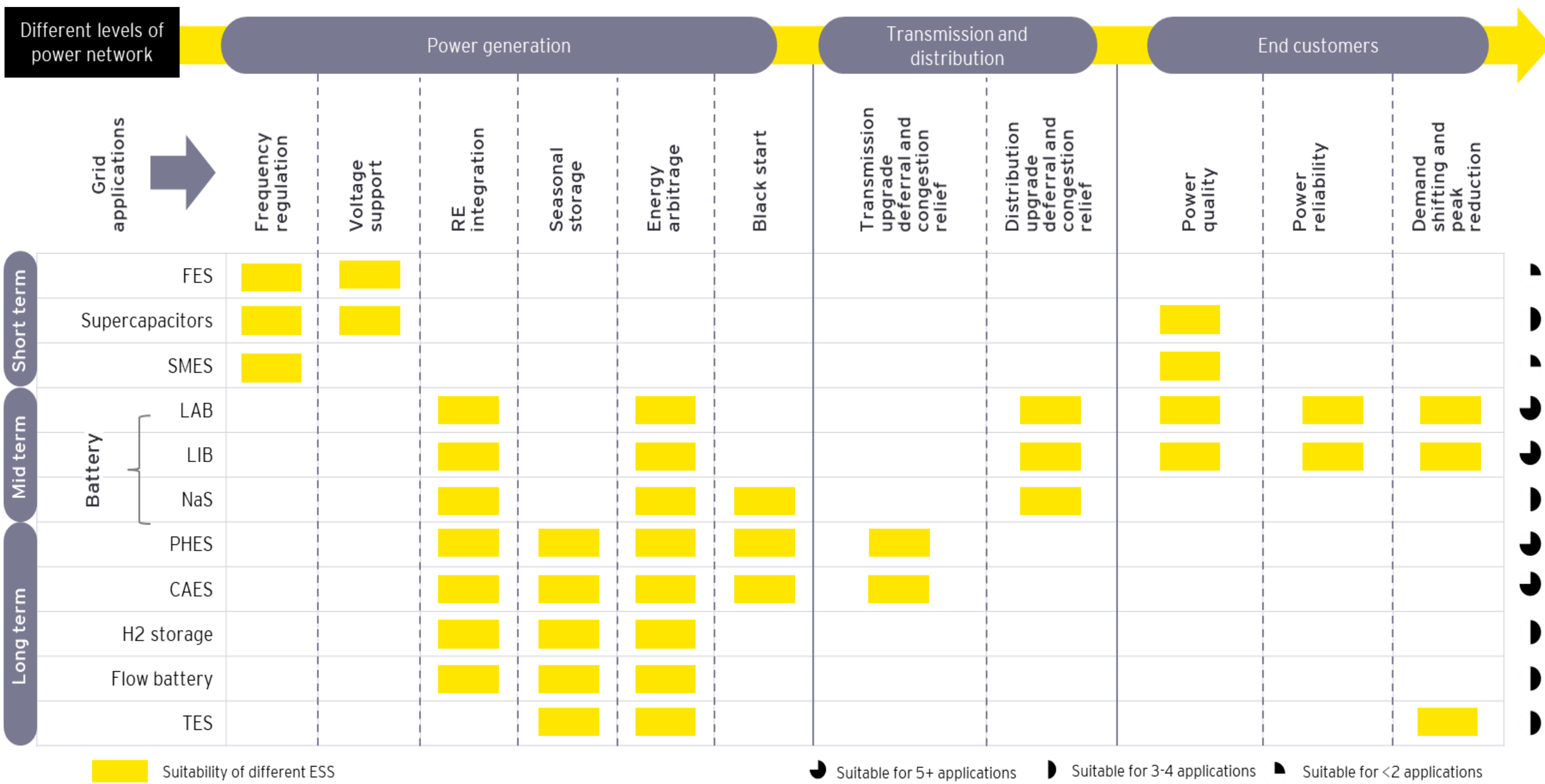
Source: EY Analysis

Note: Fully installed BESS capex is exclusive of duties & taxes

3.3. Energy storage applications

It is essential to analyze the technologies in terms of their specific energy and power, discharge, and response times pertinent to grid-scale applications. A combination of ESS technologies is required to support the grid completely. PHES, BESS, and CAES are some technologies supporting multiple applications.

Figure 13: Energy storage systems applications at different levels of the power network



Source: Centre for Study of Science, Various secondary sources, EY analysis

Grid-scale energy storage applications are categorized into four main groups:

Ancillary services

- **Voltage support**: ESS helps to maintain grid voltage within specified limits, to help manage reactive power.
- **Frequency regulation**: ESS helps in correcting frequency deviations, maintaining frequency within limits.
- **Spinning reserves**: Standby generation stations utilised during unexpected power shortage. ESS with longer discharge durations can be used as spinning reserves.
- **Black start**: ESS help in energising part of the grid during unplanned blackouts.
- **Load following**: ESS with fast-response time creates balance between load and generation when the load changes rapidly. This helps to maintain stability of grid.

Bulk energy services

- **Energy arbitrage**: This stores energy when the price is low and sells energy during peak demand when the price is high. Round-trip efficiency and operating cost play key role when ESS is involved in arbitrage.
- **RE integration**: ESS should be able to absorb fluctuations to make the power system more flexible when large share of intermittent renewables integrates into the grid.
- **Seasonal storage:** ESS with capability to discharge for days, weeks, or months can supply the seasonal mismatches in power system.

T&D infrastructure services

- **T&D upgrade deferral**: This involves using ESS to either defer or avoid the need of a T&D equipment upgrade to meet demand growth.
- **T&D congestion relief**: ESS charging during off-peak hours and discharging during peak load helps in reducing the congestion in transmission network.

Customer energy management services

- **Power quality**: ESS will help in protecting consumers from high variations in voltage.
- **Power reliability**: The ESS installed close to consumer load aids customer during an unplanned interruption from the utility.
- **Demand shifting and peak reduction**: ESS supports by reducing peak demand and shifting the demand to non-peak hours.

3.4. Present scenario of battery energy storage in India

India's stationary energy storage market is currently at a nascent stage. There are many projects, under various stages of construction, mainly for renewable energy integration. Difficulty in signing PPA with states, time lapse in bidding procedure, lack of guidelines, lack of financial support, etc., have led to the delays in implementing various projects announced in FY21. Key BESS projects commissioned in India are tabulated on the b:

Table 3: Key BESS projects commissioned in India

Location	BESS capacity	Technology
Delhi	10 MW	LIB
Andaman	16 MW	LIB
Gujarat	6 MW	Not known
Haryana	250 kW	Electrochemical
Rajasthan	3 MW	Electrochemical
Uttar Pradesh	40 kW	Advanced lead acid
Uttar Pradesh	1 MW	LIB
Puducherry	500 kW	Advanced lead acid
Puducherry	500 kW	LIB

Source: EY analysis

3.5. Policy regulations

A stable policy and regulatory environment and sustained efforts from the stakeholders push the cost downwards, thus speeding the adoption of energy storage systems in India. The government of India has taken various steps to make the policy and regulatory environment conducive. Significant actions taken by the government are mentioned below:

Table 4: Key policies/regulations and their highlights

Key Policies/Regulations	Key highlights
Guidelines for Procurement and Utilization of BESS as part of GT&D assets, along with Ancillary Services	Provide standardization and uniformity in processes and a risk-sharing framework between various stakeholders, involved in the energy storage and storage capacity procurement, thereby encouraging competition and enhanced bankability of the Projects.
Energy Storage Purchase Obligation	The total prescribed energy storage obligation will progressively increase from 1% in 2023-24 to 4% by 2029-30.
Green Energy Open Access Rules, 2022	Open access eligibility extended to consumers who have contracted demand or sanctioned load of hundred kW and there shall be no limit of supply of power for the captive consumers
Battery Waste Management Rules	The rules function based on the concept of Extended Producer Responsibility (EPR) where the producers (including importers) of batteries are responsible for collection and recycling/refurbishment of waste batteries and use of recovered materials from wastes into new batteries
Guidelines for flexibility in generation and scheduling of thermal/hydro power stations through bundling with RE and storage power	Since costly thermal power is being displaced in the merit order stack due to availability of economical RE power, a unique blending mechanism was proposed for higher dispatch of the contracted quantum from the generator. RE power with/without energy storage is to be blended with thermal/hydro power within the existing contracted capacity of the generator

Source: EY analysis

3.6. Schemes related to energy storage in India

Production Linked Incentive (PLI) scheme, 'National Programme on Advanced Chemistry Cell (ACC) Battery Storage' for implementation of giga-scale ACC manufacturing facilities in India

The Department of Heavy Industries, Govt. of India notified the Production Linked Incentive (PLI) scheme, 'National Programme on Advanced Chemistry Cell (ACC) Battery Storage' in 2021 for implementation of giga–watthour scale ACC manufacturing facilities in India with a budgetary outlay of US$2.19 billion. The scheme envisaged the setting up a cumulative ACC manufacturing capacity of 50 GWh and an additional cumulative capacity of 5 GWh for Niche ACC Technologies. A total of 10 bids with capacity ~130 GWh were received under the ACC PLI scheme. The incentive structure is designed to encourage the industry to promote fresh investments in indigenous supply chains and deep localization for ACC battery manufacturing in the country. Finally, four bidders (Rajesh Exports, Ola Electric, Hyundai global motors, and Reliance New Energy Solar ltd.) got selected for incentives for a cumulative capacity of 50 GWh per year under the scheme.

National Mission on Transformative Mobility and Battery Storage

The mission will lay down the strategy and roadmap, enabling India to leverage its size and scale to develop a competitive domestic manufacturing ecosystem. This mission is more aligned with promoting e-mobility.

