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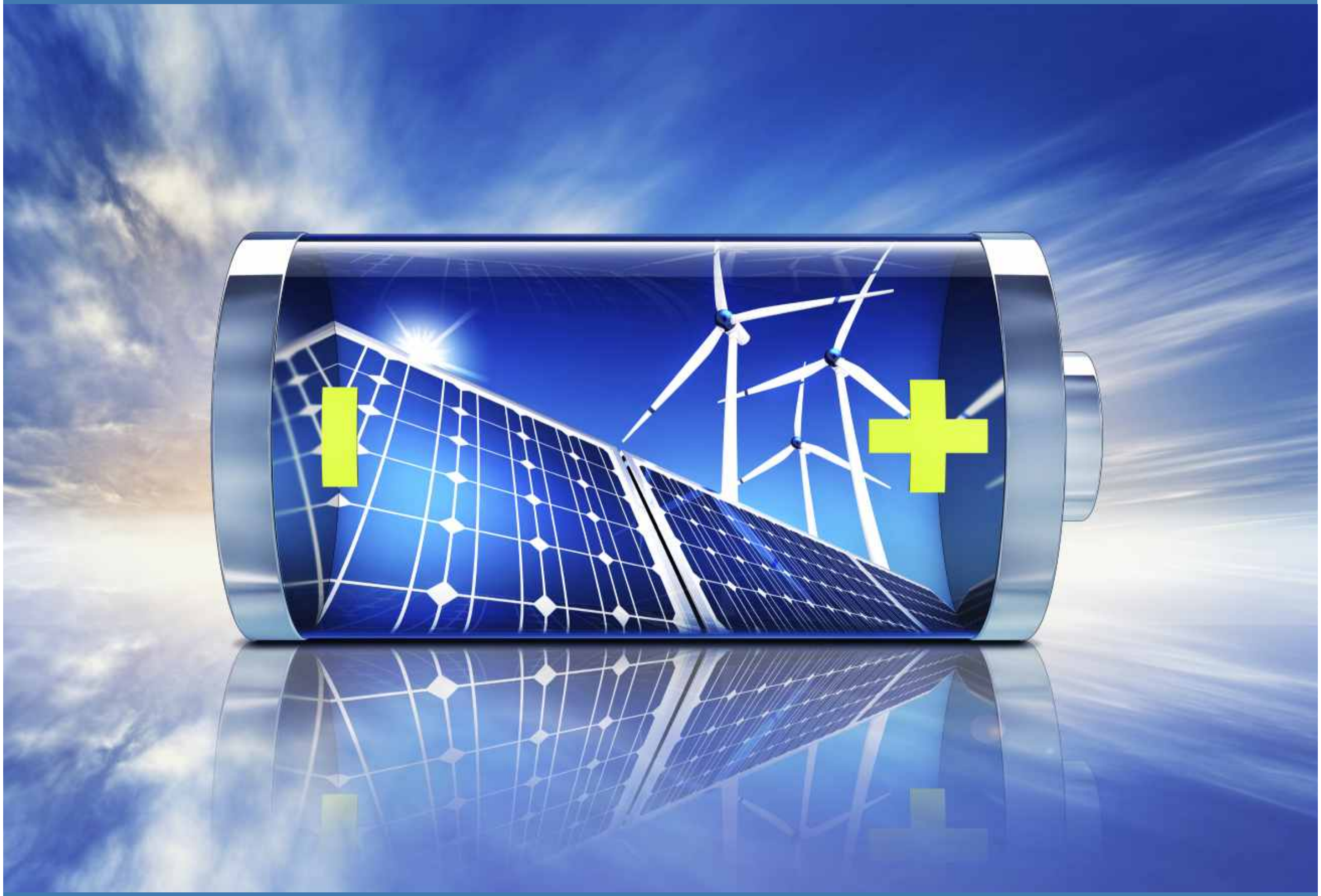
Government of India
Ministry of New and Renewable Energy
Renewable Energy is Green, Clean & Sustainable

Partnership to Advance Clean Energy - Deployment (PACE - D)
Technical Assistance Program

Assessment of the Role of Energy Storage Technologies for Renewable Energy Deployment in India



March 2014

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ACRONYMS

Acronyms	**Definition**
AC	alternating current
AFC	alkaline fuel cells
Ah	ampere hours
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
CO_2	carbon dioxide
DC	direct current
Deg C	degree Celsius
DMFC	direct methanol fuel cells
EMS	energy management system
EPRI	Electric Power Research Institute, California, U.S.
ESA	Energy Storage Association, Washington, U.S.
ESTTP	European Solar Thermal Technology Platform
EU	European Union
Ft	feet
Ft_2	square feet
Ft^3	cubic feet
GW	giga watt
Hr	hour
HVAC	heating ventilating and air conditioning
IESA	India Energy Storage Alliance
Kg	kilo gram
kW	kilo watt
kWh	kilo watt hour
Li	lithium
Li2O	lithium oxide
M	meter
M^2	square meter
M^3	cubic meter
MCFC	molten carbonate fuel cells
Mins	minutes
MNRE	Ministry of New and Renewable Energy
MW	mega watt

ACRONYMS

MWh	mega watt hour
Na-S	Sodium-sulfur
NCEF	National Clean Energy Fund
NCR	National Capital Region
NiCd	nickel cadmium
NiMH	nickel metal hydride
NPV	net present value
NREL	National Renewable Energy Laboratory, U.S.
PAFC	phosphoric acid fuel cells
PEM	proton exchange membrane
PGCIL	Power Grid Corporation of India Ltd.
PHS	pumped hydro systems
PJM	Pennsylvania-Jersey-Maryland
PV	photovoltaic
INR	Indian Rupees
RPO	Renewable Portfolio Obligation
Secs	seconds
SMES	superconducting magnet energy storage
SOC	state of charge
SOFC	solid oxide fuel cells
T&D	transmission & distribution
TANGEDCO	Tamil Nadu Generation and Distribution Corporation
TEPCO	Tokyo Electric Power Co.
U.S.	United States of America
USD	U.S. dollar
UTES	underground thermal energy storage
VRB	vanadium redox battery
VRLA	valve-regulated lead acid
W	watt
Wh	watt hour
WWSIS	Western Wind and Solar Integration Study
Yrs	years
ZnBr	zinc bromide

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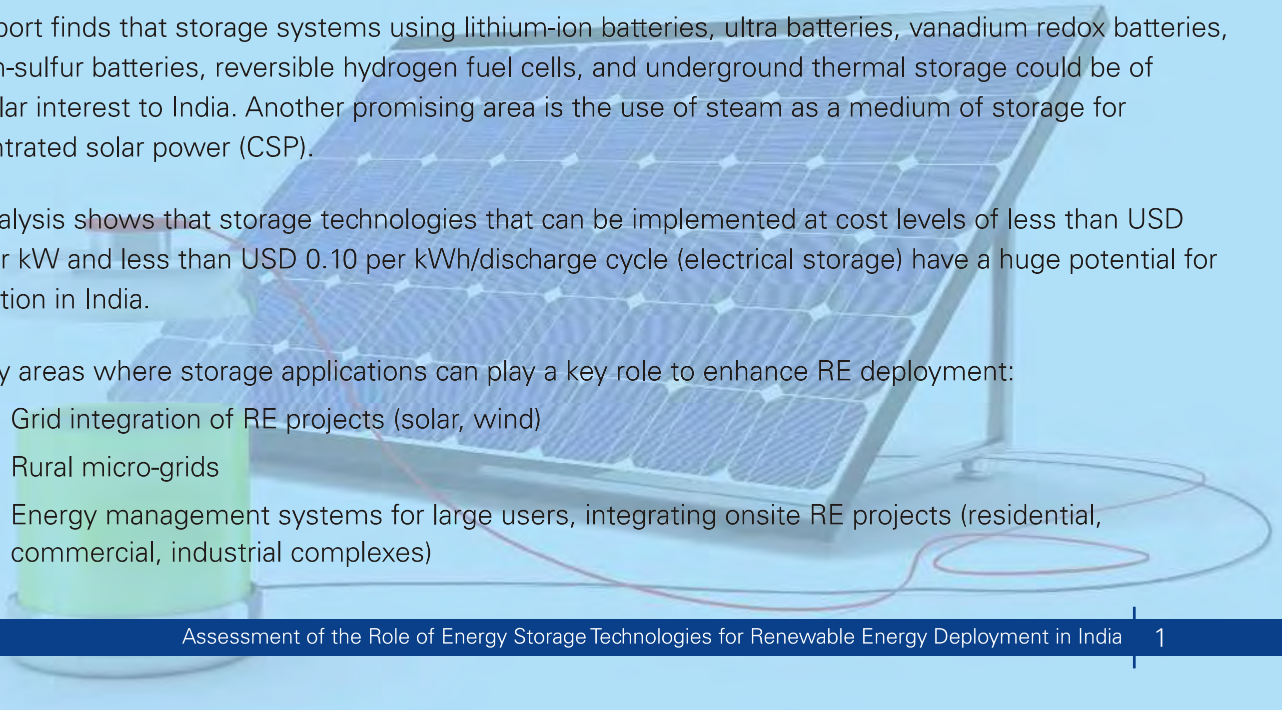
EXECUTIVE SUMMARY

India's energy system faces multiple challenges, including constrained transmission and distribution capacity, unmet energy demand, low energy access in rural areas, and a continuing dependence on coal-based generation. One of the key solutions to addressing these issues is the increased use of renewable energy (RE) sources, which are abundant in India. The Government of India has set aggressive targets for RE deployment. This is where energy storage technologies have the potential to help.

The application of energy storage technologies allows the scheduling of renewable energy generation is expected to play a crucial role in increasing the share of renewable energy in the global energy mix. Based on these benefits associated with energy storage, the consulting firm McKinsey has identified energy storage technologies as one of the 12 most important technologies for the future. This is also been seen by the importance being attached by most major economies who are actively pursuing the development and deployment of energy storage technologies.

Energy storage is evolving as a crucial component of India' energy strategy, following the launch of several Smart Grids and Electric Vehicles initiatives, as well as new programs to promote on-site solar energy and rural micro-grids. Energy storage provides multiple benefits including time shifting, grid stabilization, shaving of peak demand, improved generation efficiency, and improved utilization of transmission capacity.

This report presents a range of energy storage technologies available today and analysis of their costs, performance, and maturity levels. The report is based on a literature survey and discussions with experts and practitioners. The report covers both thermal energy and electrical energy storage and can form the basis for discussion and engagement between key stakeholder.



The report finds that storage systems using lithium-ion batteries, ultra batteries, vanadium redox batteries, sodium-sulfur batteries, reversible hydrogen fuel cells, and underground thermal storage could be of particular interest to India. Another promising area is the use of steam as a medium of storage for concentrated solar power (CSP).

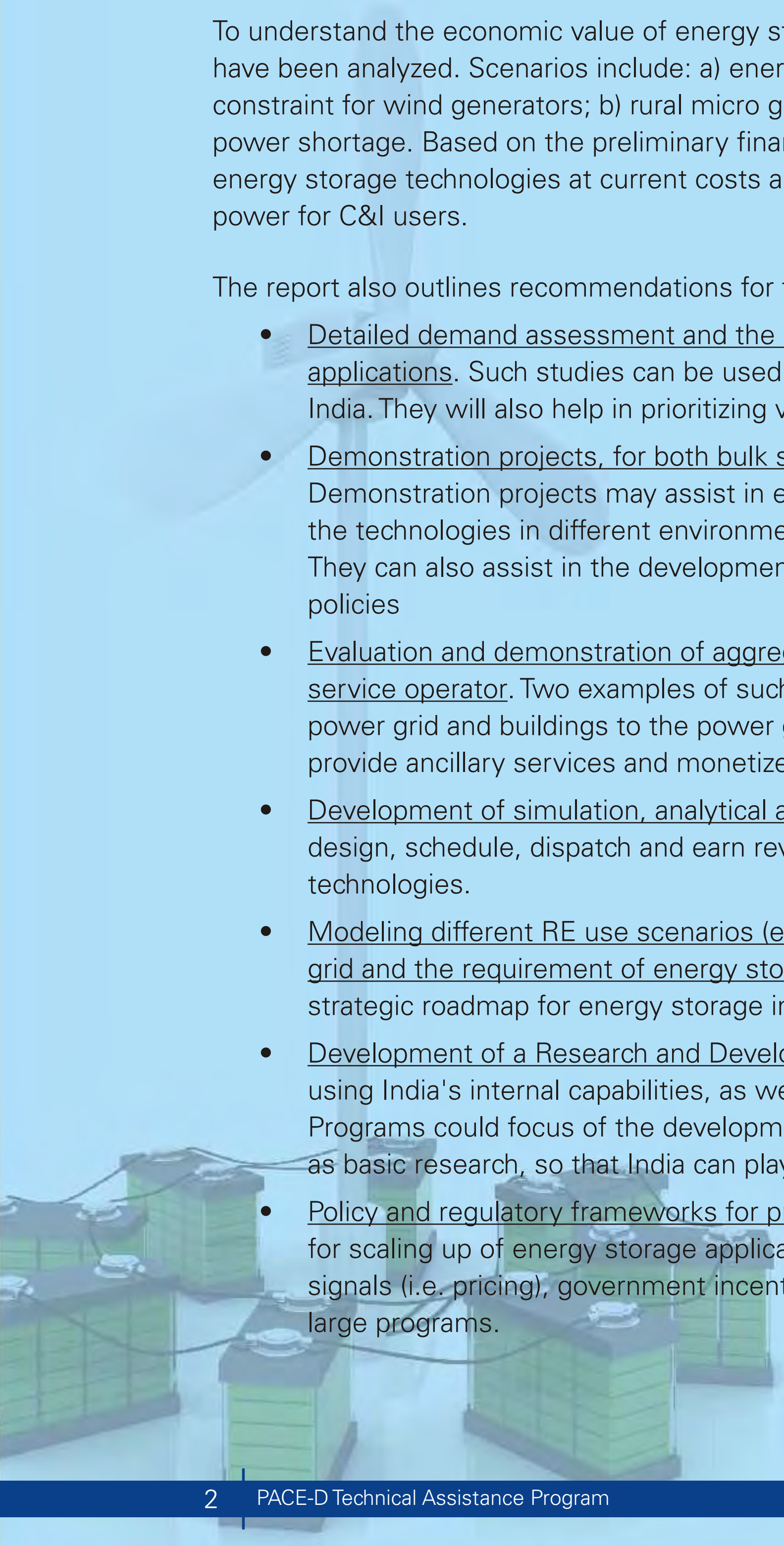
The analysis shows that storage technologies that can be implemented at cost levels of less than USD 500 per kW and less than USD 0.10 per kWh/discharge cycle (electrical storage) have a huge potential for application in India.

The key areas where storage applications can play a key role to enhance RE deployment:

- Grid integration of RE projects (solar, wind)
- Rural micro-grids
- Energy management systems for large users, integrating onsite RE projects (residential, commercial, industrial complexes)

Storage technologies create 'economic value' for a variety of stakeholders – transmission companies, generators, electricity users, system operators, etc. If storage capacities can derive value from all stakeholders, it may be possible to design appropriate business models to justify storage investments. This report identifies such sources of 'value' and models them for specific end uses.