3.7. Import duties and taxation on battery packs

Import duty / customs duty

To support the 'Make in India' initiative, the GoI announced to extend the customs duty exemption to import of capital goods and machinery required for manufacture of lithium-ion cells for batteries used in electric vehicles. This is part of the roadmap under the phased manufacturing program. The import of Lithium and Lithium-ion cells attracts a custom duty of 15%. The basic import duty on battery packs has been increased to 20%.

Goods and services tax (GST)

In line with GoI's vision of bringing down the electric vehicle prices, the Ministry of Finance slashed the GST on lithium-ion battery packs from 28% to 18% in 2018. GST on Lithium and Lithium-ion cells is 18% and 28% respectively. It is expected that the GST on the battery pack will be further lowered to 5%. The GST council, in its 47th meeting, has already announced that electric vehicles, whether fitted with a battery pack, are eligible for the concessional GST rate of 5%, thus paving the way for the lowest slab of GST on battery packs.

3.8. Stakeholders for engagement

The Ministry of Power and the Ministry of New and Renewable Energy are the key ministries handling energy storage. NITI Aayog is the premier policy 'Think Tank' of the Government of India, providing directional and policy inputs. At the state level, state energy departments and the respective state renewable energy development agencies have a key role in taking initiatives related to the deployment of energy storage. All the key stakeholders for engagement from the public and private sectors have been mapped in Appendix 4.

3.9. Research and development in the supply chain of energy storage systems

GoI, through the Ministry of Science and Technology, has supported more than 90 projects related to energy storage, resulting in more than 150 scientific publications. Four "Materials for Energy Conservation and Storage Platform" (MECSP) have been set up for the development of energy storage materials and systems at the Indian Institute of Science Bengaluru, the Indian Institute of Technology Bombay, the Indian Institute of Technology Delhi, and the Nonferrous Materials Technology Development Centre (NFTDC), Hyderabad. Various Centre of Excellence (CoE) have also been created under the schemes. These CoEs focus on different areas and aspects of the entire value chain of energy storage systems. All the major R&D activities in India are mapped in Appendix 5.

3.10. Civil society and industry associations in the domain of energy storage systems

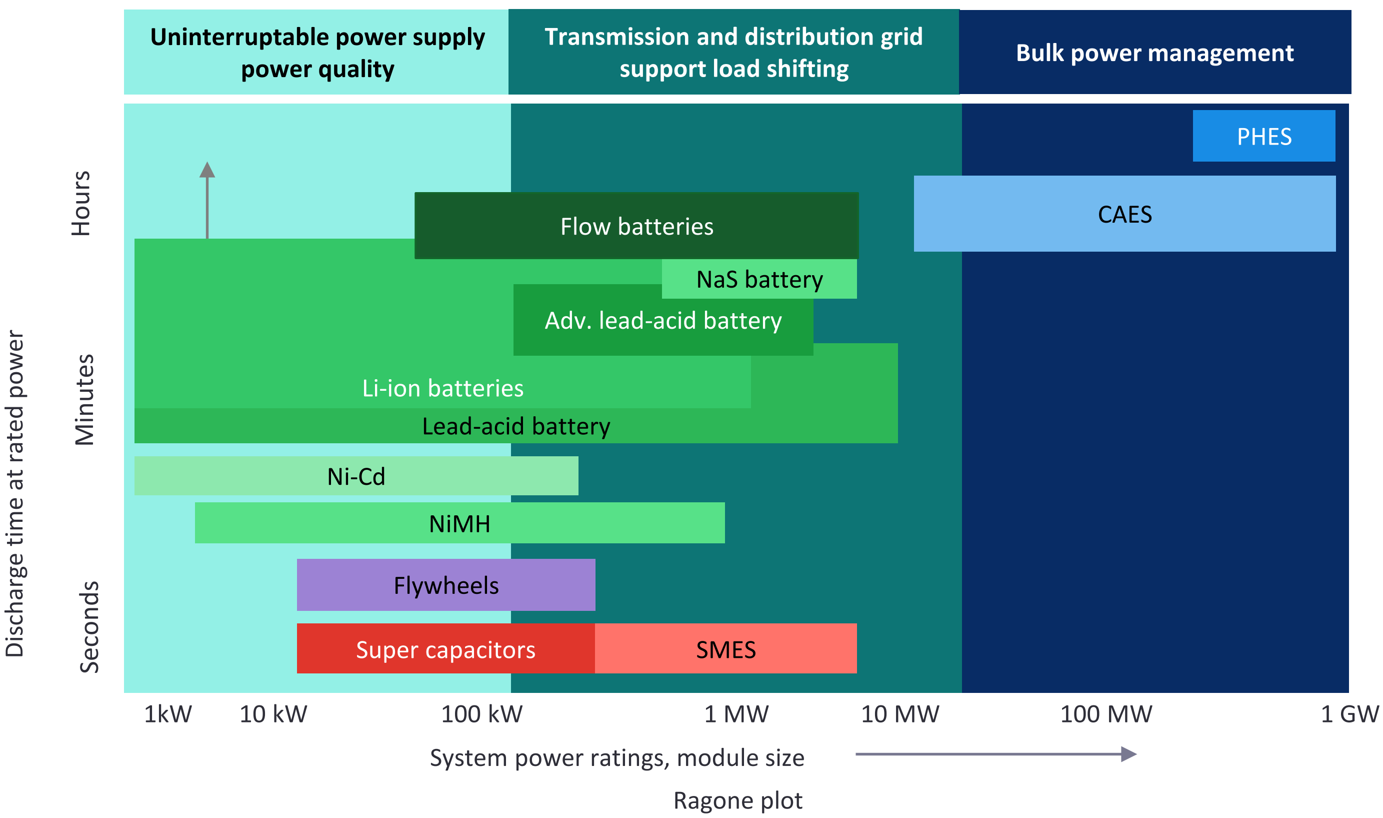
The India Energy Storage Alliance (IESA) is one of India's main bodies active in Energy Storage space. IESA has a network of 160+ member companies, encompassing industry verticals from energy storage, EV manufacturing, EV charging infrastructure, green hydrogen, microgrids, power electronics, renewable energy, research institutes and universities, and cleantech startups. Apart from IESA, few industry associations are the voice of industry players and civil society members. The description, role and significance of key associations are mapped in Appendix 6.

3.11. Technological landscape

The energy storage technologies vary in commercial viability parameters like technology maturity, energy density, operating costs, etc. Recently, the price competitiveness, the quick development of battery technologies, and the limitations of other storage systems have made BESS the first choice globally. BESS and PHES will continue to impact grid-scale applications significantly. However, post-mid-2030s, it is estimated that BESS capacity will rise rapidly, overtaking PHES – driven by advancements in technology and a reduction in its levelized cost of storage (LCOS) due to an increase in the production volume of batteries.

It is essential to analyze the technologies in terms of their specific energy and power, discharge, and response times pertinent to grid-scale applications. A comparative analysis of various ESS technologies is mentioned below:

Figure 14: Comparative analysis of various ESS technologies

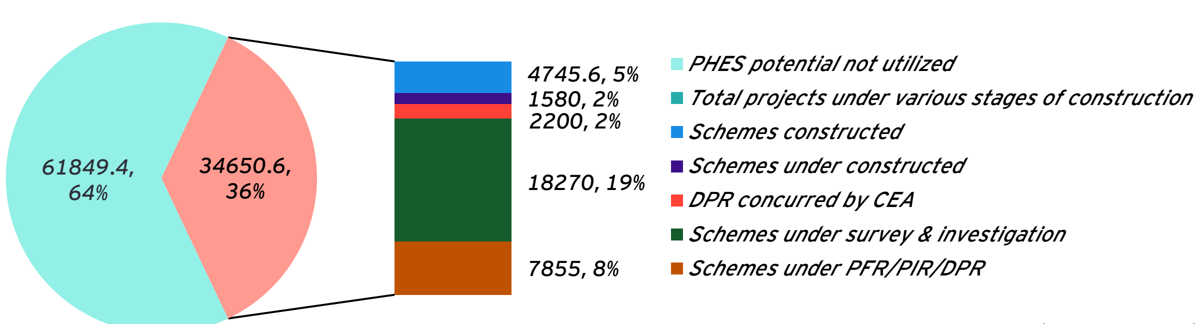


Source: ERI 2021, Various secondary sources, EY analysis

Until the technology cost curve for battery storage systems improves, pumped storage will remain a viable alternative to provide grid balancing services. Some facts about pump storage in India is mentioned below:

- 63 sites have been identified for Pumped Storage Plants (PSP), with a total potential of about 96,500 MW
- ~35 GW (36%) is the project capacity, which is under different stages of execution
- Out of 35 GW, ~26 GW (75%) of the capacity is lying at the stage of initial study, which refers to the project either under PFR/DPR preparation or under the survey and investigation stage
- Only 1.6 GW of the projects are at the construction phase, indicating less capacity addition in the coming future

Figure 15: PHS potential utilization in India (as on 30 April 22)



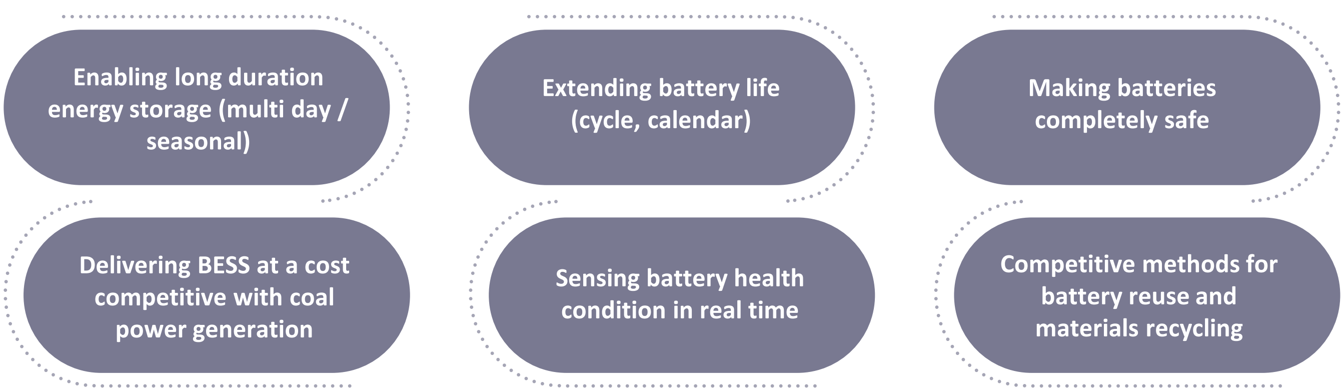
Source: Various secondary sources, EY analysis

PHS is a mature and scalable energy storage technology, accounting for over ~90% of installed global energy storage capacity in the present scenario. PHS is a type of hydroelectric energy storage that uses a two-reservoir system (upper and lower) to store energy and generate electricity. It is of two kinds: 'open loop', connected to a natural-water source for one or both the reservoirs, and 'closed loop' (or off-river PHS), which has no external water bodies connected to both reservoirs.

PHS can store surplus renewable energy and supply electricity during peak hours continuously for 6 to 10 hours, depending on the storage capacity of the upper reservoir. PHS systems have a lifetime of over 40 years, with roundtrip efficiency of 70% to 80%. Also, compared to conventional thermal generators, PHS has a higher ramping capability (the ability to quickly start-stop). These features enable PHS to provide multiple services to integrate a high share of renewables into the grid at competitive prices. But there are challenges too, including an increased initial investment (US$600 to US$2000/kW), topographical requirements like the range for elevation (20 to 1000 meter) between the two reservoirs, proximity to a large water body, and environmental impacts like loss of wildlife habitats and issues of resettlement and rehabilitation of human population. The Central Electricity Authority of India has estimated a PHS potential of 96 GW, but only 3.3 GW is currently operational in India. This slow pace is attributable to the high cost associated with the commissioning of PHS plants, the long gestation period due to delays in obtaining environmental clearances, and the low recovery from the existing pricing mechanism of PHS. The high cost and environmental clearance issues can be resolved using a closed-loop PHS system that utilizes less water, has a low gestation period, and has minimal impact on the environment. A 2019 study by the Australian National University (ANU) estimates that there are 16,000 closed-loop PHS sites in India.

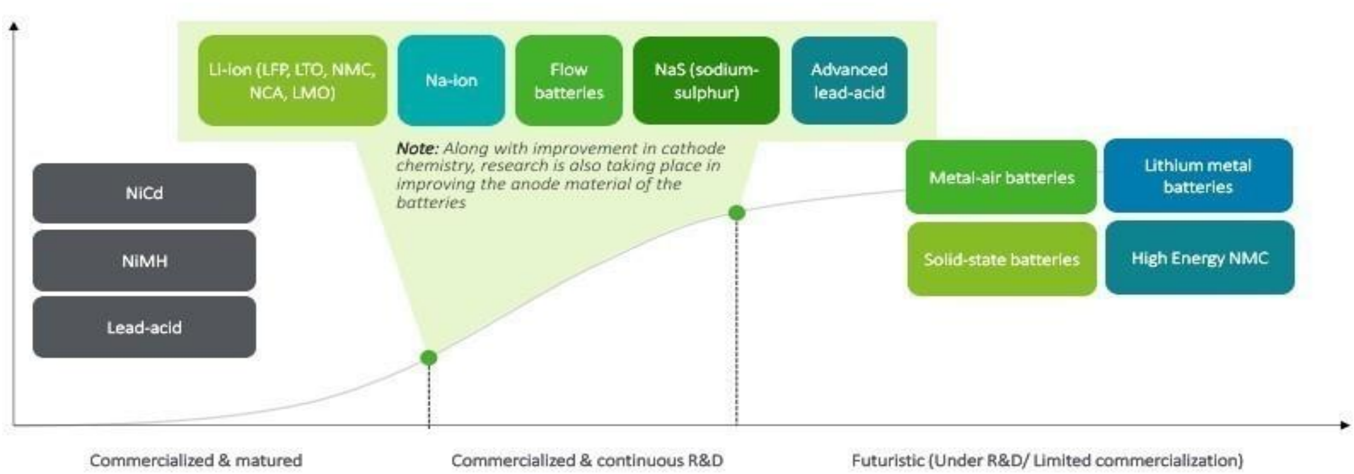
3.11.1. Battery energy storage for stationary grid applications must evolve beyond lithium-ion technologies for long-duration storage capabilities and competitiveness

Figure 16: Technological challenges for battery energy storage systems (BESS)



The stationary storage industry will need advanced chemistry battery cells enabling long-duration storage cycles (>15 hours per cycle) and long life (number of charge–discharge cycles) at competitive prices to boost demand. High-performance Li-ion batteries with high energy density and round-trip efficiency are more suited for mobility applications and less suited for multiday and beyond storage. Levelized cost of energy storage is a key performance parameter for stationary BESS solutions. It must compete with the levelized cost of energy from fossil fuels for scaling up adoption in India. In the near future, short-duration (up to 10 hours per cycle) energy storage applications will likely be satisfied with the continued reduction of the cost of Li-ion batteries. In the long term, increasing penetration of solar and wind power sources in the energy mix will drive the development of new, ultra low-cost battery chemistries made from earth-abundant elements.

Figure 17: Comparison of battery technologies



Source: Various secondary sources

3.12. Upcoming opportunities

Figure 18: Grid-scale energy storage project deployment in India (Under 5 MW)