To understand the economic value of energy storage technologies in Indian context, three scenarios have been analyzed. Scenarios include: a) energy storage for overcoming transmission capacity constraint for wind generators; b) rural micro grids; and c) Commercial & Industrial (C&I) users facing power shortage. Based on the preliminary financial modeling results, it has been noticed that the energy storage technologies at current costs are feasible for rural micro grids and offsetting diesel power for C&I users.



The report also outlines recommendations for future research topics and activities:

- <u>Detailed demand assessment and the estimation of economic value of key energy storage applications</u>. Such studies can be used to develop appropriate policies for energy storage in India. They will also help in prioritizing various applications.
- <u>Demonstration projects, for both bulk storage as well as modular technologies</u>. Demonstration projects may assist in enhancing the understanding the application, their of the technologies in different environments, costs of operation, and operational challenges. They can also assist in the development of appropriate business models, the regulation and policies
- <u>Evaluation and demonstration of aggregation of storage capacities by a utility or a storage service operator</u>. Two examples of such aggregation strategy are electric vehicles to the power grid and buildings to the power grid. The aggregated capacities may be used to provide ancillary services and monetize investments in energy storage.
- <u>Development of simulation, analytical and control tools</u>. Such tools can be used to optimize design, schedule, dispatch and earn revenue from energy storage projects, systems and technologies.
- <u>Modeling different RE use scenarios (e.g. 20/30/50 percent), and their related impact on the grid and the requirement of energy storage</u>. Such modeling will facilitate preparation of strategic roadmap for energy storage in India.
- <u>Development of a Research and Development program for energy storage</u>. This can be done using India's internal capabilities, as well as through joint research with other countries. Programs could focus of the development of cost-effective energy storage solutions, as well as basic research, so that India can play an important role in this strategic area.
- <u>Policy and regulatory frameworks for promoting storage</u>. Effective frameworks are essential for scaling up of energy storage applications. Such frameworks may include demand-based signals (i.e. pricing), government incentives, and the development of large programs.

1 BACKGROUND

Power systems are designed to match supply with demand. However with both demand and supply fluctuating continuously with time, the grid, which is the interface, remains in a state of continuous flux. This flux can create imbalances and result in grid instability, energy loss, power cuts, etc. A balance is at present achieved by the high speed ramp-up and ramp-down ability of fast responding generation plants, run on gas and diesel, operating Thermal power plants at low capacity utilization and therefore low levels of efficiency. The grid balance can also be achieved through the use of energy storage technologies. Energy storage technologies perform this through two inbuilt functions:

1. Storing the surplus energy generated in the system, and
2. Providing the stored energy for use whenever demanded by the system at the desired speed and quantum.

Though valuable for grid stability and flexibility, current energy storage technologies globally suffer from issues of high capital and operating costs, except for pump hydro used by transmission grids. Most of the applications for energy storage are found in the off-grid space, where the relatively higher cost of fuels like diesel make the use of storage financially viable. However, energy storage is becoming more competitive for energy services for the grid as well, on the back of a falling costs and enhanced performance.

It is widely expected that cost parity for renewable energy with fossil-fuel based power may be achieved by 2020. Fossil-fuel based generating plants face supply constraints, leading to rapid cost inflation. On the other hand, the cost for renewable energy options such as solar and wind is continuing to fall with technology development, increased scale and experience. By effectively integrating energy storage, a significant shift in the energy mix to renewable energy can be achieved. Developed regions[13] of the world such as the European Union (EU) plan to have between 50 and 80 percent of their generation from renewable energy technologies by the year 2050.

1.1 VALUE OF STORAGE TECHNOLOGY FOR RENEWABLE ENERGY DEPLOYMENT

Renewable energy will rapidly scale up due to its associated environmental benefits, ability to meet growing energy needs, economic and social benefits of distributed and off-grid generation and likely cost parity with fossil fuel power in the near term. However, the expansion of renewable energy systems is constrained by certain characteristics, viz;

- Fluctuating resources (e.g. the direction and speed of wind and solar irradiation intensity vary from moment to moment) leading to rapidly fluctuating energy generation.

- Inability to 'control' generation to match demand, as can be done by controlling the flow of fuel in plants run on fossil fuel.

Effective energy storage solutions have the ability to meet these challenges and enhance deployment of renewable energy technologies through:

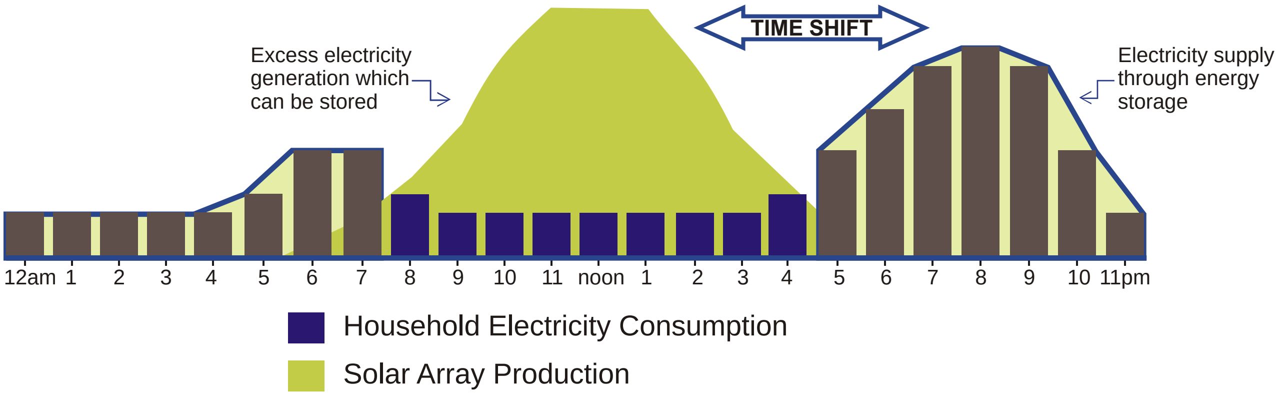
- Time Shift for generated energy
- Grid stabilization
- Peak shaving of demand
- Cost effective grid regulation
- Other benefits such as transmission capacity deferral, mobility, portability, etc.

1.1.1 Time Shift

Renewable energy sources like wind, solar, hydro, etc. are inherently variable and generation from most of these sources cannot be scheduled. The variable nature of renewable energy systems, results in a mismatch between the time of 'generation' and the time of 'consumption' of energy.

Figure 1 showcases a typical load pattern for a house in a village with lighting, fan and TV load. The generation from a typical solar plant is given alongside. It can be seen that most of the energy is required at night while most of the generation from the solar plant occurs during the day time. As can be seen from Figure 1, the generated excess power can be stored during the day so that it is available to meet the consumer's need during the night. Energy storage is the means through which this time shift takes place.

Figure 1: Typical Example of Time Shift Using Energy Storage Technologies



1.1.1 Grid Stabilization

The variability of renewable energy resources leads to a higher degree of frequency variations and harmonics in the transmission system, higher ramp rates and range, and higher uncertainty of meeting fast changing loads. It is common engineering wisdom at present[1] that share of renewable power in the grid beyond 30 percent can lead to grid stability issues, as well as additional need for reserve capacities.

The Western Wind and Solar Integration Study (WWSIS)[2] by NREL highlighted the following:

- Grid has very few issues with up to 10 percent renewable energy penetration.
- With 20 percent penetration, grid stability issues become more frequent.
- With penetration of 30 percent, grid becomes unstable, affecting performance of other generating plants such as coal and nuclear power plants.

The impact of increasing concentration of renewable energy in the grid has been highlighted in Figure 2. The figure shows the sharp increase in variability of grid supply as the concentration of renewable energy in the grid increases. One can observe significant variation in dispatches from base-load stations.

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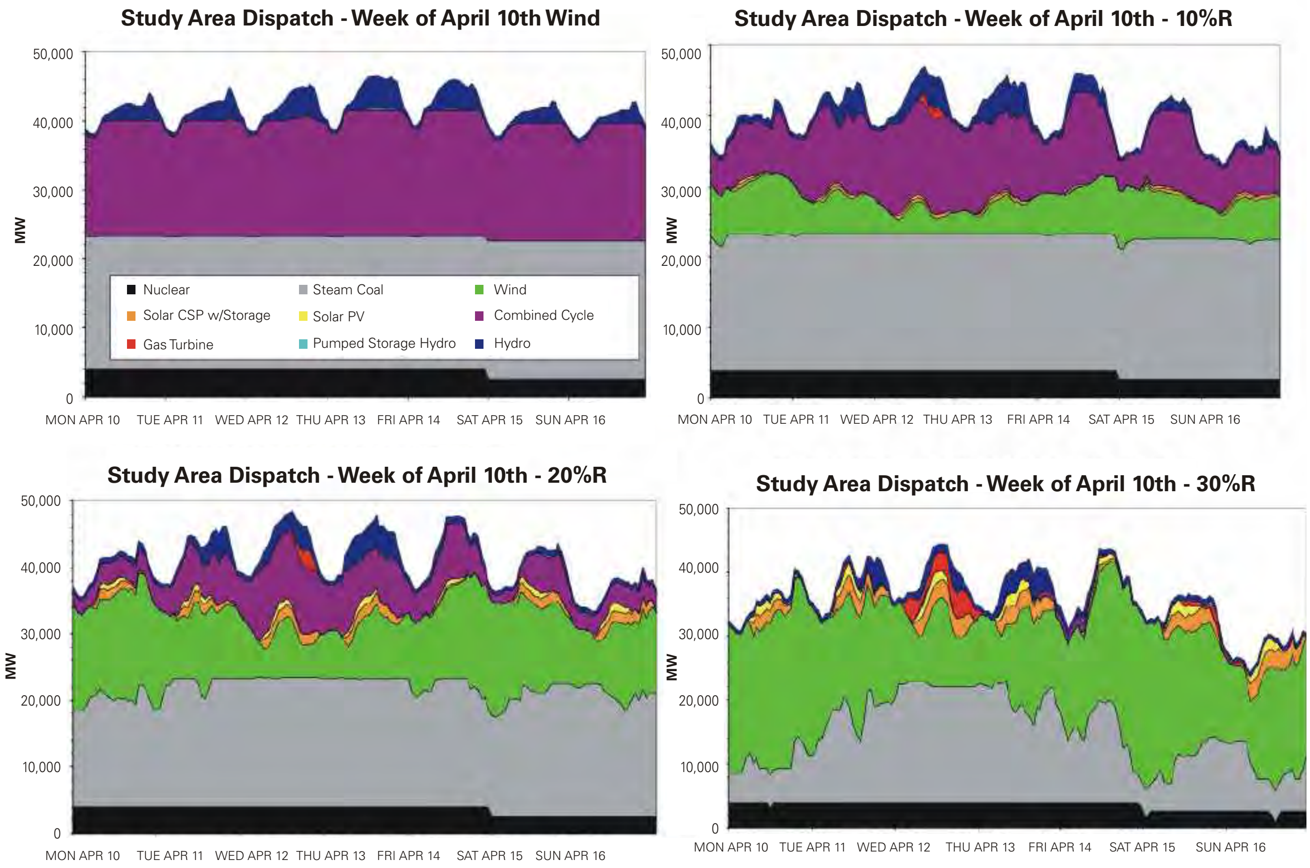
[1] Conclusions of studies conducted in the U.S. by National Renewable Energy Laboratories. Source: The role of energy storage with renewable electricity generation, National Renewable Energy Laboratory, March 2010. Report is available at http://www.nrel.gov/docs/fy10osti/49396.pdf

[2] The Western Wind and Solar Integration Study (WWSIS) is one of the largest regional wind and solar integration studies to date conducted by National Renewable Energy Laboratory (NREL) of the United States. It was initiated in 2007 to examine the operational impact of up to 35 percent energy penetration of wind, photovoltaic (PV), and concentrating solar power (CSP) on the power system operated by the WestConnect group of utilities in Arizona, Colorado, Nevada, New Mexico and Wyoming. Report available at http://www.nrel.gov/docs/fy10osti/47781.pdf

Figure 2: Impact on Grid with Increase in Penetration of Renewable Energy



Study Area Dispatch - Week of April 10th Wind

Study Area Dispatch - Week of April 10th - 10%R

Study Area Dispatch - Week of April 10th - 20%R

Study Area Dispatch - Week of April 10th - 30%R

Source: How do Wind and Solar Power Affect Grid Operations: The Western Wind and Solar Integration Study, National Renewable Energy Laboratory

The transmission grids can integrate energy storage solutions to address grid stability issues issues due to higher RE injection by:

- Bringing the demand-supply imbalance into a narrow range for power quality requirements and;
- Meeting the need for additional 'load-following' and 'reserve' capacity.

As most governments around the world target a share of over 20 percent for renewable energy in their country's overall electricity mix, over the next decade, the role of storage solutions to *'stabilize'* the grid and improve the quality of power supplied will become substantial[3].

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[3] Electric Power Research Institute (EPRI) estimates the cost of grid integration to be USD 3.13 per MWh for U.S. Including the cost of regulation, load following and contingency reserves.

1.1.3 Peak Shaving

The demand due to various loads being serviced by the grid varies routinely throughout the day, based on a multitude of factors such as varying energy use patterns by individuals, factories, commercial complexes, as well as utility tariffs, weather, etc. For example, utilities in places like California experience peak demand during the day (from around noon to early evening) when the temperatures are at their peak and commercial establishments are the load drivers. In the case of India, the peaks are experienced in the morning (between 8 and 10 a.m.) and then in the evening (between 6 and 10 p.m.). The major challenge before the utilities lies in managing peak demand. The conventional route adopted to address this issue is to have standby power available, which can be ramped up at the time of peak demand. Generally this is achieved by peaking plants using gas turbines, diesel generators, etc. In other cases, peak demand is managed by restricting supply to specific end users; load shedding across geographic areas; demand side management by pricing peak power higher than off peak power, etc. Consumers with load restriction or load shedding during peak periods either procure power from open market sources, or generate electricity using expensive captive diesel generator sets, or simply scale down operations to reduce power consumption.

With increasing renewable energy obligations and enhanced viability of renewable energy, the storage technologies can be used to shift the peak demand from the grid to locally generated and stored renewable energy. This allows smaller peak loads on the grid resulting in 'Peak Shaving'. This will become increasingly important as distributed renewable energy systems at consumer levels increase and the transmission grids are used to supply only the balance power needs. This also provides an alternative form of time shift at consumer level.

1.1.4 Cost Savings

Energy storage options today are very expensive, though they have a significant potential for adding economic value to our energy systems. An analysis undertaken by the U.S. National Renewable Energy Laboratory (NREL)[4], estimated that energy storage added the following values to the power systems: energy arbitrage value[5] (annual value between USD 37 and 240 per kW), frequency regulation (annual value between USD 236 and 429 per kW), and contingency reserve (annual value between USD 66 and 149 per kW). The net present value of gains from energy storage is estimated to be about USD 2,500 per kW[5]. With these added values levels many storage technologies are economically competitive.

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[4] Source: The role of energy storage with renewable electricity generation, National Renewable Energy Laboratory, March 2010, report is available at http://www.nrel.gov/docs/fy10osti/49396.pdf.

[5] Energy arbitrage value derives from the option to use a cheaper energy source by using storage; frequency regulation is linked to grid stabilization; contingency reserve is the energy reserve to start a system/grid when large generation base load capacity shuts down, which is important for mission-critical applications.

[6] Annual savings discounted at 10 per WACC.

Another cost analysis study, undertaken by the California Energy Storage Alliance, showed that storage technologies are commercially more effective as compared to gas turbines[7] for frequency regulation[8] and meeting peak loads[9].

As depicted in Table 1, the fly wheel has better returns than the combined cycle gas turbines for frequency regulation in the grid. On the other hand, Table 2 highlights the favorable performance (in terms of energy and capacity cost) of lead acid batteries vis-à-vis Simple Cycle Gas Turbine.

Table 1: Comparison of Combined Cycle CT to Flywheel for Regulation

	Combined Cycle Gas Turbine	Flywheel
IRR	14.6%	25.7%
Payback Period	8.1 years	3.9 years

Table 2: Comparison of Gas Simple Cycle CT to Lead Acid Battery for Peaking

	Simple Cycle Gas Turbine	Lead Acid Battery
Cost of Energy	USD 492/MWh	USD 377/MWh
Cost of Capacity	USD 203/kW-yr	USD 155/kW-yr

Most of the studies on storage and its benefits have been undertaken in the U.S, Japan or Europe. In the case of India, till now, no comprehensive cost benefit analysis has been undertaken for energy storage technologies. However, given India's goals for increasing renewable energy use, smart grids, electric vehicles, etc., as well as significant expansion needed in energy supply and energy access, a strong economic case for energy storage exists. India faces considerable power shortages and uses very expensive diesel to meet the demand supply gap. The arbitrage values in India could be higher than the U.S., as there is a high rate difference between the cheapest off peak-power (about INR 2.75 per kWH/U.S. cents 4.4 per kWH on short term energy exchanges)[10] and

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[7] Currently, Combined Cycle Gas turbines are used for frequency regulation and Simple Cycle Gas turbines are used to meet peak demands in grid.

[8] Source: Energy Storage—A Cheaper, Faster, & Cleaner Alternative to Conventional Frequency Regulation, California Energy Storage Alliance. Report can be found at http://www.ice-energy.com/stuff/contentmgr/files/1/76d44bfc1077e7fad6425102e55c0491/download/cesa_energy_storage_for_frequency_regulation.pdf

[9] Source: Energy Storage—A Cheaper Cleaner Alternative to Natural Gas Fired Peaker Plants, California Energy Storage Alliance. Report can be found at http://www.ice-energy.com/stuff/contentmgr/files/1/232cbe65ef0301ca206aa98af99a4cbf/download/cesa_peaker_vs_storage_2010_06_16.pdf.

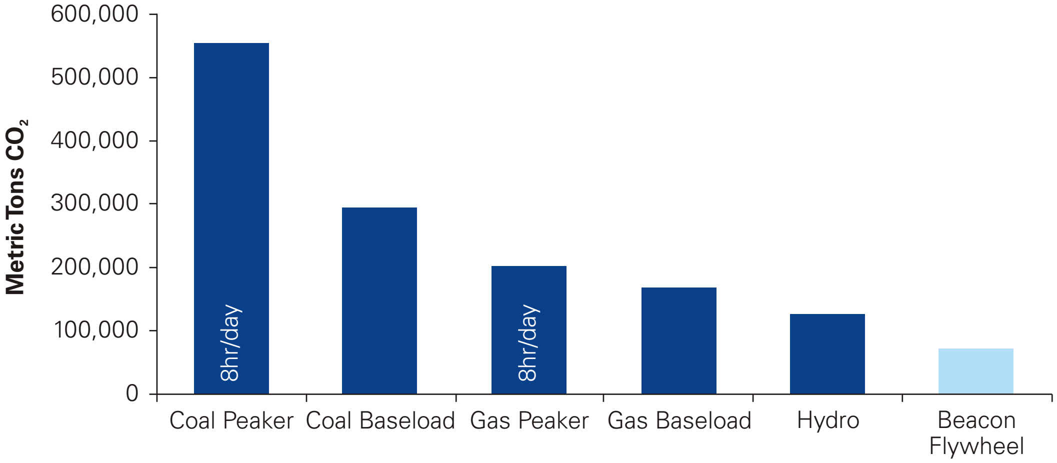
[10] Considering the U.S. dollar exchange rate as on November 15, 2013 i.e., INR 63.1.

diesel generation (the normal means of generation when there is a dearth of power from the grid, with the cost of this coming in at over INR 18 per kWh, equivalent to U.S. cents 28.5 per kWh).

1.1.5 Reduction in Carbon Emissions

Almost all utilities at present use conventional energy generators to regulate frequency variations in the grid and also to meet peak demand requirements. Very often these conventional energy generators operate at low capacities and efficiencies and end up generating costly power while increasing carbon emissions. A study commissioned by the Beacon Power Corporation and undertaken by the KEMA,[11] compared carbon emissions from the use of a 20 MW flywheel as against conventional energy sources for frequency regulation,[12] and found that carbon emissions from the flywheel were lower than any other form of conventional energy generation.

Figure 3: Emissions Released over 20-year Operating Life for Various Peak Electricity Technologies



Source: KEMA

1.1.6 Other Benefits of Energy Storage

Apart from the benefits listed above, storage technologies also offer a set of subsidiary benefits such as:

- Energy efficiency benefits from reducing fossil fuel consumption in plants running at less than optimum capacity and therefore at low efficiency, just to provide spinning reserves.

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[12] KEMA Inc., one of three companies in the DNV Group.

[13] Design and Development of a 20 MW Flywheel based Frequency Regulation Plant report, A Study for the DOE Energy Storage Systems Program, Sandia National Laboratory. Report can be found at http://prod.sandia.gov/techlib/access-control.cgi/2008/088229.pdf.

- Savings in Transmission and Distribution (T&D) capacity (capital cost deferral) from maximizing the throughput of the transmission and distribution system, using load leveling by storage capacities.
- Continuity from allowing the grid to shift from one type of generation source to another and thus helping diversification of the generating sources.
- Mobility (e.g. electric vehicles) and portability (being able to use power without connection to grid such as mobile phones, computing devices, etc.).
- Lowering cost of energy resources (e.g. allowing generation in solar plants in desert areas at low costs).

Large scale deployment of energy storage solutions would depend on technology innovations as well as effective business models and policies.

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[13] Source: Renewable Global Futures Report 2013, REN21. Document is available at http://www.worldfuturecouncil.org/fileadmin/user_upload/PDF/REN21_GFR_2013.pdf.

1.2 STAKEHOLDER WISE ANALYSIS OF BENEFITS OF STORAGE

In any application of energy storage, the benefits of energy storage are distributed across the stakeholders. There is a need to develop appropriate business models for participation of storage capacities in the grid and aggregating revenue stream from services to many beneficiaries, without counting the same benefits twice. Typical benefits of energy storage to these stakeholders are:

The electricity users may be willing to pay for the cost of storage if it improves the quality and reliability of power. This willingness to pay will vary with the effect of poor quality power on the user's electrical equipment and processes, and their downstream impact on the life of appliances and quality of life.

Benefits to Electricity Users

- Improved access to energy
- Improved power quality/reliability, hence lower process interruption costs and maintenance costs
- Peak load reduction leading to reduced demand charges and energy costs
- Ability to use higher on-site renewables – meeting renewable energy obligations and ensuring long-term energy security.
- Overall lower costs due to price-arbitrage and use of off-peak power at low cost

When viewed from the perspective of distribution company, value of storage would be felt if the distribution company is able to meet contractual commitments related to the delivery of quality power to its users, preventing users from switching to another supplier (in states where such switching is allowed), avoiding regulatory pressures and penalties if quality commitments are not met, preventing potential grid interruptions, reducing negative impact on equipment of the distribution or transmission company and shaving peak power loads.

Benefits to Transmission and Distribution Companies

- Transmission and Distribution (T&D) capacity addition deferral
- Peak-load shaving
- Reduction in contingency reserves, including for black start; reduction in spinning reserves
- Ability to diversify generation resources
- Management of grid stability, grid voltage (sag, VAR) and frequency regulation
- Meeting off-grid mandates and demands

Benefits to Renewable Energy Generation Companies

- Improved capacity utilization, reduction of grid non-availability hours and therefore better evacuation and faultride through capabilities
- In some cases, ability to meet peak demand and therefore better tariff realization
- Voltage and frequency regulation at the point of injection - avoidance of grid penalties
- Load leveling and better ability to forecast and schedule power, which modern grid systems require[14]

With introduction of storage, traditional distinction between the generator, the transmission company, the distribution company or the consumer blurs. A consumer may also become a supplier of ancillary service or energy to the grid. Similarly a transmission company which creates storage space to meet capacity requirements can also sell the stored energy as a trader.

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[14] e.g., Indian Electricity Grid Code.

2 STORAGE TECHNOLOGY CHOICES

2.1 AVAILABLE ENERGY STORAGE TECHNOLOGIES

Energy can be stored in a number of forms, among them chemical, mechanical, static electricity or thermal. Energy storage technologies are classified on the basis of the 'form of energy' and the 'storage medium'. Some important energy storage technologies are described below:

- **Electro Chemical Storage**

  Electrolytes[15] are used as a medium for electro-chemical energy storage. Electrolytes can be broken down into positive and negative ions using electricity, which can then be combined to give electric current. This is a reversible process. Electro-chemical storage is the most popular as well as the most commercialized form of energy storage technology in the market today, especially for small-scale applications. Batteries are the foremost example of this form of storage, with Lead Acid being the most common amongst batteries. Sodium-sulfur, Lithium Ion, and Flow batteries are gaining traction for energy storage applications.

- **Chemical**

  The chemical method of storage consists of converting energy into chemicals which store energy and can be reconverted into electrical or thermal energy when needed. The most common chemical for storage is hydrogen, which can be generated and re-converted to energy using reversible fuel cells. Hydrogen can also be used as a fuel directly. Other options are conversion into bio-fuels, hydrogen peroxides, liquid nitrogen, vanadium-pentoxide and so on.

- **Electrical**

  While electricity cannot be stored, it can be converted into a static charge or into a magnetic field which can store the energy and release it later. Charge is most commonly stored in high capacity capacitors. The magnetic field storage is created by a direct current passing through a superconducting coil, cooled below the superconducting critical temperature. This method gives interesting possibilities of combining with hydrogen systems, as hydrogen is used for cooling the superconductor.

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[15] An electrolyte is a compound that ionizes when dissolved in suitable ionizing solvents such as water. This includes most soluble salts, acids, and bases.

- **Thermal**

  Thermal energy storage is becoming increasingly popular, especially for solar thermal applications and for heating or cooling applications. In this form of storage, electric energy or thermal energy is used for heating or cooling a medium like ice, steam, molten salts, etc., which can later be used to generate electrical or thermal energy. Thermal technologies are used for air conditioning and heating requirements of buildings, for inter seasonal energy storage and so on.

- **Mechanical Storage**

  Machines also have the ability to store energy in the form of potential or kinetic energy. The flywheel is a popular mechanical energy storage technology. Flywheels store energy in the form of rotational energy, which is then converted back into electricity using an electromagnetic field as and when required. Flywheels are used as reserves in grids for short-term energy storage and frequency regulation.

- **Pumped Hydro**

  Pumped hydro constitutes the largest form of grid connected energy storage (almost 99 percent) across the globe. Using this storage method, water downstream is pumped to a reservoir upstream during times of low energy demand. When energy is required, the water is released from the storage reservoir or container through hydro turbines or other electricity generating equipment.

- **Compressed Air Systems**

  In the compressed gas system of energy storage, the principle is similar to that used in pumped hydro except for the medium used. In this case, air is compressed and stored in a container or /earth cavity and, when required, is released in the form of compressed air fed to a gas turbine along with fuel. The recovery of energy is in the form of reduced gas consumption in the turbine. Large scale compressed air systems are generally stored in underground caverns while above ground storage containers are used for small-scale applications.

  A detailed storage technology tree with capability and maturity levels of various technologies has been given in Annex 1. Table 3 highlights the various technologies used in each storage type.

Table 3: Technology Tree for Various Storage Methods

Storage Method	Technology	Sub-technology	
Electro-Chemical	Battery	Lead Acid	Flooded Cell
			Valve Regulated Lead Acid (VRLA)
		Nickel Cadmium (NiCd) and other Ni family	
		Nickel Metal Hydride (NIMH)	
		Sodium-sulfur (Na-S)	
		Lithium Ion	
		Lithium Air	
		Zinc Air	
		Iron-Air	
	Flow batteries	Zinc Bromine	
		Vanadium Redox (VRB)	
		Sodium Polysulfide (Na-S)/Bromine	
		Cerium Zinc	
	Fuel cells (using hydrogen/methanol or other fuel produced using RE)	Proton Exchange Membrane (PEM)	
		Solid Oxide Fuel Cells (SoFC)	
		Alkaline Fuel Cells (AFC)	
		Phosphoric Acid Fuel Cells (PAFC)	
		Direct Methanol Fuel cells (DMFC)	
		Molten Carbonate Fuel cells (MCFC)	
Chemical	Conversion to Hydrogen	Underground hydrogen storage	
		Alternate storage in Active Carbon or Carbon nanotubes	
		Absorption in Metal Hydrides and Fullerines	
	Conversion to Hydrogen–> methane		
	Conversion to Oxy–Hydrogen mix		
	Conversion to Hydrogen peroxide		
	Bio-fuels		
Electric	Capacitors	Nano scale capacitor	
		Super-capacitors	
	Superconducting magnet energy storage (SMES)		

Storage Method	Technology	Sub-technology
Thermal Energy Storage (TES)	Molten Salts	
	Steam accumulators	
	Cold storages	
	Ice	
	Under Ground Thermal Energy Storage (UTES)	
	Cryogenic liquid air or nitrogen	
	Seasonal thermal store	
	Solar pond	
	Thermal Energy Storage in Closed Greenhouses	
Mechanical	Flywheel	
	Gravitation potential energy devices	
	Springs	
Pumped Hydro	Hydro-electric- large pump hydro	
	Hydraulic Accumulators	
	Micro Pump Hydro	
Compressed gas systems	Underground Air Enclosures (caves, mines, etc.)	
	Smaller hybrid CAES system- above ground	
	Compressed CO_2 (sequestered)	

Historically, the most popular energy storage solutions have been pumped hydro, flywheels and batteries. The key features of these technologies are described below:

Pumped Hydro Storage has large power and energy ratings, and low cost of storage. It constitutes almost 99 percent of energy storage capacity globally. Approximately 90 GW installed capacity of pumped hydro exists across the globe. India also has nearly 5 GW capacity. Pumped hydro can have very large single location capacities (GW scale), with discharge time of a few hours to a few days and ability to respond quickly (tens of seconds), and between 70 and 85 percent round trip efficiency.[16] This form of storage is very appropriate for 'regulation', 'reserve' and 'time shift' applications. Like any hydro plant, it has to be set up at special locations and takes a long time to develop. Its life cycle is long and can outlast any other storage technology, though it cannot meet consumer level storage needs due to storage constraints. The cost ranges between USD 140 and 700 per kWh.