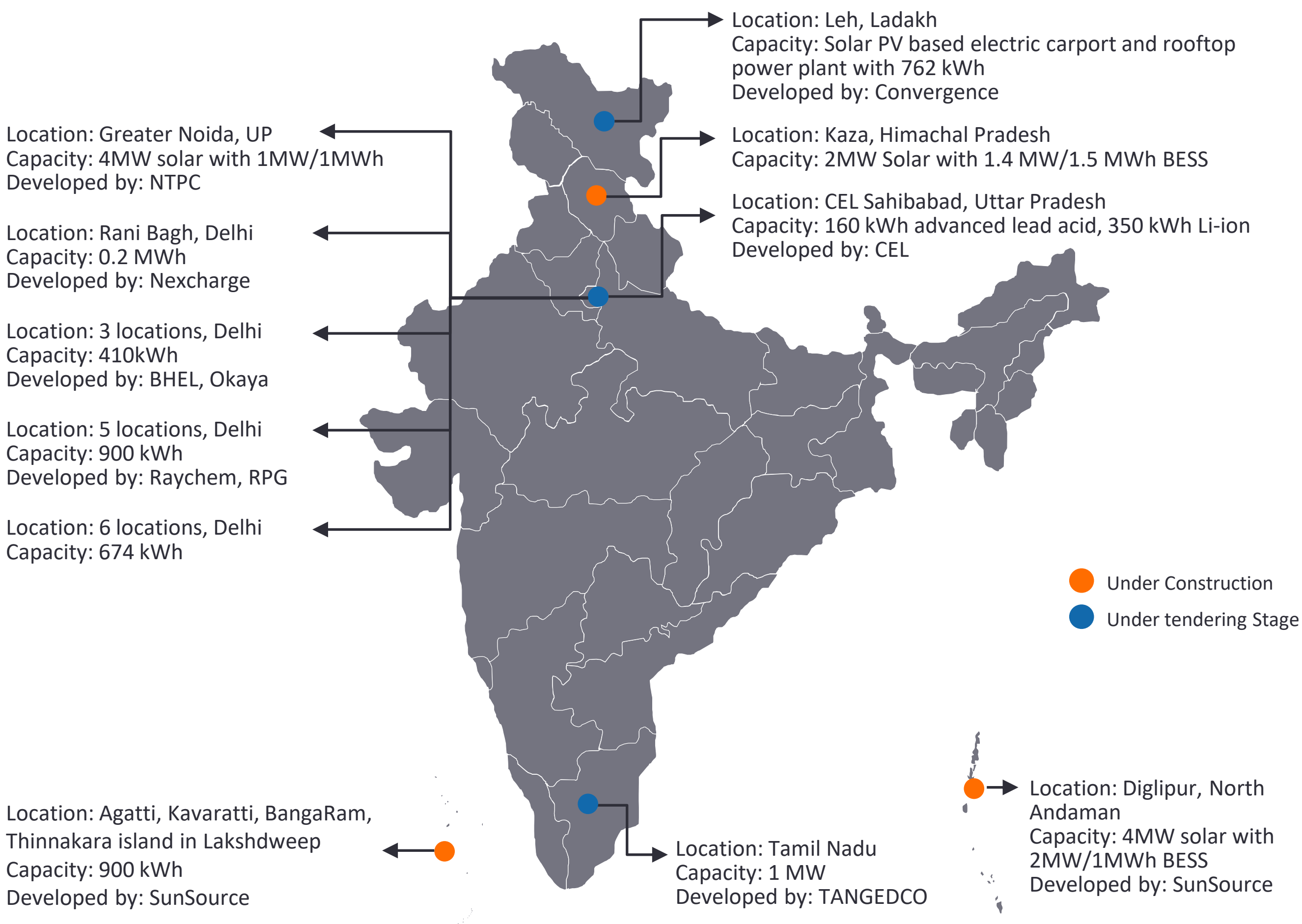
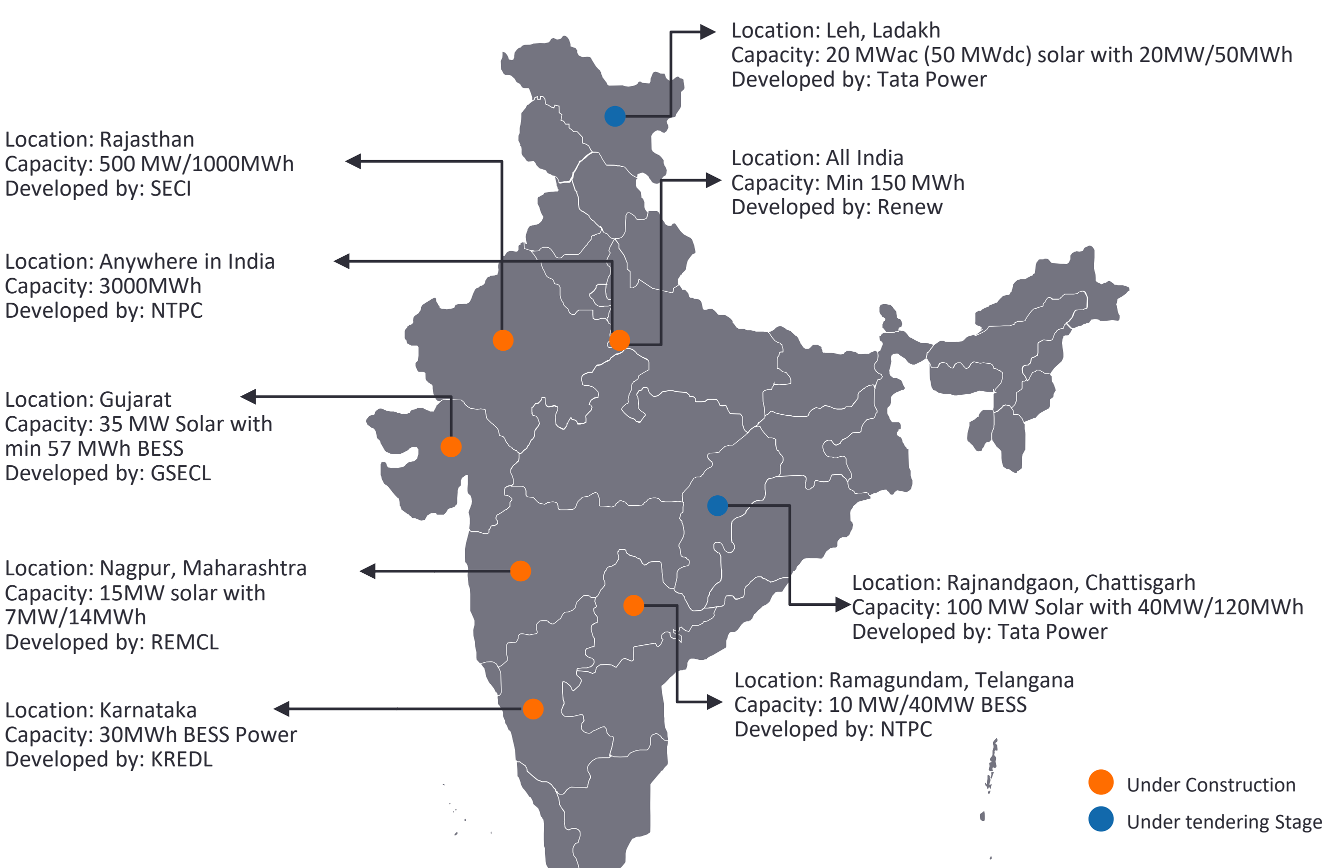
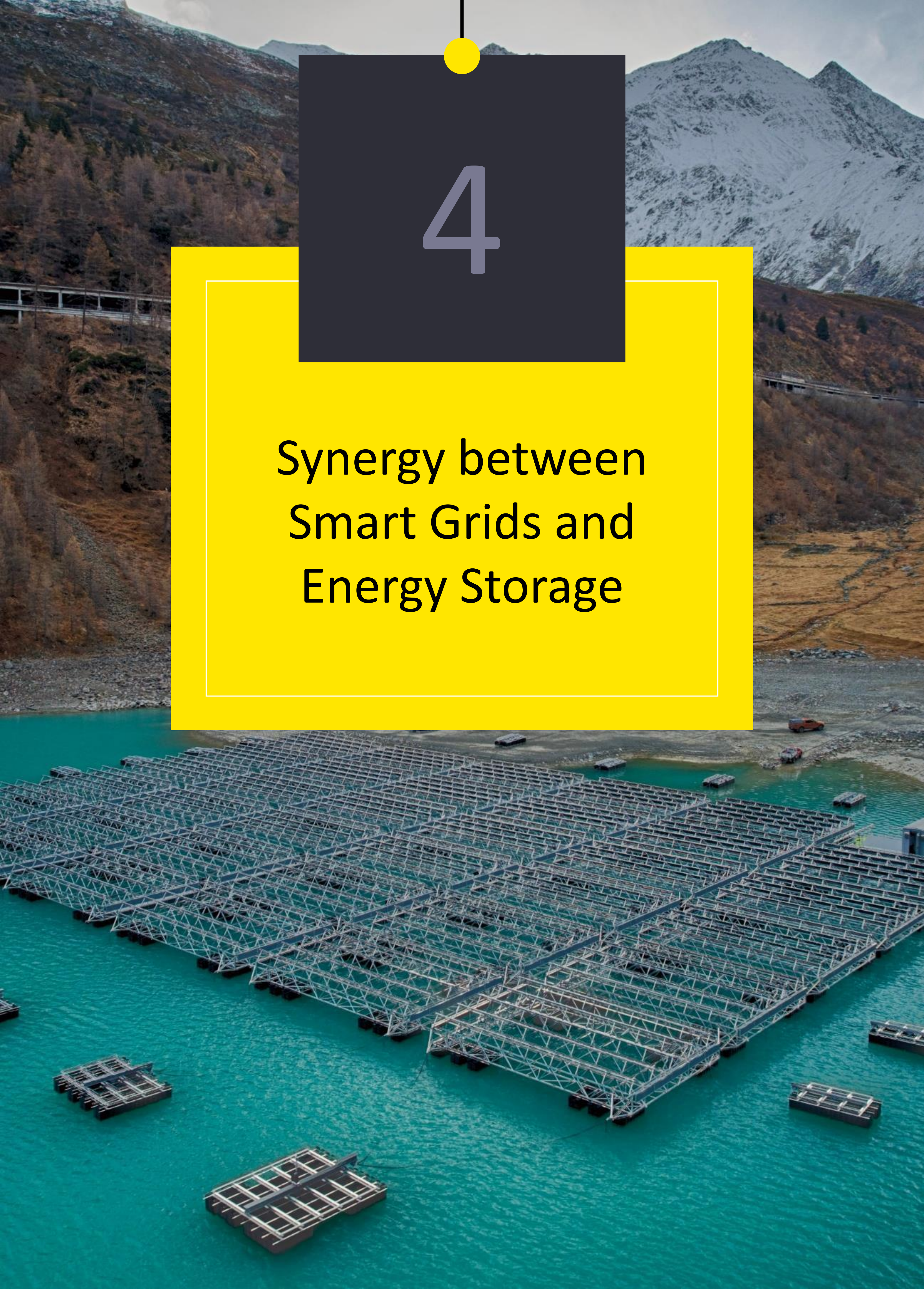


Figure 19: Grid-scale energy storage project deployment in India (above 5 MW)



Source: Various Secondary sources, EY Analysis



4

Synergy between Smart Grids and Energy Storage

4 Synergy between Smart Grid and Energy Storage

The Battery Energy Storage System (BESS) is a key technology with unique capability to meet the hourly variation in power demand and electricity pricing in smart grid systems. Smart grids encourage more renewable energy sources in the grid system to reduce CO2 emission. BESS reduces the cost of electricity use by charging storage batteries during off-peak hours and supplying energy to the grid during peak hours. BESS improves the reliability of supply by supporting users during power failures due to disaster periods. It maintains and improves power quality, frequency, and voltage stability when connected in the power network.