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[16] Round trip efficiency is defined as amount of energy delivered versus the amount it takes in.

Low Speed Flywheels, with power rating in the range of kW to MW and energy density of between 50 and 100 Wh/kg, have been mostly used for grid 'regulation' and for bridging to back-up generators. Flywheels have also been proposed for distributed usage such as electric vehicles and telecom towers, as well as integrating wind capacities with grid. Flywheels with efficient bearings can have efficiency levels of nearly 95 percent, and have discharge time of a few minutes to a few hours, with fast response times. Flywheels are expected to have a short life (a few years), although Beacon Power System promises their system to have a life of 20 years. The cost of the system is reported to be about USD 1,500 per kWh, which is at the higher end.

Lead Acid Batteries, the most common distributed storage technology used in off-grid applications, as well as commercial and industrial applications, has the big advantage of low costs of storage (between USD 100 and 250 per kWh). It is the most competitive storage technology in terms of capital costs. However, it has low energy densities (between 25 and 45 Wh/kg), low depth of discharge (about 50 percent), short life (about 500 cycles) and between 60 and 80 percent round trip efficiency, varying with usage conditions. It is facing stiff competition from Lithium-ion, Sodium-sulfur, Flow batteries, etc.

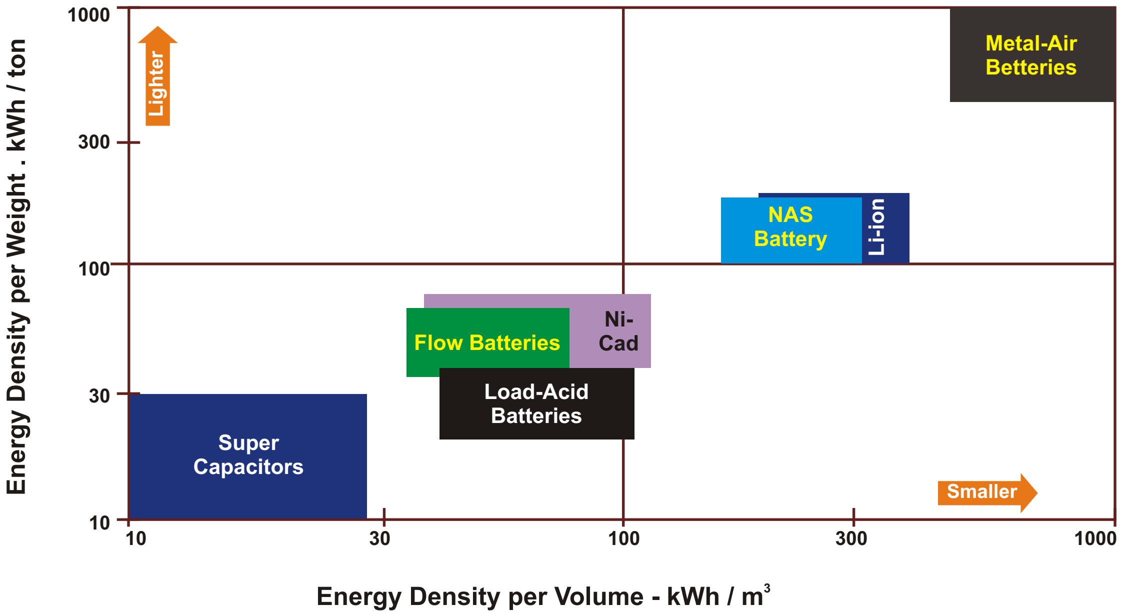
2.2 KEY PERFORMANCE PARAMETERS FOR EVALUATING ENERGY STORAGE TECHNOLOGIES

A number of energy storage technologies are now available in the market and each one of these offers different performance parameters. The performance needs to be matched with the specific requirements for different applications.

For example, batteries need to be relatively small and portable, with the ability to store power for long durations to make them suitable for domestic, off-grid and small sized industrial applications while pumped hydro on the other hand has to have a large storage capacity and fast response time, which is essential for grid regulation applications. The key performance parameters for evaluating energy storage technologies are:

Energy Density: Energy density is the amount of energy that can be supplied by the storage technology per unit weight (measured in Watt-hours per kg, Wh/kg) or volume (measured in Watt-hours per liter, Wh/l). This defines the quantity of energy that the device can store and deliver. It is very useful where space or weight become critical parameters for the success of the system, such as electric vehicles, defense and space applications, portable computing or communication devices. The energy density values of batteries can vary from 25 Wh/kg (VRLA) to as high as over 400 Wh/kg (metal air batteries). The energy densities of various energy storage technologies are highlighted in Figure 4.

Figure 4: Energy Density for Various Energy Storage Technologies[17]



Note

The above energy densities are based on input energy. The output energy densities depend on the charge / discharge efficiency that varies from 75% for most flow batteries to almost 100% for supe capacitors and most advanced batteries.

Source: Analysis of Energy Storage Association

Discharge Time: This is the period of time over which an energy storage device releases its stored energy (till its designed Depth of Discharge). This parameter when viewed with the power capability of the device i.e. its rating in kW or MW, indicates the application for which the energy storage technology can be used. For example, super-capacitors or superconducting magnet energy storage (SMES) technologies are very quick acting with discharge times of seconds, but have very large power rating, and therefore are very useful for gird regulation needs. Sodium-sulfur batteries, vanadium redox flow batteries, pumped hydro and compressed air energy systems on the other hand have long discharge times and therefore can be used for time-shift applications.

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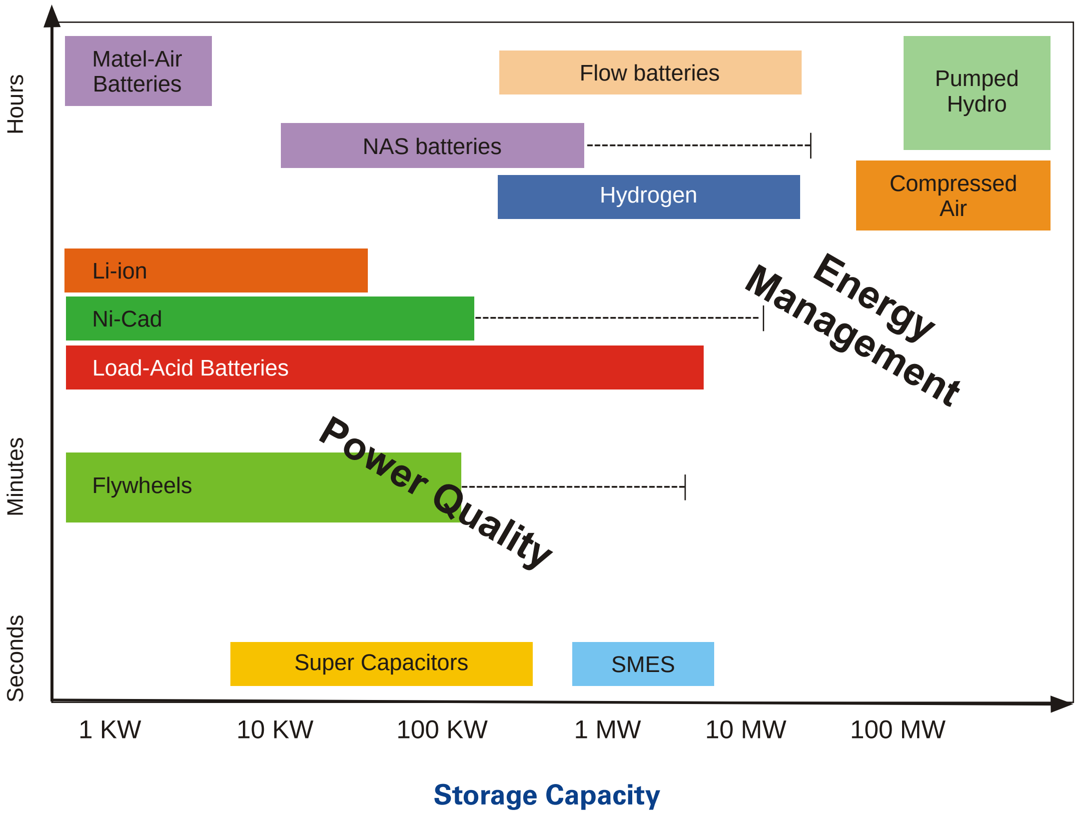
[17] Source: Analysis of Energy Storage Association.

A related concept is C rate, which defines the number of hours in which full capacity of the battery can be charged or discharged. Thus a rate of 1C means full discharge of battery in one hour.

Figure 5: Typical Discharge for Energy Storage Technologies[18]



Power Rating is the peak capacity of a storage system in terms of kW or MW of power generation that it can handle. Large power ratings are needed for grid regulation or energy management systems for large users.

Energy Rating (expressed in kWh or MWh) determines how long a device can supply energy for a given power output. An example is that of a 100 kWh device rated at 20 kW, which can supply 20 kW of output for 5 hours (20kW x 5 hours = 100 kWh). This remains the most important characteristic of storage devices, especially for 'time-shift' applications.

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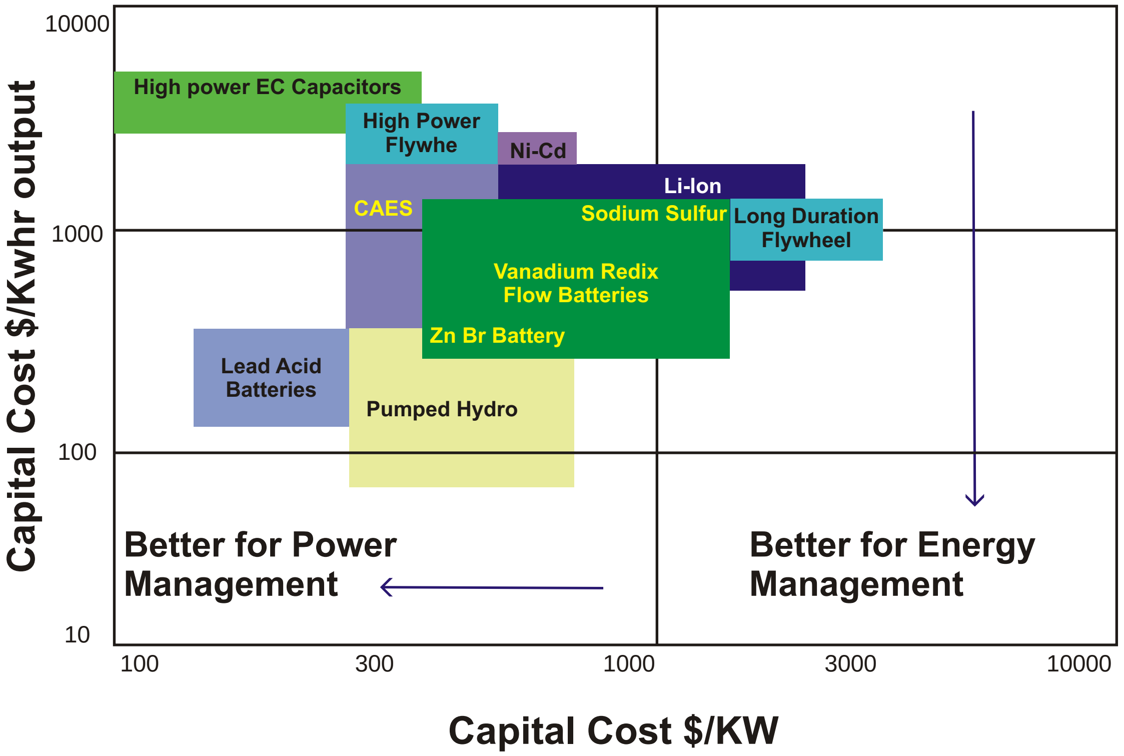
[18] Source: Outlook of Energy Storage Technologies, Policy Department, Economic & Scientific Policy, European Parliament.

Depth of Discharge (expressed as a percentage of energy rating) expresses the percentage of energy stored that can be safely discharged in a single discharge cycle without affecting the performance characteristics of the storage device. Depth of discharge is an important parameter for batteries as higher Depth of Discharge translates into lower capital costs, lower control costs, longevity of device, etc. This is particularly important for time-shift off-grid applications where the storage device would go through a deep discharge cycle at least once in a day. Lead acid batteries theoretically can go up to 80 percent depth of discharge; however practitioners feel that, due to the sensitivity of battery efficiency and life to depth of discharge, the right level of depth of discharge for lead acid batteries is 50 percent. New battery technologies like vanadium redox flow batteries, ultra batteries, and sodium-sulfur batteries can achieve 90 percent depth of discharge, and have improved cycle efficiency and life cycles as well. Most lithium ion batteries work with 80 percent depth of discharge and have high (over 95 percent) cycle efficiency. These improvements make these technologies competitive vis-à-vis lead acid batteries despite higher capital costs.

Costs of Energy Storage Devices are usually quoted in terms of cost per kWh or cost per kW. The units used for denoting the cost of the energy storage technology depend upon the end use application for which the device is to be used. Some devices have a high cost per kWh but relatively lower cost per kW while for others it is the reverse. Range of costs of various storage technologies have been highlighted in Figure 6. The issue of cost economics depends greatly on the application, which means that there is a need to be sure which units should be used for measuring the cost of energy that derives from the storage technology.

Figure 6: Capital Cost per Unit Energy for Energy Storage Technologies[19]



Life Discharge Cycles denote the number of cycles of charge and discharge that a storage device can handle without significant deterioration in performance. This parameter is useful for time shift applications which require regular deep discharge and which are located in difficult to maintain terrain, thus requiring higher life. This is especially important for off-grid applications like batteries for solar lanterns and solar photovoltaic (PV) based home lighting systems.

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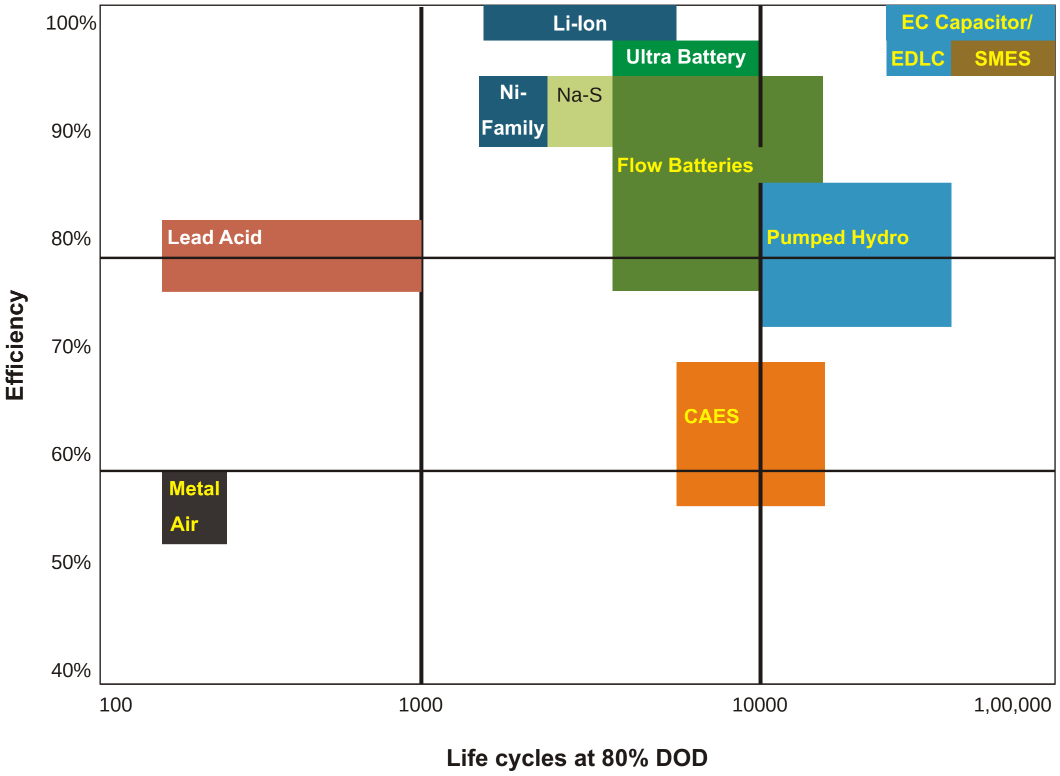
[19] Source: Analysis of Energy Storage Association.