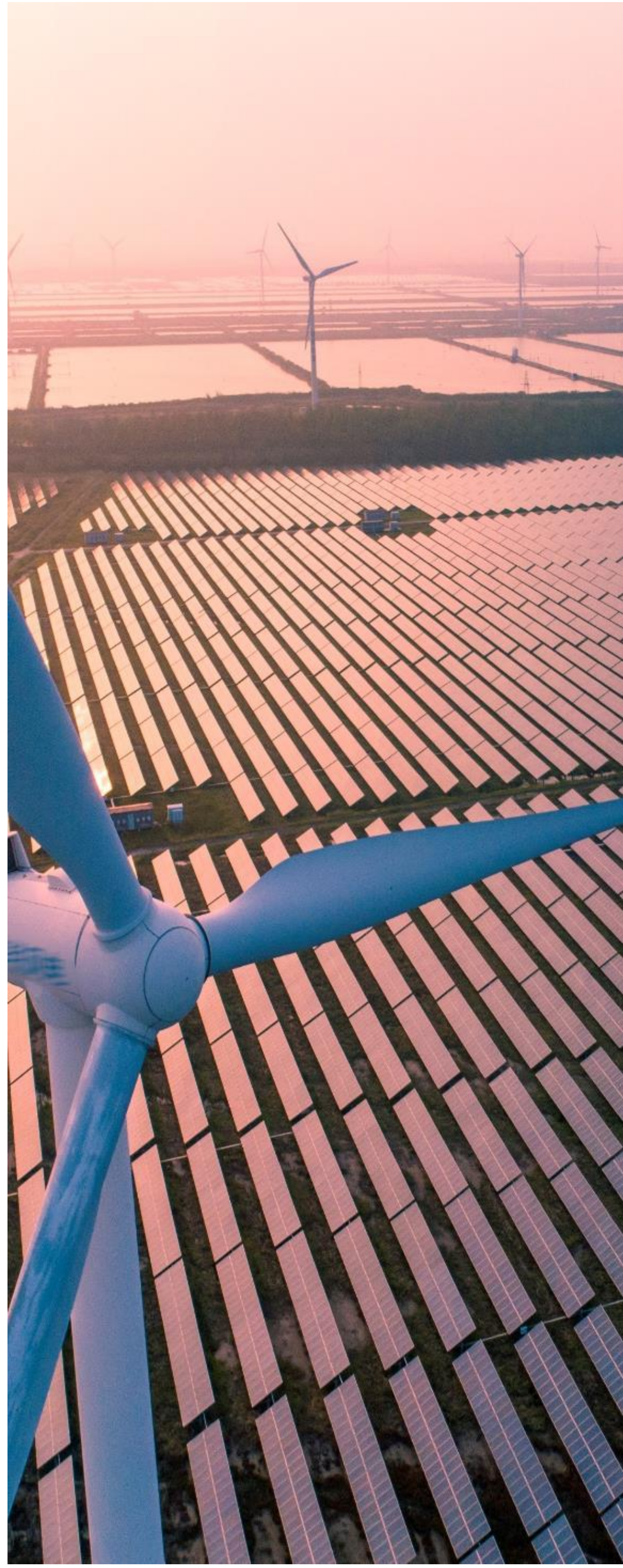
Renewable energy sources have excessive power fluctuations and undependable supply. ESS solves these problems with the use of large amount of renewable energy sources, when connected on grid. During the off-grid period, plug-in electric vehicles with batteries are the most promising technology to replace the fossil fuels from electricity, mostly from renewable energy sources.

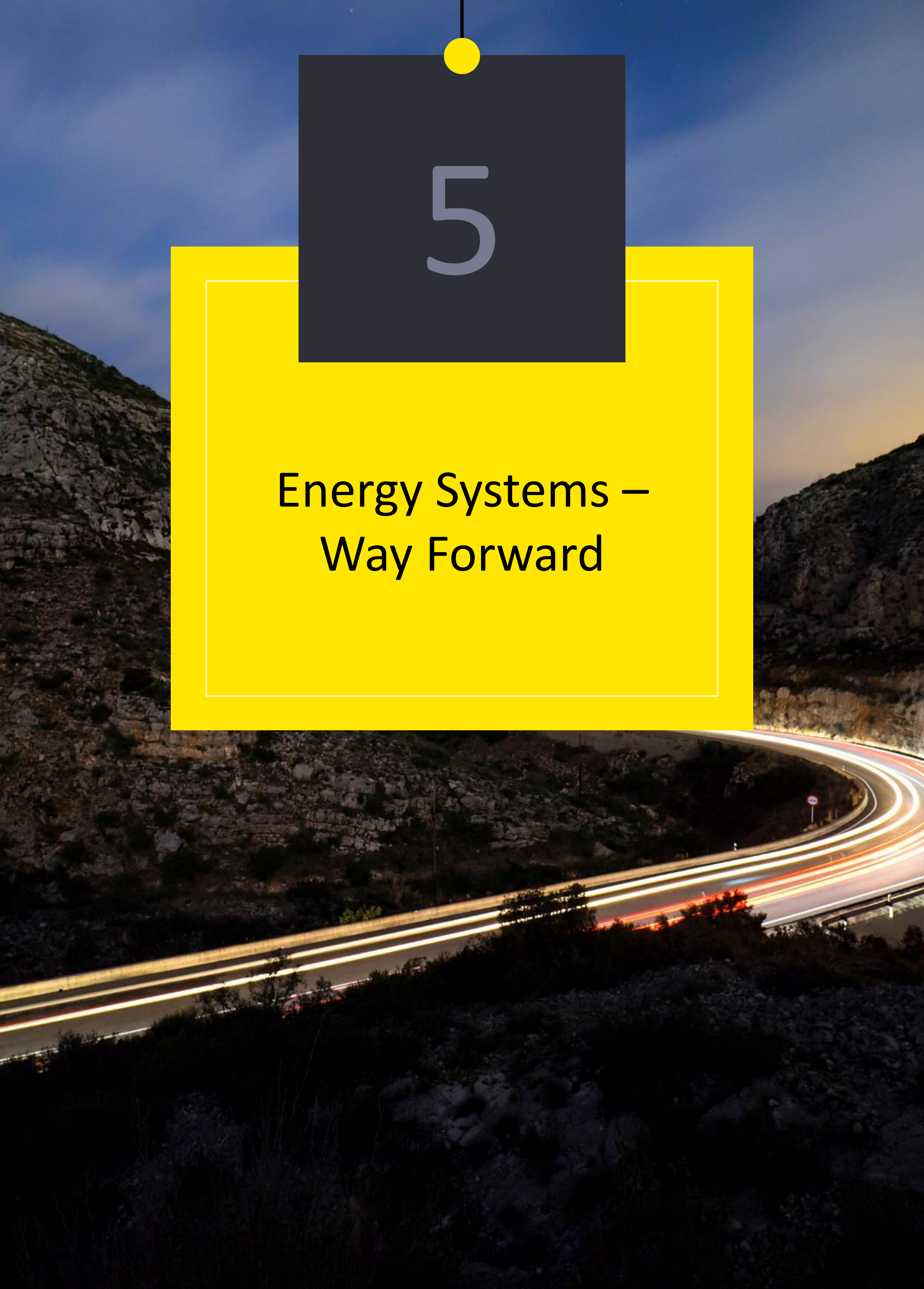
Smart grid technologies keep the grid more flexible and interactive with consumers with information on low pricing of electricity and availability of opportunity to sell power to the grid between power production and consumption. BESS is one of the key elements in developing a smart grid.

The emerging trends for BESS technology are to use more renewable energy sources and to make the future smart grids more efficient. The use of BESS is thus summed up: Time shifting of load balancing, power quality by frequency control, mitigating the congestion in the power flow in the transmission line, supplying power to isolated grids, providing emergency power supply to protection and control equipment, and time shifting of power from renewable sources to recharge batteries, when power demand is low in the grid.

Battery energy storage and smart grid, together, will create new avenues and business opportunities in the time to come

The new technology of modernizing the grid is the smart grid that is emerging to integrate the power network with a smart digital technology of communication network. The smart power grids are more efficient with the use of Information Communication Technology and integration of variable renewable energy sources, PEVs and electrical energy storage technologies. There are opportunities and challenges to these technologies related to manufacturers, electric utilities, vehicle charging companies, battery manufacturers and all levels of governments, and the power and vehicle users.





5

Energy Systems – Way Forward

5 Energy Systems – Way forward

"

A transition to clean energy is about making an investment in our future."
- Gloria Reuben

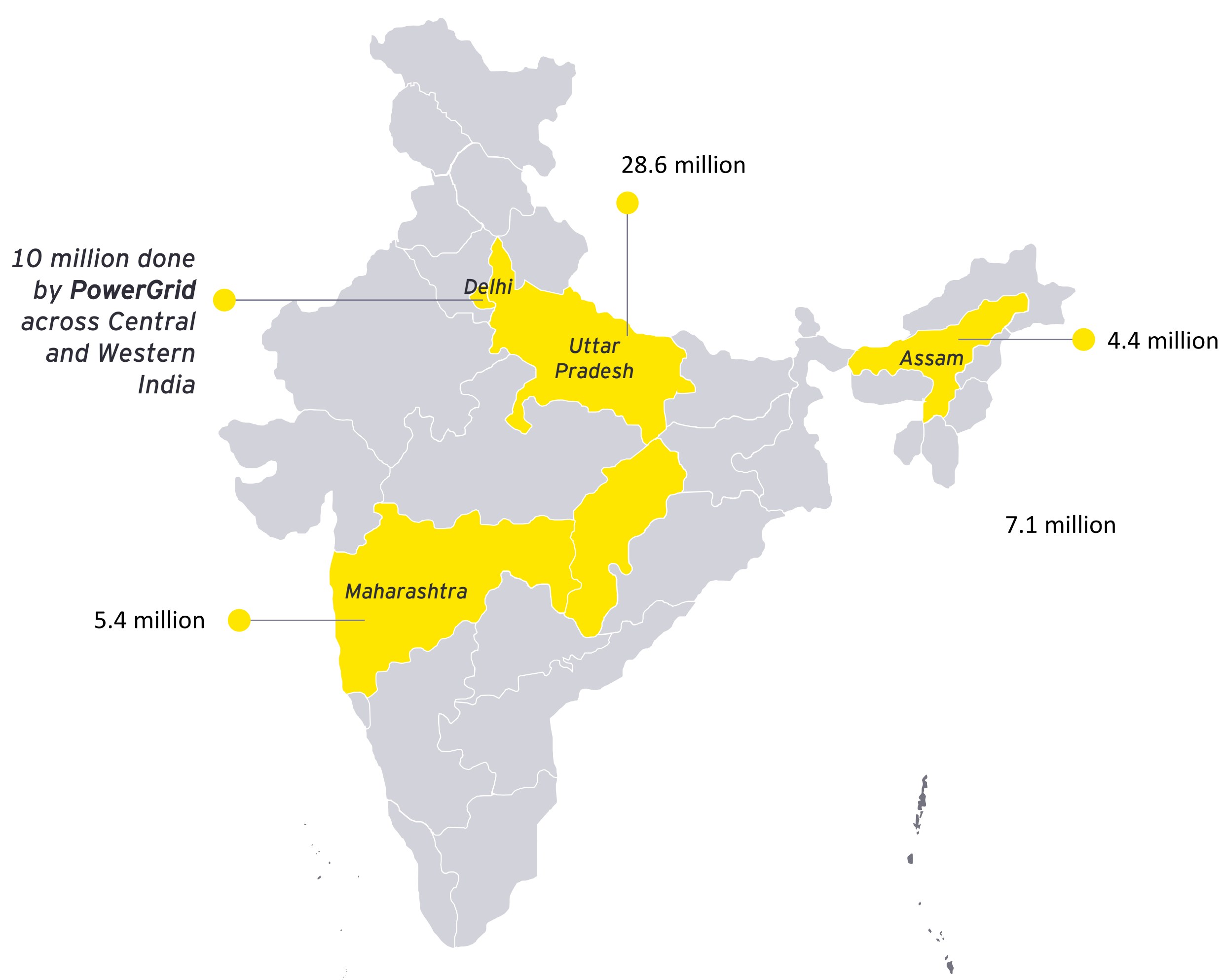
5.1. Summary

The present report provides a technology outlook on the roll-out of smart grids and the implementation of energy storage in India in 2022-23. For India to achieve its goal of net-zero emissions by 2070, it is imperative that these technologies are utilized.

One of the major techno-economic challenges in the transition toward a sustainable energy sector is to ensure an optimal balance between the volatile power generation from renewable energies and the dynamics of energy utilization on the demand side. Smart grids and energy storage are two key technologies for adding the required flexibility to our future energy system. In most situations, these two technologies complement and supplement each other very effectively.

As of now, smart grid projects worth US$19.6 billion have been sanctioned in over 13 states in India. Additionally, tenders of more than 54 million smart meters are already active across the country, with an ambition to achieve about 250 million smart meters by 2025 (see figure 20). These smart meters, along with an advanced metering infrastructure, are necessary to enable an optimal integration of power generation and energy demand with grids and utilities.

Figure 20: Current opportunity in smart meter space in India



Source: Various secondary sources, EY Analysis

At the same time, stationary battery energy storage projects with 2.3 GW power and 10 GWh energy capacity for grid services and short-duration energy storage are already in the pipeline. To increase self-reliance in India's supply chain, up to 50 GWh/year battery cell production capacity is targeted to support the country's energy storage agenda. Lithium-based battery technology is the current choice for industrial upscaling, but alternative battery materials are continuously evaluated. Around 63 sites in India have already been identified as suitable for pumped hydro storage power plants with a joint power capacity of more than 96 GW.

These numbers are only the beginning of India's path to achieving its goal of net-zero emissions by 2070, which is a challenge taking into account India's population growth. According to the United Nations, India is expected to surpass China as the most populous country in the world in April 2023. This underlines the importance of engaging in constructive collaborations with partner countries like Denmark.

5.2. Outlook

In the bilateral collaboration between India and Denmark, it is often said, "Denmark has the skills, whereas India has the scale". Essentially, skills need scale as much as scale needs skills. This opens opportunities for constructive collaboration on smart grids and energy storage for Indian and Danish stakeholders.

In Denmark, a nationwide rollout of smart meters was decided by the Danish Parliament in 2013. Today, the country has one of the highest smart meter coverage rates in the world, while also having one of the highest penetrations of volatile renewable electricity and the highest supply security in its electric energy system.

Danish partners could provide necessary competences to support Indian stakeholders in their smart meter rollout. Besides this, such technological leaps in Denmark can help accelerate activities in India. A classical electric grid can only be transformed into a smart grid if, for example, the smart meter rollout on utility-scale and on prosumer-scale are planned in coordination with each other.

The pure scale of smart grid ambitions in India can establish the required conditions for Danish solutions to be scaled up to a competitive level globally.

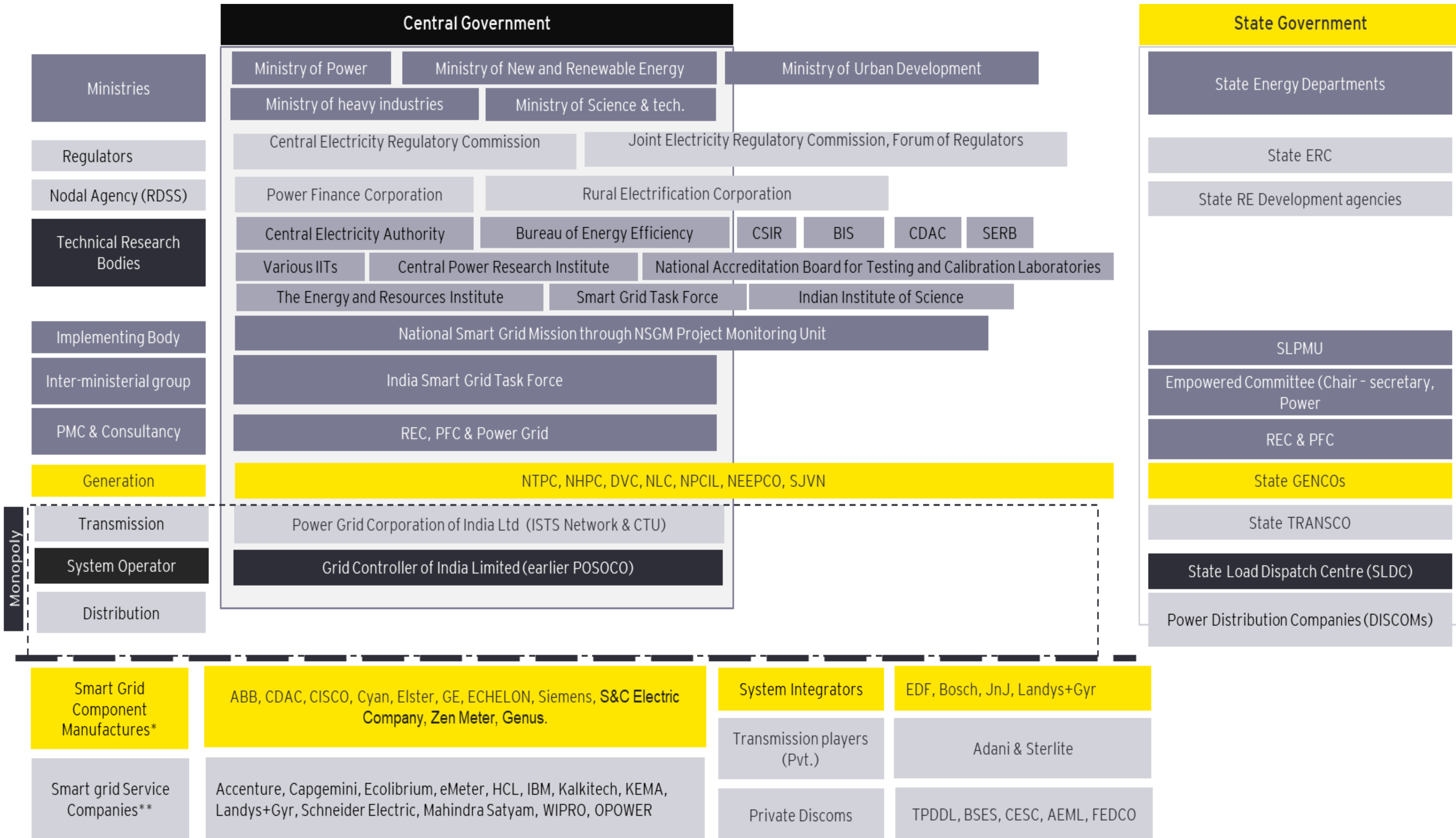
In India, there is an open market for projected stationary battery energy storage systems. Danish firms can enter this market and partner up with Indian firms. This collaboration will be beneficial for both parties. Danish partners can contribute to competences in battery management and power electronics systems. Meanwhile, Indian partners can help them navigate the Indian politico-cultural and business environment.
In addition, Danish research and development within the area of novel battery materials can prepare the production industry in India to be ready for a post-lithium era. Different technologies for electric energy storage have an enormous potential for a Danish-Indian collaboration.

6

Appendix

A

Appendix: relevant stakeholders in smart grid space for engagement



*including hardware & software

** including smart meters

B Appendix: research and development in smart grid space in India (1/2)

Name	Description	Role and significance
US-India Collaborative for Smart Distribution System with Storage (UI-ASSIST)	UI-Assist is a five-year multi-partner research project that focuses on research, development, demonstration and pilot-scale implementation of Battery Energy Storage Systems (BESSs) at the distribution grid level for various applications under the smart grid paradigm. The US Department of Energy (DoE) and the Department of Science and Technology of the Government of India jointly funded this project.	▸ A pilot has been set up by Installing BESS at the local substation level, from where supply goes to individual households. The performance is being monitored. ▸ It sowcases the impact of BESS integration on the distribution system. The wide spectrum of distribution level consumers covered and the type of BESS application that will be implemented on field make this project unique.
Smart grid Knowledge Centre	Established by the POWERGRID, with support from the Ministry of Power (MOP) and the National Smart Grid Mission (NSGM), the SGKC showcases smart grid technologies through demonstrations and provides training and capacity building support to power distribution companies. The SGKC is located within the POWERGRID Academy of Leadership (PAL) complex at Manesar, Haryana.	▸ The SGKC is a state-of-the-art platform for demonstration and outreach of smart grid technologies. ▸ Houses one of its kind Technology Incubation Hub to promote innovative ideas ▸ Address market gaps in research and development in power distribution ▸ Build value proposition of smart grid for different stakeholders (power utilities, policy makers, regulators, etc.)
Indo Sweden Collaborative Industrial Research and Collaborative Programme	Sweden-India program aims to foster and support the development of collaborative R&D projects that bring together companies, research organizations, academics and other collaborators from both countries for the joint development of innovative products or processes in the following technology sectors: (1) Smart and sustainable cities and transport systems (2)Clean technologies, IoT and digitalization	▸ Under this program, the Swedish Energy Agency and Department of Science and Technology will finance research and collaborative projects. The funding will be in a form of a grant.