Figure 7: Cycle Efficiency of Energy Storage Technologies[20]



Rapidity of Charge/Discharge Cycle (min/secs) determines how quickly a storage device can go through a charge/discharge cycle. This is especially important for storage devices which are used for power quality improvement of the grid and require large power rating and very fast response times.

Loss of Energy in One Discharge Cycle or Cycle Efficiency (Percentage) is an important characteristic determining overall cost of storage as an estimated 5 to 50 percent of power is lost every time a charge/discharge cycle is executed. Some of the efficiency figures for the all of the technologies highlighted above are provided in Figure 7.

Operating Temperature range determines the optimum temperature range under which the storage technology functions efficiently without any negative impact on life of the technology/ device. This is critical for temperature sensitive technologies like batteries, especially when used in remote installations, micro grids, etc.

Annex 2 highlights the key performance parameters and their variation across a wide range of energy storage technologies. As the benefits of storage vary with end use and are usually diverse, each storage technology needs to be evaluated on the basis of application requirements and the beneficiary.

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[20] Source: Analysis of Energy Storage Association.

2.3 ENERGY STORAGE TECHNOLOGY OPTIONS FOR INDIA

At present, a majority of the residential, commercial and industrial establishments depend on the grid for meeting their electricity needs. The cost of power procured from the grid varies between INR 5.5 and INR 10.0 per kWh (between U.S. cents 8.7 and U.S. cents 15.4 per kWh)[21]. During grid outages, diesel generators are used, and this means costs over INR 18 per kWh (U.S. cents 28.5 per kWh). The difference between cost of power from grid and diesel generators is over INR 10 per kWh (U.S. cents 15.4 per kWh). Cost of electricity generation from solar is between INR 8 and 10 per kWh[22] (between U.S. cents 12.7 and U.S. cents 15.4 per kWh) (without storage). Energy storage devices which can store and supply electricity at costs lower than INR 8 per kWh (U.S. cents 12.7 per kWh) (on a levelized cost basis) would be commercially attractive[23] as substitutes for diesel generators when used with solar. Since energy storage systems are capital intensive, capital cost (cost per kW) is also a critical criterion[24] when taking a decision on whether to go in for storage rather than some form of alternative back-up generation.

In view of the above, storage technologies which have the potential for being implemented at cost levels of less than USD 500 per kW and less than USD 0.1 per kWh/discharge cycle (electrical storage) have a good potential for application in India.

2.3.1 Electrical Energy Storage Technologies

Batteries are one of the most popular energy storage technologies. Modern life depends heavily on battery technologies for communication and transportation, since batteries represent electro-chemical energy storage. They are built in modular form, so capacity expansion is easy. Due to easy portability, expandability and safety batteries are deployed for a wide variety of applications, with capacities also ranging widely (kWh to MWh). Apart from lead acid batteries, other battery technologies such as Ultra battery, Sodium-sulfur (Na-S) storage, Lithium Ion and Vanadium Redox Flow batteries are proving to be very useful, especially from the perspective of supporting renewable energy systems.

Valve Regulated Lead Acid (VRLA) Battery

The lead acid battery is the oldest form of the electro-chemical storage. VRLA batteries are commonly used for a variety of applications such as automotive, telecom, UPS and others. The key

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[21] Electricity tariffs are different for each user group, for each utility and they also depend on time during a day.

[22] Without the effect of subsidies or future escalations.

[23] INR 10 per kWh (U.S. cents 15.8 per kWh) solar energy cost + INR 5 per kWh (U.S. cent 7.9 per kWh) storage cost about INR 15 per kWh (U.S. cents 23.8 per kWh), which is below INR 18 per kWh (U.S. cents 28.5 per kWh), the lower boundary of cost for diesel generation.

[24] Capital cost defines upfront investment needed. If it is high, it is difficult to finance, especially in distributed generation systems, rural applications etc where financing is scarce.

limiting factors of VRLA batteries are low efficiency (between 60 and 95 percent) sensitivity to temperature, low number of life cycles (between 500 and 1,500 cycles), and maintenance issues.

Ultra Battery

Ultra-battery technology is a new technology in the early phases of commercialization. Ultra battery technology combines lead acid with capacitor technology. The ultra battery has higher power rating, efficiency (over 94 percent) and a high number of discharge cycles (over 10,000 cycles). The lifecycle cost of the ultra battery is lower than VRLA batteries, while the initial capital cost per kW is higher. Ultra batteries are suitable for both sub kW, kW and MW scale applications.

Sodium-sulfur (Na-S) Battery

Sodium-sulphur battery technology uses molten sodium as anode and molten sulfur as cathode, separated by solid aluminum based electrolytes[25]. Na-S batteries are suitable for large-scale capacities. This technology has been available in the market for the past 20 years and used for commercial applications. Na-S batteries have been used for large capacity grid connected storage applications, especially for integrating wind farms with utility grids.

Na-S batteries have been developed and used extensively in Japan. They offer a number of advantages: low cost, high discharge efficiency (about 90 percent), and capability to store power for long (over 8 hours) as well as short duration rapid discharge. The life of a Na-S battery is 2,500 cycles at 100 percent depth of discharge and 4,500 cycles at 80 percent depth of discharge. Current technology, however, requires operation at 350° C, which coupled with corrosive Sodium/Sulfur, can pose safety issues, especially when used in a non-industrial environment.

Na-S batteries are attractive due to capability to offer both 'time-shift' and 'frequency regulation' capabilities, at low cost. Sumitomo is working on a version which will require lower temperatures to operate (100° C) and will reduce the corrosion and safety issues.

GE has introduced Sodium metal halide batteries, competing with Japanese products. These batteries have a more reliable, low temperature operation.

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[25] Electro-chemical technologies generally use solid anode and cathode and liquid electrolyte.

Lithium Ion (Li Ion) Battery

Li ion batteries are commonly used in consumer electronic applications due to their high energy density and low loss of charge when not in use. Li Ion batteries have higher efficiency (over 90 percent) and a high number of lifetime discharge cycles (over 2,000 cycles, in some cases life of 7000 cycles is also claimed) compared to lead acid batteries.

Li-Ion batteries have been extensively used in mobiles, computing devices, and are hot favorites for automotive and home applications. Li-ion batteries have had problems of runaway temperatures and require strict control on operating conditions through a battery management system. To improve on these aspects, Lithium Ferrous Phosphate (LFP) batteries have been developed which offer significant improvement in life, charge/discharge rates and efficiency levels. These are being recommended for extensive off-grid applications as well as grid tied renewables.

The EU has a program called POMEROL, which aims to reduce the cost of Li-Ion batteries as low as USD 25 per kW.

Vanadium Redox Battery

Vanadium Redox batteries use Vanadium based electrodes and sulfuric acid based electrolyte. Vanadium redox batteries have been commercially used. The advantage this technology brings is its ability for use in large-scale applications. These batteries can achieve 100 percent depth of discharge limit; however, their low energy density has been a major limiting factor.

United Technologies has developed a Vanadium Redox battery which claims to target reduction of over 10 times in cost per kWh and seems to have reached 50 percent of this target[26].

Brief characteristics of these technologies are provided in Table 4.

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[26] Discussions with company representatives in India in April 2013.

Table 4: Identified Electrical Energy Storage Technology Options

Technology		Efficiency	Life	Cost	Development stage	Remarks
Batteries	Valve Regulated Lead Acid (VRLA)	60-95%; 20% self-discharge/ month	<1,500 cycles. Most experts believe this to be about 500 deep discharge cycles.	About USD 0.15 per kWh/ discharge cycle	Available, widely used	• Low maintenance requirements • Temperature sensitive-can't be exposed to high temperatures. Energy rating falls at lower temperatures (< 200 C) • Pose problems of loss of efficiency when continuously used in partial charge state • Widely used for industrial and domestic applications
	Ultra battery	> 94%	>10,000 cycles	USD 0.05 per kWh/discharge cycle or less	Early phase of commercializationcurrently used for automobile applications	• This combines a VRLA battery with an asymmetric capacitor, improving the power rating, efficiency as well as response time of the battery • No significant degradation over 10%-90% discharge depths
	Sodium Sulphur	90%	2,500-4,000 cycles with deep discharge	USD 0.06-0.25 per kWh/discharge cycle	Available. Developed for last 20 years. Mostly used in Japan. 300 MW under implementation	• Molten sodium (cathode) and sulfur (anode) separated by aluminum ceramic electrolyte which only allows sodium ions to pass • High power density, high efficiency and both long storage (over 8 hours) and rapid discharge capability • High temperatures create a safety issue • 2 Plants in Japan of 9.6 MW and 64 MWh capacity are in operation - one at a water treatment plant and one at a utility operated by Hitachi. Also a wind farm of 51 MW at Rokkasho Island has been implemented. AEP Installations in U.S. for 6 MW x3 each at West Virginia and Ohio. Long Island bus depot installation 1 MW (2006)

Technology		Efficiency	Life	Cost	Development stage	Remarks
	Lithium Ion	90-100%	>2,000 cycles	USD 0.25-0.5 per kWh /discharge cycle.	Available. Popular in small scale applications and electric vehicles	• Nano Powders and Nano Composite electrodes are being used to increase capacity. • Li batteries now account for 50% of small battery market. • Tesla has developed a battery for BEV 200 kW. SAFT SATCON 100 kW/1 min storage for stabilizing grid. • LFP (lithium ferrous phosphate) batteries are latest version with better life and thermal management characteristics. • Limited environmental issues. LiO2 (Lithium Oxide) can be easily recycled. • EU has taken up an initiative POMEROL to reduce the cost of LI batteries to less than Euro 25/kW which is almost 4 times cheaper than current LA batteries
	Vanadium Redox (VRB)	85%		USD 0.03-0.1 per kWh/ discharge cycle	Early phase of commercialization. Limited implementation	• These have the best life and 100% discharge ability. • Being tried in many wind farms currently e.g. Sorne Wind Farm (Ireland). • The system will provide pulses of 3 MW for 10 minutes every hour

2.3.2 Thermal Energy Storage Technology

Thermal energy storage technology has been gaining in popularity over the past few years. The electrical or thermal energy is stored in thermal form. The design is very specific to applications and conditions surrounding the applications. In most of the cases, these technologies are integrated into the buildings utilities and are built to last over the long term (15-20 years). Efficiency levels, cost, life, etc. vary with design and applications. Following are the thermal technologies with high potential being developed these days:

Concrete and Ceramic Blocks, Hot Bricks, etc.

Materials like clay, ceramic material, concrete etc. can withstand high temperatures (between 1,000 and 1,600 Celsius). Due to this property, these materials have high volumetric capacity for storing thermal energy. By providing insulation, a large quantity of thermal energy can be stored in these materials. Storing thermal energy in ceramic and concrete blocks is a common practice in Europe for heating a building. Stored thermal energy is used through radiation or convention processes to meet thermal needs. In many cases, where electric energy is used for thermal needs, it is used to heat these blocks as they provide high energy storage density.

Steam Accumulators

Steam is commonly used in industrial processes. In most cases, steam is generated and consumed through boilers as and when required. With steam accumulators, steam can be generated using solar energy or off-peak grid power and stored. Steam accumulators are insulated steel pressure tanks. Stored steam can be used to meet thermal energy needs and also electric energy needs (through steam turbines) when required.

Ice

Thermal energy can be stored using water, which is commonly available, by converting water into ice. Ice can be stored in insulators. Energy stored in ice can be used for cooling applications like air conditioning, cooling units, etc. Several buildings globally have used ice as a storage medium for HVAC applications. Most of these installations are developed to arbitrage differences of energy cost between peak and off-peak hours. During night times, when the cost of electricity is lower, and when energy consumed/unit of cooling produced is lower due to low outside temperatures, water is converted to ice and subsequently during peak hours when cost of electricity is higher, energy stored in ice is tapped to chill water. This has also been tried in India.

Underground Thermal Energy Storage (UTES)

UTES technologies use underground structures for storage of heat for the purposes of efficient heating and cooling for buildings. Excess heat is stored during summers in underground structures like aquifers, bore holes, caverns, mines, etc., where a stratum of the underground structures holds the heat. The storage medium can be sand, earth, bed rock, crystalline hard rock, water, grout, etc. During winters, the stored energy can be extracted by pumping out the medium. UTES technologies are generally used for inter seasonal storage and have been widely implemented in Europe.

Molten Salt

Molten salt is a good heat storage medium that can retain thermal energy very effectively and operates at temperatures greater than 5,000 Celsius. Through heat exchangers, heat from molten salt can be gradually utilized to generate steam at high temperature. Since high temperatures are possible, steam generated from molten salts can be utilized for both electric (through steam turbines) and thermal loads. Solar thermal technologies can be effectively used with molten salt technology for meeting thermal and electric loads throughout the day.

Table 5 highlights the chief characteristics of some of the technologies mentioned above. It is pertinent to note that the costs and performance characteristics of these technologies are very application specific.