B Appendix: research and development in smart grid space in India (2/2)

Name	Description	Role and significance
India EU Integrated Local Energy Systems	This joint initiative between India and EU aims to develop and demonstrate novel solutions, integrating all energy vectors like electricity, heating, cooling, water, wastes, etc., including possibilities offered by batteries and electric vehicles, interconnect them and optimize joint operation with an increased share of renewables and higher energy efficiency.	▸ As part of the implementation of this Partnership, a joint call for proposal has been launched which aims at smartly integrating large amounts of renewable energy in local energy systems, thus making energy supply cleaner, more efficient and affordable. ▸ For this joint call for proposals, the European Union has committed €9 million under Horizon 2020, Work programme (2018-2020) on secure, clean and efficient energy; and the Department of Science and Technology (DST), Government of India, agreed to match that amount. In total, funding of €18 million will be available.
Centre of Excellence in Smart Grid	iEnergy has spear-headed the industry-University collaboration by setting up "Centre of Excellence" at several prestigious universities in India such as ITM (Gwalior), Trident (Bhubaneshwar) and Chitkara (Chandigarh).	▸ The CoE incorporates a HCPV Incubation centre in collaboration with iEnergy catering to the local market needs of HCPV. ▸ The Incubation centre(s) acts as a business hub, elevating the university campus to inculcate a business culture among the students. ▸ iEnergy is facilitating introduction and evolution of state-of-the-art technologies in power sector such as HCPV Lab, Smart-Grid Lab and Smart-Grid Research Centres.
Centre of Excellence in Smart Grid Technologies	The CoE has been established by NIT Surathkal with the support of the Newton-Bhabha project and the United Kingdom	▸ Collaboration with institutions and industries in India and abroad. ▸ Indigenously Design and Development of Smart Grid Technology Experimental Prototype. ▸ Capacity Development in Smart Grid Technologies through research, training programs, conferences, workshops and seminars.
Research Activities being undertaken by various universities in India with Support of NSGM and Department of Science & technology	NSGM and DST are supporting various research activities in universities like IIT Kanpur, IIT Roorkee, IIT Delhi, IIT Kharagpur, IIT Bombay, VNIT Nagpur, etc.	▸ The research and development activities are focused on Smart Grid-dC grids, Prevention of blackouts, control of micro-grids, Smart grid-micro-grids, Protection and Renewable Energy integration to grid, Power electronic interfaces for non-conventional energy sources ▸ It aims to provide a base for industry-academia collaborative pilot projects

C Appendix: civil society and industry associations in the domain of smart grid

Name	Description	Role and significance
Indian Smart Grid Forum	The India Smart Grid Forum (ISGF) is a Think-Tank of global repute on Smart Energy, Electric Mobility and Smart Cities. ISGF, established as a Public Private Partnership initiative of the Government of India in 2011, is spearheading the mission to accelerate electric grid modernization and energy transition in India.	▶ ISGF works with government institutions such as NITI Aayog, CEA, CPRI, CERC, NSGM and NCIIPC; ministries such as MoP, MNRE, DoT, MoUD, MoHI etc and other stakeholders like state governments, electric utilities and electricity regulatory commissions. ISGF has over 170 members comprising ministries, government institutions, utilities, technology providers, academia, and research. ▶ They conduct their annual flagship Indian Smart Grid Week which brings together India's leading Electricity, Gas and Water Utilities, Smart City Developers, Policy Makers, Regulators, Investors and world's top-notch Smart Energy Experts and Researchers to discuss trends, share best practices and showcase next generation technologies and products in smart energy, electric mobility and smart cities domains
Indian Electrical and Electronics Manufacturers Association	Apex Industry Association of the Indian electrical equipment, industrial electronics and allied equipment manufacturers. IEEMA Smart Grid Division is IEEMA's initiative toward a resilient, sustainable and secure electricity infrastructure.	▶ To support the utilities and the government in their respective smart grid initiatives IEEMA Smart Grid division has formed Focus Groups in critical areas, which need immediate co-operation amongst the various stakeholders to enable the realization of Smart Grid Vision and Roadmap of the Ministry of Power. The goal is to reach out to all the direct and indirect stakeholders in various government departments, research and academic institutions, industry associations, regulators and standards developing organizations to have inclusive deliberations and actionable insights to resolving the various challenges being faced by all the stakeholders in their respective endeavours to make our nation 'smart green & secure'. Initial few focus groups: ▶ Smart Grid Architecture and Framework FG ▶ Smart Grid Interoperability, Standards and Harmonization FG ▶ Unified Communication Architecture FG ▶ Network and Cyber Security FG ▶ Grid Automation and Resilience FG ▶ Renewable Integration FG ▶ Energy Efficiency FG ▶ Electric mobility FG ▶ Policy and Regulations FG ▶ People, Processes and Systems FG ▶ New challenges FG

D Appendix: relevant stakeholders in battery storage space for engagement

	Central Government	State Government
Ministries	Ministry of Power; Ministry of New and Renewable Energy; Ministry of Science & Technology; Ministry of Heavy Industries	State Energy Departments, Departments of Heavy Industries
Regulators	Central Electricity Regulatory Commission; Joint Electricity Regulatory Commission, Forum of Regulators	State ERC
Key Tendering Agencies	Solar Energy Corporation of India; National Thermal Power Corporation	RE Development Agencies
Technical Research Bodies	Central Electricity Authority; Bureau of Energy Efficiency; Niti Aayog; Central Power Research Institute; Various IITs; National Accreditation Board for Testing and Calibration Laboratories; India Institute of Science; Bureau of Indian Standards; Council of Scientific & Industrial Research	Energy Management Centres
Generation	NTPC, NHPC, DVC, NLC, NPCIL, NEEPCO, SJVN	State GENCOs
Monopoly: Transmission	Power Grid Corporation of India Ltd. (ISTS Network & CTU)	State TRANSCO (InSTS Network); Private players: Adani & Sterlite
Monopoly: System Operator	Grid Controller of India Limited (earlier POSOCO)	State Load Dispatch Centre (SLDC)
Monopoly: Distribution		Power Distribution Companies (DISCOMs)

BESS Component Manufactures* (Public & Private)	Reliance New Energy Limited, Ola, Rajesh exports, Amara Raja, Exide, L&T power, Lucas, TVS, Epsilon advanced materials, Primet precision, BASF, BHEL, BEL, Manikaran Lithium, Loom	Major private Renewable power developers in India	Reliance New Energy (upcoming), Adani, Azure, Greenco, Ayaana, Renew, Tata Power Solar, AMP, Amplus, Suzlon, Torrent, Avaada, Cleantech Solar, Fourth partner, NTPC Renewables, Sembcorp, Spring Energy, Continuum, Hinduja, Cleanmax, Radiance, Mahindra Sustain, Hero Energies etc.
BESS Integration & EPC palyers	Fluence, Exicom, Livguard, Nexcharge, Tata Powe, Targray (upcoming), Siemens	Transmission players (Pvt.)	Adani & Sterlite

*e.g. battery raw materials, chemical processing for active materials, electrodes, cells, cell to pack assembly, BMS, balance of system etc.

E Appendix: research and development in the supply chain of energy storage systems (1/2)

Name	Description	Role and significance
International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI)	Autonomous Research and Development Centre of Department of Science and Technology (DST), Government of India with its main campus at Hyderabad, spread over an area of around 95 acres of land, Telangana and with operations in Chennai and Gurugram.	▶ 2-D nanolayered transmission metal sulphides ▶ Large-scale production of lithium titanate materials by cost effective and high energy milling process ▶ Development of high-performance carbon coated LiFePO4 with a cost-effective and scalable process
Centre of Battery Engineering and Electric Vehicles (C-BEEV)	IIT Madras has set up CoEs to offer guidance and resources to R&D centres, start-ups and to propel path-breaking research	▶ Promoting path-breaking research and development in the burgeoning field of electric mobility in India, in collaboration with major automotive companies and battery manufacturers from across the world. They are exploring different ACC technologies suitable for India's Energy Storage needs
Centre of Excellence on Rechargeable Battery Technology (Pre-cell) – Ministry of Electronics & Information Technology	MeitY has initiated a Centre of Excellence (CoE) on Rechargeable Battery Technology (Pre-cell) at CMET for scale up and transfer of indigenous technology on Lithium ion battery and Sodium ion battery (post lithium) to Indian SMEs for manufacturing of battery cells.	▶ The CoE has completed SME business plans for its indigenous technology, showing profitability under current market conditions; it has provided paid services to 20 industry partners; achieved a breakthrough in electrode manufacturing to reduce investment and running cost and created NMC 111 and LCO chemistries production on indigenous machines. It aims to create at least 25 start-ups in the next five years in collaboration with its industrial partners.
Amara Raja Centre for Energy Storage Devices – SRM University	SRM – Amara Raja Centre has been established to design and develop low-cost, fast-charging, next-generation Lithium-ion battery innovations in collaboration with Amara Raja Batteries Ltd. (ARBL), in India	▶ The union government has state-of-the-art facilities, powered by top researchers from industry and academia to drive innovation from the laboratory to market. Researchers working on this include cross-discipline experts from ARBL and SRM-AP faculty ▶ It is one of the very few Centres of Excellence with direct collaboration with Industry and academia in India

E Appendix: research and development in the supply chain of energy storage systems (2/2)

Name	Description	Role and significance
Centre of Excellence in Thermal Energy Storage (CoE-TES) located in TERI University, New Delhi	Centre of Excellence in Thermal Energy Storage (CoE-TES) has been established under the FAST scheme of the Ministry of Human Resource Development, Government of India. The centre envisages to work in basic and applied research, including new material development, low and medium temperature application, sub-ambient and low temperature application.	▸ The current research in the centre is focused on latent heat storage systems for low and medium temperature applications (-20 °C top 200 °C). ▸ Thermal energy storage finds its application in a variety of areas like refrigeration and air conditioning and improving the capacity factor of a solar thermal power plant.
Science and Engineering Research Board (SERB)	It is a statutory body under the DST and has supported 46 projects until Feb 2022, to facilitate the research work on developing the technology for storage of energy	▸ Most of the projects supported by SERB have focussed on field of metal-based air electrodes, electroactive polymer nano composites, hybrid DC bus power supply, utilization of agricultural waste as an electrode material, lead free disordered ferroelectrics, etc .

F Appendix: civil society and industry associations in the domain of energy storage systems (1/3)

Name of associations	Description	Role and significance
India Energy Storage Alliance (IESA) located in Pune. Founded in 2012, by Customized Energy Solutions (CES).	IESA's vision is to make India a global hub for R&D, manufacturing, and adoption of advanced energy storage, e-mobility, and green hydrogen technologies. Currently, IESA has a network of 160+ member companies, encompassing industry verticals from energy storage, EV manufacturing, EV charging infrastructure, green hydrogen, microgrids, power electronics, renewable energy, research institutes and universities, and cleantech startups.	▸ The alliance has been at the forefront of efforts seminal in shaping an enabling policy framework, providing in-depth analysis of the market, facilitating dialogue between industry and government stakeholders, and providing the latest skill-development training. ▸ IESA has launched several initiatives that support its member companies to stay ahead of the curve.
Confederation of Indian Industries	CII is a non-government, not-for-profit, industry-led and industry-managed organization, with around 9000 members from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 300,000 enterprises from 286 national and regional sectoral industry bodies.	▸ CII has a separate committee for Future Mobility and Battery. They are one of the most active industry association along with FICCI in India. They regularly come out with thought leadership and their suggestions to the government carry high weight age.
Federation of Indian Chambers of Commerce & Industry (FICCI)	FICCI is one of the largest and oldest apex industry association in India. As a non-government and not-for-profit organization, it serves its members from the Indian private and public corporate sectors and multinational companies, drawing its strength from diverse regional chambers of commerce and industry across states, reaching out to over 2,50,000 companies.	▸ FICCI has different committees for different key sectors. For Energy Storage. They have a FICCI Energy Storage Committee (FESC). The FESC is working toward developing and evolving a consolidated industry position for the cost-effective deployment of Energy Storage technologies in the country. FICCI is also a member of the Expert Committee on Energy Storage constituted by the Ministry of New and Renewable Energy (MNRE) for laying down the National Energy Storage Mission.
Long Duration Energy Storage (LDES) council	The LDES Council provides fact-based guidance to governments and grid operators and major electricity users on the deployment of long-duration energy storage.	▸ The Council covers a wide range of LDES technologies, including mechanical, thermal, electrochemical and chemical solutions. ▸ Provide education and advocacy services supporting the adoption of LDES

F Appendix: civil society and industry associations in the domain of energy storage systems (2/3)

Name of associations	Description	Role and significance
ASSOCHAM	It brings in actionable insights to strengthen the Indian ecosystem, leveraging its network of more than 4,50,000 members, of which MSMEs represent a large segment. With a firm presence in states and key cities globally, ASSOCHAM also has more than 400 associations, federations and regional chambers in its fold.	▶ The National Council on Renewable Energy at ASSOCHAM aims at highlighting and solving issues that make the transition of energy to newer sources an effortless process. ▶ The council is a group of eminent industry leaders across the country. The stakeholders involved in the council are RE developers, Solar Module Manufacturers, Generators, Consultants, associations, etc. ASSOCHAM has also signed MoU with other small industry representative organizations they intend to work in. This makes it different from CII and FICCI.
Indian Battery Manufacturers Association	The Indian Battery Manufacturers Association aims to bring together various stakeholders in the Indian Battery industry — manufacturers, recyclers, smelters, traders, suppliers and technology partners and experts under one umbrella for advancement of common causes.	▶ IBMA was established with the motive of promoting lead-acid batteries in the past. With changing scenario, it is including stakeholders from other battery chemistries. All major battery manufactures are associated with IBMA and represent the industry's points of view with regard to fiscal and trade policies impacting the industry liaising with Min. of Heavy Industries, Min. of trade and commerce, GST council and others. This is to encourage the development of rational policies that will promote the development of the industry as a whole.
Federation of Indian Small Scale Battery Association and other similar small associations	The FISSBA intends to promote research and development of batteries and battery applied products, environmental preservation, recycling, quality and performance improvement, and product safety. Like FISSBA, there are many small associations which are very active at regional levels. They were mainly established with the intention of promoting lead-acid batteries.	▶ FISSBA runs various programs such as standardization activities of battery specifications, education of equipment engineers and approval of storage battery equipment models, training and research activities, promotion of safe recycling, etc. ▶ They are more technical/engineering oriented and prove to be a good platform for promoting new technologies in battery space. Many of its members are trying to enter lithium-ion battery space focused on mobility. To remain relevant, they have started being vocal about other application of batteries such as Energy Storage. Due to their deep regional integration, their presence is very effective at state level

F Appendix: civil society and industry associations in the domain of energy storage systems (3/3)

Name of associations	Description	Role and significance
Think tanks (CEEW, TERI, CSTEP, Rocky Mountain Institute, ISGF, Shakti Foundation, Centre for Science and Environment)	There are many major think tanks in India which have a very high focus on renewable energy, emerging technologies, advanced chemistry cell chemistries and energy storage. They are independent organizations	▸ These think tanks are regularly producing reports, thought leaderships, research papers, case studies, best practices, policy advocacies and suggestions to government. Their materials are acting as the guiding source for all the stakeholders as these emerging technologies are still in a nascent stage in India and the surrounding awareness is low. Their opinion holds a lot of value as they directly work with governments many-a-times most prominently being RMI (working with NITI Aayog and TERI (working with various ministries). ▸ All the think tanks have different style of working. For example, CEEW is more focused on extensive research policy advocacy. CSE works with ground level civil society actors and its works focusses on critical environmental and social aspects which sometimes get ignored up to a large extent.

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Our offices

Ahmedabad
22nd Floor, B Wing, Privilon
Ambli BRT Road, Behind Iskcon Temple,
Off SG Highway
Ahmedabad - 380 059
Tel: + 91 79 6608 3800

Bengaluru
12th & 13th floor
"UB City", Canberra Block
No. 24, Vittal Mallya Road
Bengaluru - 560 001
Tel: + 91 80 6727 5000

Ground Floor, 'A' wing
Divyasree Chambers
11, Langford Gardens
Bengaluru - 560 025
Tel: + 91 80 6727 5000

Chandigarh
Elante offices, Unit No. B-613 & 614
6th Floor, Plot No- 178-178A
Industrial & Business Park, Phase-I
Chandigarh - 160 002
Tel: + 91 172 6717800

Chennai
Tidel Park, 6th & 7th Floor
A Block, No.4, Rajiv Gandhi Salai
Taramani, Chennai - 600 113
Tel: + 91 44 6654 8100

Delhi NCR
Golf View Corporate Tower B
Sector 42, Sector Road
Gurugram - 122 002
Tel: + 91 124 443 4000

3rd & 6th Floor, Worldmark-1
IGI Airport Hospitality District
Aerocity, New Delhi - 110 037
Tel: + 91 11 4731 8000

4th & 5th Floor, Plot No 2B
Tower 2, Sector 126
Gautam Budh Nagar, U.P.
Noida - 201 304
Tel: + 91 120 671 7000

Hyderabad
THE SKYVIEW 10
18th Floor, "SOUTH LOBBY"
Survey No 83/1, Raidurgam
Hyderabad - 500 032
Tel: + 91 40 6736 2000

Jamshedpur
1st Floor, Shantiniketan Building,
Holding No. 1
SB Shop Area, Bistupur
Jamshedpur – 831 001
Tel: + 91 657 663 1000

Kochi
9th Floor, ABAD Nucleus
NH-49, Maradu PO
Kochi - 682 304
Tel: + 91 484 433 4000

Kolkata
22 Camac Street
3rd Floor, Block 'C'
Kolkata - 700 016
Tel: + 91 33 6615 3400

Mumbai
14th Floor, The Ruby
29 Senapati Bapat Marg
Dadar (W), Mumbai - 400 028
Tel: + 91 22 6192 0000

5th Floor, Block B-2
Nirlon Knowledge Park
Off. Western Express Highway
Goregaon (E)
Mumbai - 400 063
Tel: + 91 22 6192 0000

Pune
C-401, 4th floor
Panchshil Tech Park, Yerwada
(Near Don Bosco School)
Pune - 411 006
Tel: + 91 20 4912 6000

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