Table 5: Identified Thermal Energy Storage Technology

Technology		Development stage	Remarks
Thermal Storage	Concrete and ceramic blocks, hot bricks etc.	Available. Limited use in buildings	• Because these blocks can be heated to high temperatures (1,200+ °C) a small block can store a large quantity of thermal energy and release it over time. • Good for residential buildings etc.
	Steam	R&D, CSP thermal use	• Steam accumulator stores solar thermal energy at intermediate stage and converts it into power. Staged steam engines are power generators. • Terra-joule, U.S. has set up a demonstration plant 100 kW (24x7) supply. The peak solar collection capacity is for a 300 kW plant. Thus a 100 kW (24x7 Plant) is expected to cost USD 600,000 (USD 2 per W) with this technology, which is very attractive to most process industries. Also expected to use only 0.7 acres of collection area/land, which is 50%-70% less than PV.
	Ice	Available, limited	• With high specific heat of fusion of water, ice can store 93 kWh /m3 or 26 tons of HVAC Hrs. • Low cost, less space than water. • In 2009, used in 3,300 buildings and 35 countries. • Can also be used for converting cheap power in the night conversion, and use in the daytime for ACs.
	Underground Thermal Energy Storage (UTES) Inter seasonal thermal storage	Available though not fully commercialized. IEA Research goal under ECES (energy conservation through energy storage program)	• Heat pump injects heat into the ground and is used when needed. Heat is retained in aquifers or earth (around a network of boreholes), flooded mines or caverns, or lined pits filled with gravel and water. • Germany, the Netherlands and Sweden have extensive experience in the technology. More than 300,000 systems worldwide, with 80% + systems in Sweden. • "Zonnige Kempen", Westerlo (Belgium). Social housing project with BTES in combination with solar panels and asphalt collector. • Wiggenhausen-Süd solar development at Friedrichshafen features a 12,000 m3 (420,000 ft3) reinforced concrete thermal store linked to 4,300 m2 (46,000 ft2) of solar collectors, which will supply the 570 houses with around 50% of their heating and hot water. Excellent application for buildings.

Technology		Development stage	Remarks
			• The more recent "Zero Heating Energy House", completed in 1997 in Berlin as part of the IEA Task 13 low energy housing demonstration project, stores water at temperatures up to 90 °C (194 °F) inside a 20 m3 (710 ft3) tank in the basement] and is now one of a growing number of similar properties. "Jenni-Haus" built in 1989 in Oberburg, Switzerland has three tanks storing a total of 118 m3 (4,200 ft3) providing far more heat than is required to heat the building.
	Molten Salt	Available – being commercially used in CSP plants with storage in Spain and the United States	• Thermal energy storage systems store excess sensible heat collected by the solar field and keep the plant running under full-load conditions even after sunset. This storage capability leads to more economically competitive design options since only the solar part is oversized. • Molten salt is one of the commercial options available in the market for storing energy when coupled with Concentrated Solar Power plants. This storage medium is employed to store the thermal energy during the day and which can be released at night. The system usually requires a larger solar field so as to generate the excess thermal energy which is then stored using either a two or a single tank system. These storage systems have high efficiency and the energy stored in these systems can be used to generate electricity in bad weather or at night. The most common mixtures contain sodium nitrate, potassium nitrate and calcium nitrate.

2.4 STORAGE SOLUTIONS UNDER DEVELOPMENT

New solutions are also under development, for individual energy units and micro grids. The following are a few examples:

- An off-grid system design was presented by a student team from the Great Lakes Institute[27] in Renewable Energy Expo 2012 (NCR, India), and Clean Energy Ministerial (CEM, April 2013). This system used hydrogen as the storage medium and reversible Proton Exchange Membrane (PME) fuel cell to convert hydrogen into electrical power. Hydrogen is generated using power from rooftop solar PVs. The solution has a potential to be developed at a cost level of USD 6 per W, although current costs are high.

Similar solutions have been developed in the U.S.[28] in the range between 1 and 10 kW, providing a continuous power supply to individual homes or for the micro-grid. However at present these have very high costs (between USD 6 and 10 per W) and need cost optimization.

- Technology Management Inc. (U.S.) has proposed a reversible SOFC (solid oxide fuel cell system) with over 80 percent round trip efficiency to combine with solar PV or CSP systems[29]. The expected cost of the system is about USD 3.5 per W.

- Terra Joule U.S. has developed a solar thermal distributed generation and storage plant which can supply 100 kW load continuously throughout day using steam accumulators, with peak generation capacity of 300 kW. The cost is likely to be USD 5 per W (average capacity). This system on a generator cum storage basis works out to be much cheaper (about USD 175 per kWh) compared to existing technologies, with very high cycle efficiency (over 90 percent) and long life (over 20 years).

- Gravity based storage has been proposed by Gravity LLC U.S. and this will have the ability to provide pumped hydro storage type capability anywhere. A drive shaft (10 m diameter, between 1,000 and 2,000 m deep) lifts a piston using a pump during storage. During generation, the same pump acts as a turbine as the piston weight pushes water out. Eight such shafts can provide storage of equivalent of 150 MW for four hours, with over 75 percent cycle efficiency and very long life. The space required would be about 1000 MW storage per acre, a much denser storage capacity than other storage options.

Figure 8 summarizes the energy storage technologies studied (costs vs. experience).

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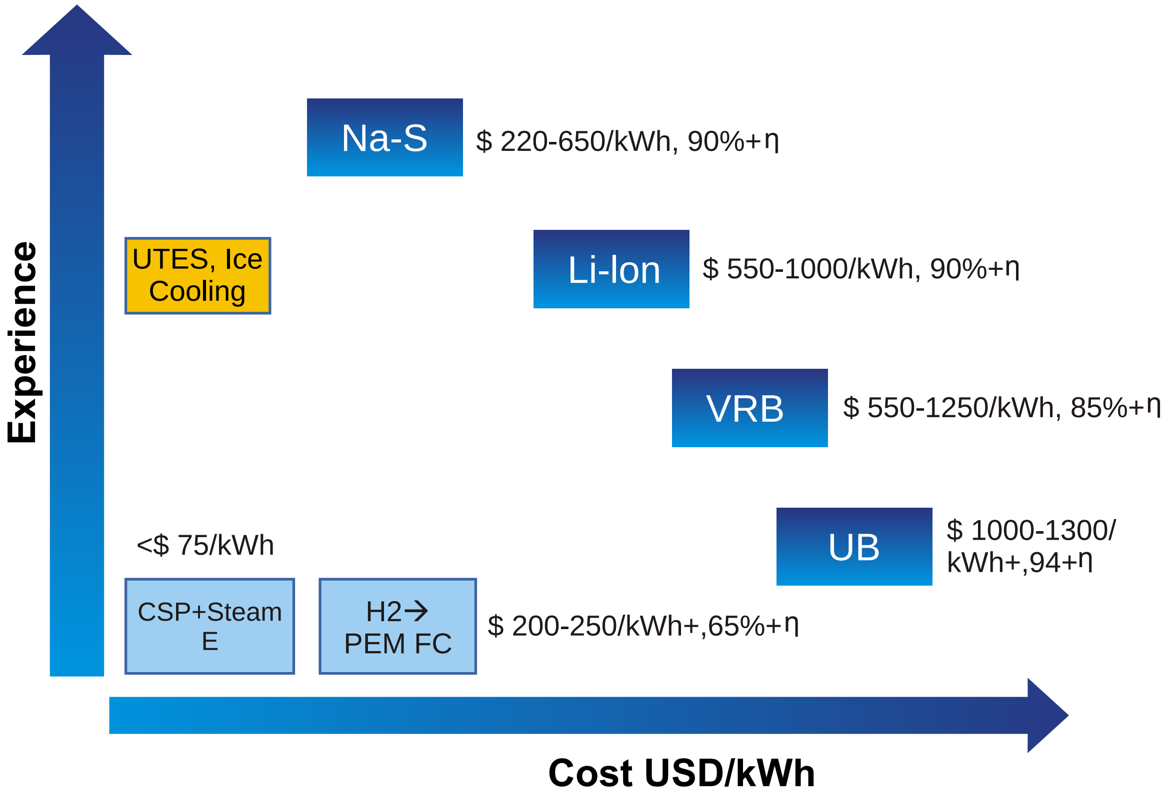
[27] www.greatlakes.edu.in.

[28] Michael Strizki has developed a Hydrogen House Project. Details of the project can be found at www.hydrogenhouseproject.org.

[29] Technology Management Inc. is a U.S.A. based Fuel Cell manufacturing company funded by U.S Gov. agencies Contact .details : 9718 Lake Shore Boulevard Cleveland, Ohio 44108 216-541-1000 email: tmi@stratos.net. More details can be found at http://www.tmi-anywherenergy.com/Home.html.

Figure 8: Cost and Experience of Energy Storage Technologies Relevant for India



3 APPLICATIONS FOR STORAGE TECHNOLOGIES - THE INDIAN CONTEXT

The power sector in India is facing a number of challenges, among them power shortages of over nine percent of peak demand, transmission and distribution constraints, lack of energy access in rural areas and so on. Moreover, the increasing share of renewable energy in the grids can cause stability issues within the grid.

The Indian grid needs to be upgraded with capabilities such as better forecasting and scheduling, fault ride through by connected RE farms, two way interaction with distributed on-site generation and micro grids, wide area management for grid balancing (WAMS), tighter grid regulation and adequate reserve capacities. Energy storage technologies can provide or support many of these capabilities.

In its present scenario, the Indian energy market offers an appropriate environment for the use and scale up of energy storage solutions[30]. Key issues which can be addressed by the use of energy storage technologies include:

- **Peak Power Shortage:** Severe national and state level peak power shortage (over nine percent[31]) and extensive use of on-site diesel generation to meet the shortage. This is a very expensive option (cost over INR 18 per kWh/U.S. cents 28.5 per kWh) compared to low-cost power available in off-peak hours (about INR 2.75 per kWh/ U.S. cents 4.4 per kWh). This leads to significant *arbitrage value for 'time-shift'* and energy storage can support such a time-shift.

- **Large Renewable Capacity Expansion:** India has announced a target to achieve 15 percent share[32] of renewable energy (in kWh terms) by 2020. This means substantial expansion of renewable capacity, which would need to be integrated into the national grid[33]. India also plans to operate as a single national grid by 2015, which would require much stronger grid discipline. These two drivers together could create a large demand for use of energy storage technologies.

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[30] Generic list of applications of energy storage, and ancillary services, is given in Annex-3.

[31] Source: Central Electricity Authority (CEA).

[32] Current share in 2012 about 5 percent. Source: Ministry of New & Renewable Energy.

[33] Expansion of renewable capacity expected, from current capacity of 29.8 GW to 120 GW by 2022 and about 300 GW+ by 2030, as outlined in various plans and expert assessments.

The key issue of integrating large renewable capacity is *grid flexibility*. Flexibility can be enhanced by energy storage, flexible generation capacity (e.g. super critical thermal power plants or gas based power plants) and demand side response.

The Power Grid Corporation of India Ltd. (PGCIL), which is the national grid company, estimates that it would need 20 GW of flexible generation like super critical thermal generators, as well as energy storage solutions, to take care of peak load requirements by FY 2016-17[34]. PGCIL is also planning development of Regional Energy Management centers with advanced forecasting tools to reduce the need to do forecasting at individual renewable energy farm levels. Significant investments are planned for building dedicated green transmission corridors for large renewable energy zones. PGCIL has identified storage requirements for RE integration.

- **Constrained Transmission:** States such as Tamil Nadu which have a high level of renewable energy generation (about 15 percent during FY 2011-12[35]) and very high connected renewable energy capacity, about 44 percent[36] of total generation capacity, suffer from transmission capacity constraints. This prevents evacuation of renewable energy during the peak season. With significant solar capacity addition expected in coming years, the grid will continue to face severe transmission capacity constraints and stability issues.

  Wind generators already face periods of 'back-down' during peak generation season (May to September) in Tamil Nadu, despite large scale shortage of power in the state.[37] During such periods wind generators are usually asked to reduce generation as the grid does not have sufficient capacity to evacuate all of the generated energy. Similar evacuation problems are also faced in other states such as Rajasthan.

  This means that during peak generation season, a significant portion of power (between 30 and 50 percent in many cases) may not get evacuated, resulting in loss to the system as well as the generators. While transmission capacity is being expanded to take care of evacuation needs, expansion has been slow. Moreover, an increase in renewable energy mix is likely to put further pressure on the system. Energy storage can be used as an option for reducing 'back-down' of generation, and also reducing or postponing transmission capacity expansion.

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[34] Transmission Plan for Renewables Capacity Addition in 12th Plan. http://www.powergridindia.com/_layouts/PowerGrid/WriteReadData/file/ourBusiness/SmartGrid/Vol_1.pdf.

[35] Source: Energy Department, Gov. of Tamil Nadu. File available at : http://mnre.gov.in/file-manager/UserFiles/presentation-01082012/Presentation%20on%20Wind%20Power%20Scenario%20in%20Tamil%20Nadu%20by%20Shri%20Rajeev%20Ranjan,%20Chairman,%20TNEB.pdf.

[36] Source: Tamil Nadu Energy Development Authority. Website: http://www.teda.in/.

[37] Discussions with industry, during Oct to Dec 2012, indicated 12-18 hours of power shortage in most industrial areas in the state.

- **Forecasting and Scheduling Requirements of New Grid Code:** India is implementing the Indian Electricity Grid Code[38], which mandates forecasting and scheduling for renewable energy generators. Although the current accuracy levels allowed are ± 30 percent of the forecast (and the generators are allowed to adjust the forecast up to three hours before the injection time), the bands are likely to be tightened in the future.

  This is leading to increased interest by the generators in energy storage solutions, because with storage, it would be possible to meet the forecasting requirements and avoid payment of Unscheduled Interchange (UI) charges. The costs can be significantly reduced if generators were to come together, and implement a forecasting system as a group, prior to connecting with an evacuation substation. This will give them the benefit of reduced variability at an aggregated level and consequently lead to better accuracy of forecasting and lower investment in storage.

- **Significant Energy Access Needs:** A large number of Indian villages, though technically grid connected[39], have very little access to power. India had a 2010 target for the provision of universal energy access, which the government now plans to meet by 2017. The Ministry of New and Renewable Energy (MNRE) is keen that renewable energy options be used as much as possible for meeting power needs in rural areas, as these are remote and can be better served using local generation. A challenge has been posed, however, by the need to time shift widely available renewable energy resource such as solar, used frequently for developing micro-grids. The use of energy storage technologies would support the use of solar micro grids.

- **Need for Local Energy Management Systems (EMS):** Industrial zones, commercial complexes and large residential complexes in most urban areas suffer from power shortages and bad quality of power. With mandated renewable power obligations, especially for large users[40], the need to effectively integrate on-site renewable generation with renewable power procurement has increased. EMS, with the help of energy storage technologies, can help industrial zones, commercial complexes and large residential complexes, using renewable energy and the grid more efficiently by providing the following key functions:

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[38] The grid code came into force from 2010. For wind projects, the grid code was expected to be implemented from January 1, 2012, but due to technical problems and lack of preparedness of SLDCs, the grid code for wind projects are not yet implemented.

[39] 95 percent of villages in India are technically grid connected, though with low and infrequent access to power due to power shortage.

[40] A case in point is the recent renewable policy in Tamil Nadu (Oct 2012) which obligates most High Tension connection users including industries, commercial establishments, colleges and residential schools http://www.teda.in/pdf/tamilnadu_solar_energy_policy_2012.pdf.

    - Scheduling power procurement from short-term markets or through bilateral arrangements from generators at aggregated level, after accounting for energy from on-site renewable energy solutions and generation using diesel or gas. The goal would be to ensure 24x7 power availability.
    - Having adequate energy storage capacity which can be used for balancing micro-grid requirements and ensuring power quality regulation.
    - Ensuring access to adequate renewable energy (through on-site and captive / group captive generation modes) to meet Renewable Power Obligations for the group of users.

- **Building Efficiency Standards:** India is launching a number of initiatives to improve energy efficiency and the use of renewable energies in buildings. Since rapid urbanization is likely to accelerate, it will be possible to design new buildings with effective and efficient on-site thermal and electrical energy storage solutions.

Based on these considerations, PACE-D TA program have identified opportunities in three areas, and done a detailed analysis and suggested possible business models for implementation.

- RE Integration into the grid
- Rural Micro grids
- Energy Management Systems for large user groups (Commercial, Industrial, and Residential)

3.1 RE INTEGRATION INTO THE GRID

3.1.1 Wind Integration into the Grid

States like Tamil Nadu face transmission capacity constraints. Wind generators are asked to back down when evacuation capacity is short. States like Tamil Nadu, Karnataka, Rajasthan, and Gujarat will need assistance in balancing and integrating the huge renewable energy capacity likely to come up in the future. Energy storage technologies can play an effective role in wind farm integration by supporting the following functions, in combination with special design of wind generators, power electronics, etc.:

- Active power control
    - o Load balancing for transmission and distribution capacity
    - o Improved forecasting and scheduling of power
- Reactive power control
- Voltage and frequency control

- Management of flickers and harmonics
- Fault ride-through capability

Energy storage could be deployed either in individual generating units (each wind turbine) or for aggregated generation at an evacuation sub-station level.

PACE-D TA program have modeled the 'Value of Active Power Control' so as to meet transmission capacity constraints[41]:

- Reducing loss of power generation due to 'backing down' instructions from the grid in peak season. By storing energy either at the wind farm level or the sub-station level during peak generation and releasing it back during lean periods in any one day, the loss of energy due to inadequate transmission capacity can be reduced. In some substations this can allow transmission operators to postpone transmission capacity addition till a minimum economic need is reached. The energy storage option would result in value to the consumers, wind generators and utilities like the Tamil Nadu Generation and Distribution Corporation (TANGEDCO).
- The energy storage option will also support better forecasting and scheduling as per the proposed grid code, minimizing unscheduled UI charges for the generators.

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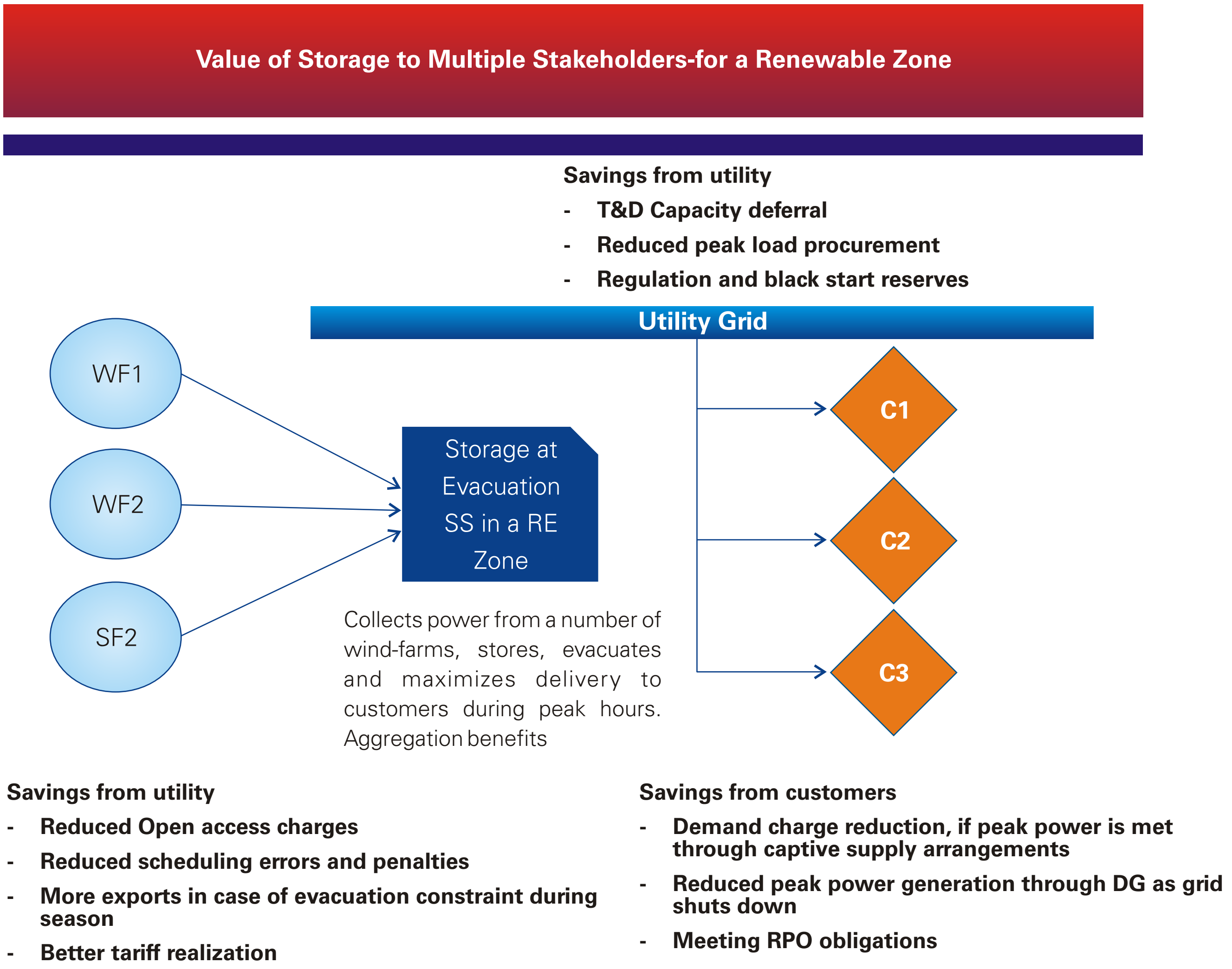
[41] Analysis presented in section of the chapter on Business Case.

Figure 9: Value of Storage for Stakeholders in a Renewable Zone



Value of Storage to Multiple Stakeholders-for a Renewable Zone

Savings from utility

- **T&D Capacity deferral**
- **Reduced peak load procurement**
- **Regulation and black start reserves**

Collects power from a number of wind-farms, stores, evacuates and maximizes delivery to customers during peak hours. Aggregation benefits

Savings from utility

- **Reduced Open access charges**
- **Reduced scheduling errors and penalties**
- **More exports in case of evacuation constraint during season**
- **Better tariff realization**

Savings from customers

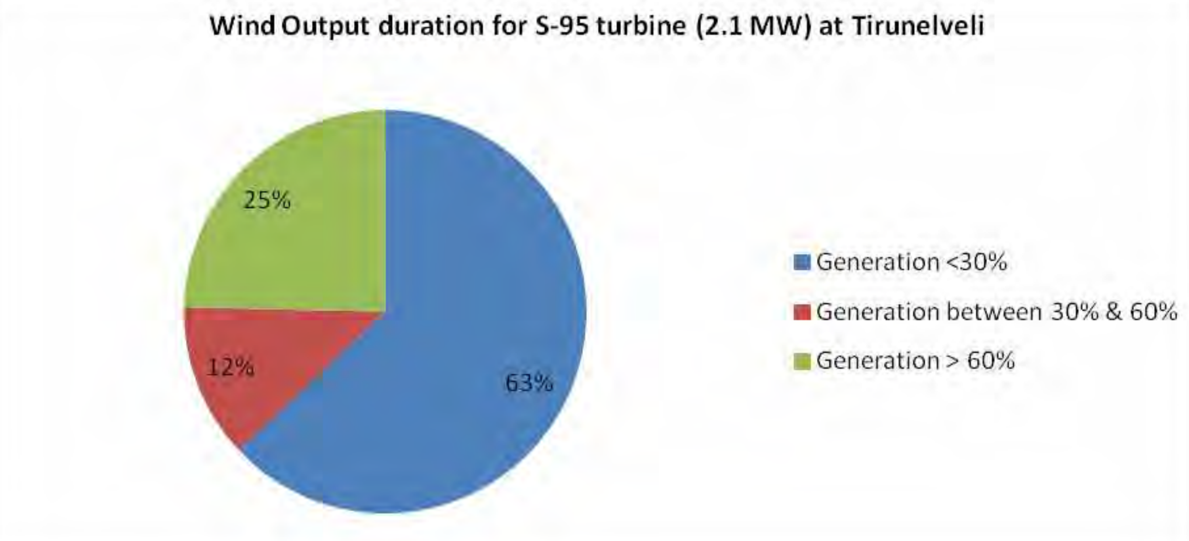
- **Demand charge reduction, if peak power is met through captive supply arrangements**
- **Reduced peak power generation through DG as grid shuts down**
- **Meeting RPO obligations**

The following text boxes showcase the case studies where energy storage supports integration of renewable energy into the grid.

Case Study 1: Saving the Transmission Capacity Required by Wind Generators

Based on three years data collected at a site in Tirunelveli, Tamil Nadu, WindForce Management undertook an analysis of the electricity generation pattern of an S-95 turbine of Suzlon (2.1 MW). The focus of the analysis was on outlining whether the constrained transmission capacities would need to be augmented or could be addressed more economically by using energy storage. Figure 10 below highlights the generation of the plant vis-à-vis its installed capacity, since this would have a direct bearing on transmission capacity requirements.

Figure 10: Distribution of Generation from S-95 Turbine at Tirunelveli



The analysis of the above figure highlights the following,

- Generation at above 60 percent of peak capacity takes place only 25 percent of the time when the turbine is generating power
- Generation at above 30 percent of peak capacity takes place only 37 percent of the time

This indicates potential savings of transmission capacity by using energy storage. It is expected that if aggregation of energy outputs is made across a number of wind turbines, the savings in transmission capacity can be further increased between 10 and 15 percent.

This has been modeled in detail into an economic analysis of storage for wind farms, which has been presented in the section on Business Case.

Case Study 2: Energy Storage for Grid Frequency Regulation Application

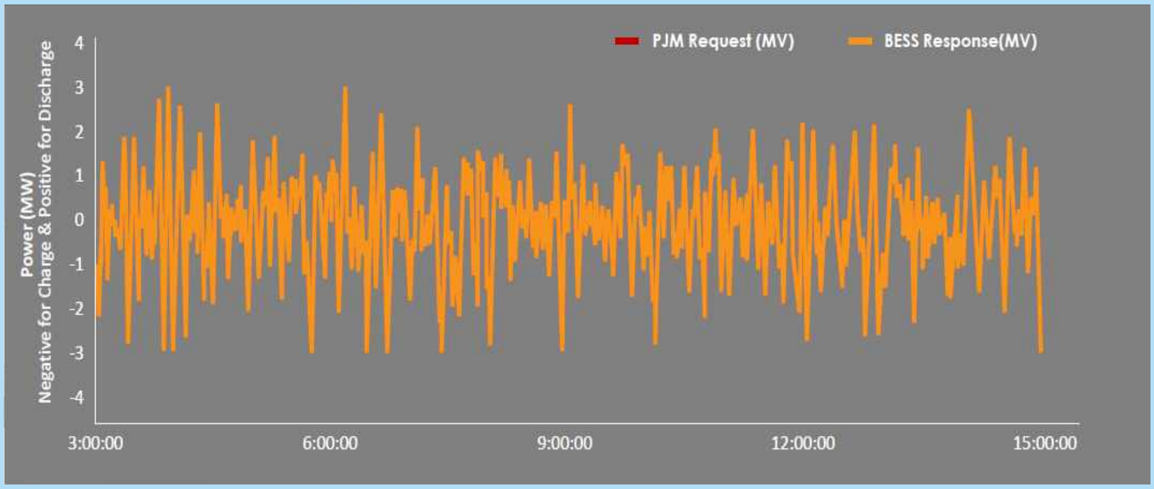
Ecoult, in collaboration with Pennsylvania-Jersey-Maryland Interconnection (PJM network), has developed an energy storage system to demonstrate the performance of the Ultra battery for frequency regulation of the grid. The project was commissioned on June 15, 2012. PJM is the largest Regional Transmission Organization/Independent System Operator in the U.S.

A 4 MW capacity was connected to the PJM network for the twin purposes of frequency regulation and load management. The system provides:

1. 3 MW capacity for continuous frequency regulation services
2. 1 MW capacity (1-4 hour) for load management services to the local utility during peak periods

Figure 11 highlights the response of the Ultra battery to the grid demand for frequency regulation.

Figure 11: Response of the Ultra Battery to the Frequency Fluctuation of the Grid



As illustrated in the above figure, the ultra-battery based energy storage system was able to track the requirements of the grid with a response time of just a few seconds and with high levels of accuracy.

The system was developed at a cost of about USD 5 million, out of which the U.S. DOE provided a support of USD 2 million. The grid pays the system a fee of USD 2 million per annum, based on committed performance.

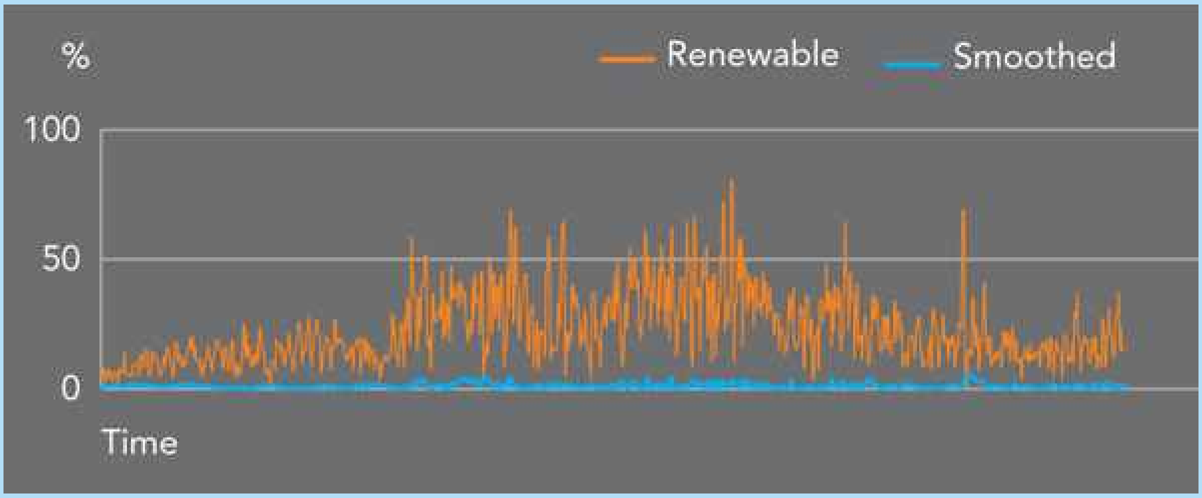
As can be seen from the above demonstration, energy storage technologies can provide a creditable and viable solution for continuous frequency regulation for grids.

Source: Ecoult Pty Ltd, Australia; Department of Energy, Government of U.S.

Case Study 3: Energy Storage Solution for Smoothening of Wind Farm Output

The Commonwealth Scientific and Industrial Research Organization (CSIRO) and Ecoult have implemented a frequency and energy smoothening system at Hampton Wind Farm (near Sydney, Australia) using the Ultra battery and advanced algorithms. Figure 12 illustrates the frequency smoothening provided by the Ultra-battery based solar system.

Figure 12: Frequency Smoothening by Ultra Battery®

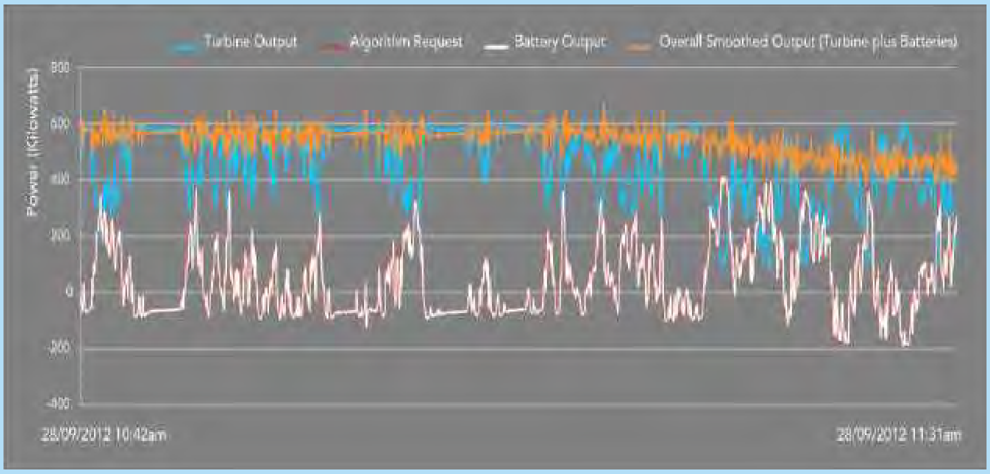


Source: Ecoult Pty Ltd., Australia

Figure 13 illustrates the variation in wind energy pumped into grid before and after using the Ultra Battery.

Figure 13: Smoothening of Output of a Wind Farm to Export to Grid

Smoothing of Wind Power and Ramp Rate Reduction : (Hampton Wind Farm Example)



Through this project, Ecoult was able to demonstrate that the Ultra-battery technology has the ability to reduce ramp rate to one-tenth of the original with energy storage capacity of one-tenth size of the wind project.

Source: Ecoult Pty Ltd., Australia

Based on the results of the case studies elaborated above,, the following inferences can be drawn regarding the value of storage for grid integration of renewables:

- With energy storage, transmission capacity can be saved
- With energy storage frequency regulation can be provided; at wind farm level regulation can be achieved with storage capacity size of less than one-tenth the size of a wind farm

Besides these three cases, a number of other wind projects across the globe have used energy storage technologies for improved revenue generation and better balancing:

- Primus Power is implementing a 25 MW/75 MWh wind farm energy storage system for a wind farm of 75 MW rated capacity at Modesto Irrigation District in California[42]. This is going to replace a flex plant, based on gas, costing USD 78 million, required to support the variable generation of the wind farm. The project will use Zinc Chlorine Redox flow batteries.

- Duke Energy, together with Xtreme Power, is implementing a 36 MW/40 min storage solution (expected to cost USD 44 million[43]) for electricity generated at its 153 MW Notrees Windpower Project in west Texas. The system aims to benefit from *price arbitrage as well as frequency regulation*. The system will use Xtreme Power Cell technology, which is 12 V, 1 kWh, dry cell battery technology, using bipolar plates made of a mix of copper, lead and tellurium, providing a large surface area at nano scale and reduced internal resistance. The batteries will have 98 percent efficiency (due to low internal resistance) and will be able to provide a life of 1,000 cycles at 100 percent change in State of Charge (SOC) to 500,000 cycles at one percent change in SOC.

- Sorne Wind Farm (38 MW), Buncrana, Donegal, Ireland has implemented a storage solution using Vanadium Redox Batteries. VRB Power Systems Inc. have been contracted to supply a 2 MW system with 12 MWh of storage (costing about EUR 6 million). Prices for generation in Ireland is about EUR 86 MWh for conventional power, whilst for wind the price is about EUR 57 MWh. This difference (wind being on the lower side) reflects the back-up potential required for intermittent energy, the cost borne by utility providers to keep reserve power on standby or to purchase on the spot power, both of which are expensive options. The system at Sorne will provide 3 MW of pulse power for 10 minute periods every hour in order to combat short term volatility. The grid pays for the reserve capacity[44].

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[42] Project supported by the U.S. DOE. Project details available at http://www.energystorageexchange.org/projects/9.

[43] Also supported by the U.S. DOE. Project details available at http://www.energystorageexchange.org/projects/11.

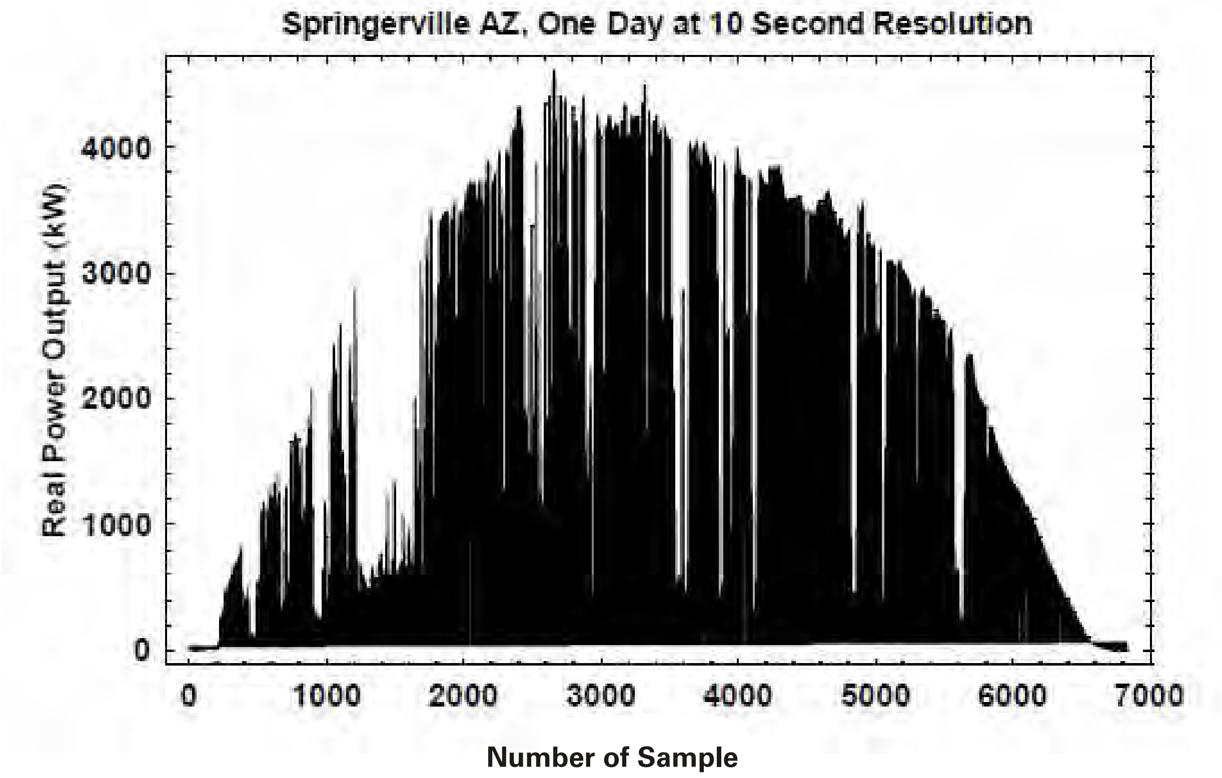
[44] Source: http://www.prnewswire.co.uk/news-releases/size-of-vrb-ess-for-sorne-hill-increased-to-2mw-x-6hr-and-completion-of-sustainable-energy-ireland--tapbury-feasibility-study-155663045.html.

- A Na-S battery system (34 MW sodium Na-S system), manufactured by a consortium of Tokyo Electric Power Co. (TEPCO) and NGK Insulators (NGK), has been set up with a 51 MW Japan Wind Development project. The project is located at Futamata in the Aomori Prefecture (May 2008)[45].

3.1.2 Solar PV Integration into Grid

Megawatt-scale, utility connected solar photovoltaic installations will need energy storage because of potential voltage sags in weak evacuation grids, and in rapid generation change due to cloud effects (as highlighted in Figure 14). These effects can be more severe than wind ramps as they are much faster.

Figure 14: Variation in Energy Generation from Solar Plant[46]



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[45] Source: Clean Energy Action Project. Available at http://www.cleanenergyactionproject.com/CleanEnergyActionProject/CS.Rokkasho-Futamata_Wind_Farm___Energy_Storage_Case_Study.html.

[46] Source: Electricity Energy Storage Technology Options, Electric Power Research Institute.

Such swings have posed problems for utilities. These problems can be sorted out by using high power (between 500 and 1,000 kW), low-energy storage systems (between 15 and 60 minutes), capable of fast response. These systems may be implemented at each solar farm or at the evacuation sub-station (higher benefits of aggregation) and can be developed using appropriate technologies such as advanced lead acid batteries, lithium-ion batteries, and super-capacitors. Such storage capacities would support capability for output smoothing, voltage support and fault ride through. Grid-connected as well as off-grid solar systems also require a time-shift, as the peak demand occurs in the evenings compared to peak generation in the noon.

For distributed, grid connected, roof top solar capacities, storage can play an important role by islanding at the time of grid shutdowns or instability and allowing the generation to continue. Along with power electronics and smart meters, it can provide two way active/reactive power control on inputs/off take and therefore contribute to grid stability.

A joint research program has been launched between the U.S. and India, involving the Solar Energy Research Institute for India and U.S. (SERIIUS) with participation of Indian Institute of Science (IISc) and NREL. The key objectives of this program include quantification of the grid impact of various types of solar generators (e.g. utility scale plants, distributed on-site generators, etc), and an analysis of the storage options, including conversion to hydrogen. Figure 15 showcases the case study where energy storage has been built for integration of solar PV with the utility grid.

Case Study 4: Energy Storage Solution for Smoothening and Shifting of Solar Output

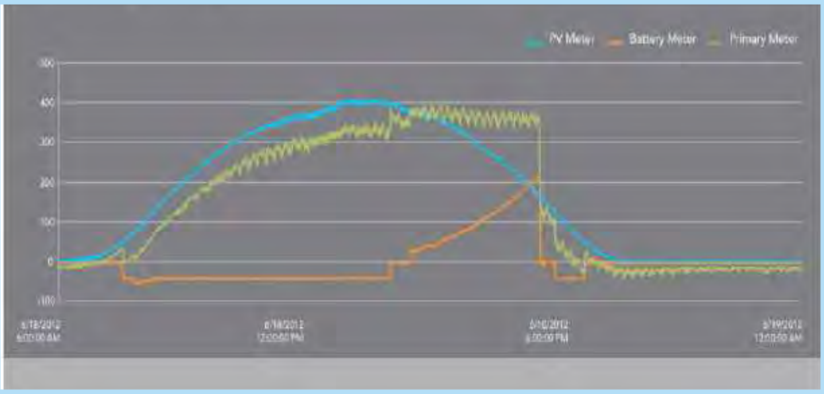
Ecoult in collaboration with Public Service Company of New Mexico (PNM) developed an energy storage system to demonstrate the performance of Ultra-battery for energy smoothening and shifting of grid exporting solar power plant. The project was commissioned in September 2011.

For demonstration, a 500 kWp capacity grid exporting solar plant is installed. Energy storage capacity is designed to perform simultaneous energy smoothening and peak shifting. Energy storage capacity includes

1. 0.5 MW smoothing battery utilizing UltraBatteries
2. 0.25 MW/0.99 MWh peak shifting battery utilizing advanced lead acid batteries

Figure 15 showcases solar energy generation, battery response and energy exported to grid.

Figure 15: Smoothening and Shifting of Solar Output



As illustrated in the figure, the energy storage system was able to perform energy smoothening and peak shifting simultaneously. The energy storage system reduced the impact of radiation fluctuation and smoothened output to match demand.

As can be seen from the above demonstration, energy storage technologies can provide a creditable and viable solution for energy smoothening and peak shifting

Source: Ecoult Pty Ltd., Australia

3.1.3 Potential Demand for Storage for Wind and Solar Integration

The IESA recently estimated the potential market size for grid connected wind and solar farm integration at 2,200 MW by 2020[47]. Pilots which are being carried out in Europe, U.S. and Japan indicate storage capaity between 5 and 15 percent of RE farm capacity with the lower levels being required for just voltage/frequency regulation purposes and higher capacity for time-shiift needs. If capacity is expcted to grow from the current 20 GW to 55 GW for solar and wind by 2020 and if farms end up using 5 percent storage for incremental capacity, a potential of 2,200 MW is indicated. The use of storage at solar and wind farms will, however, be driven by stricter regulation on power quality, output, forecasting, and such measures will take time. Users and policymakers will also need operating performance from demonstration projects to asess the value of storage. In the light of this, we feel that actual demand by 2020 may be lower.

3.2 RURAL MICROGRIDS

Over 43 percent of rural households do not have access to electricity. Providing electricity to these households through grid extension would need a huge investment both in terms of generation and transmission capacities. Moreover, grid extension would take a very long to connect these

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[47] June 2013 IESA Market Assessment report.

households. Decentralized and distributed generation (DDG) using renewable energy is a better alternative to grid extension considering the fact that lesser time is required for deployment and lesser dependence on conventional sources of energy. Acknowledging the importance of DDG, the GOI has launched village electrification programs to encourage electrifying rural households through DDG schemes. The GOI is also encouraging private developers to develop and invest in village electrification through DDG, using renewable energy. Village electrification programs are implemented predominantly using solar PV because of the availability of solar radiation across the geographies, operational and maintenance simplicity, and suitability for all size of loads. These programs are implemented in the following possible modes:

- **Individual Energy Units** using solar photovoltaic along with storage (for residences, community buildings, pumps, etc.) with capacities of 50 W to a few kW. These are often designed as DC to DC systems.

- **Micro-grids** designed to operate with a variety of energy sources such as wind, biomass, solar (photovoltaic, thermal), waste to energy, etc. and combining both AC and DC types of loads and generation. These can be integrated with the main grid, but can also operate in an island mode when needed, and have the capability for local optimization and control.

Individual energy units are for standalone applications and are simple. However, individual energy units suffer from problems related to maintenance and also do not support productive loads.

Micro-grids cater for a variety of loads from residential, agricultural, community infrastructure (such as schools, health centers, information centers, etc.) and commercial and industrial loads. They are larger (between 50 and 100 kW for a village) and can be run by technically qualified staff which can provide desired operation and maintenance reliability. Micro grids also have ease of scaling, optimized design, improved financing, and the ability to provide a more assured energy supply (as both consumption and supply are averaged out over a number of sources). With power management systems coupled with energy storage capacity, renewable energy can be effectively utilized and micro grids can also be integrated with the grid.

Micro grids are critical for the future of village economics because they can serve the productive loads and can increase in scale as demand grows. Government attention is therefore shifting from just meeting basic rural needs through standalone systems, to micro grids to accelerate rural businesses and governance. A micro grid implemented by the ZBB Energy Corporation (ZBB)[48], using ZnBr flow batteries is depicted in Figure 16.

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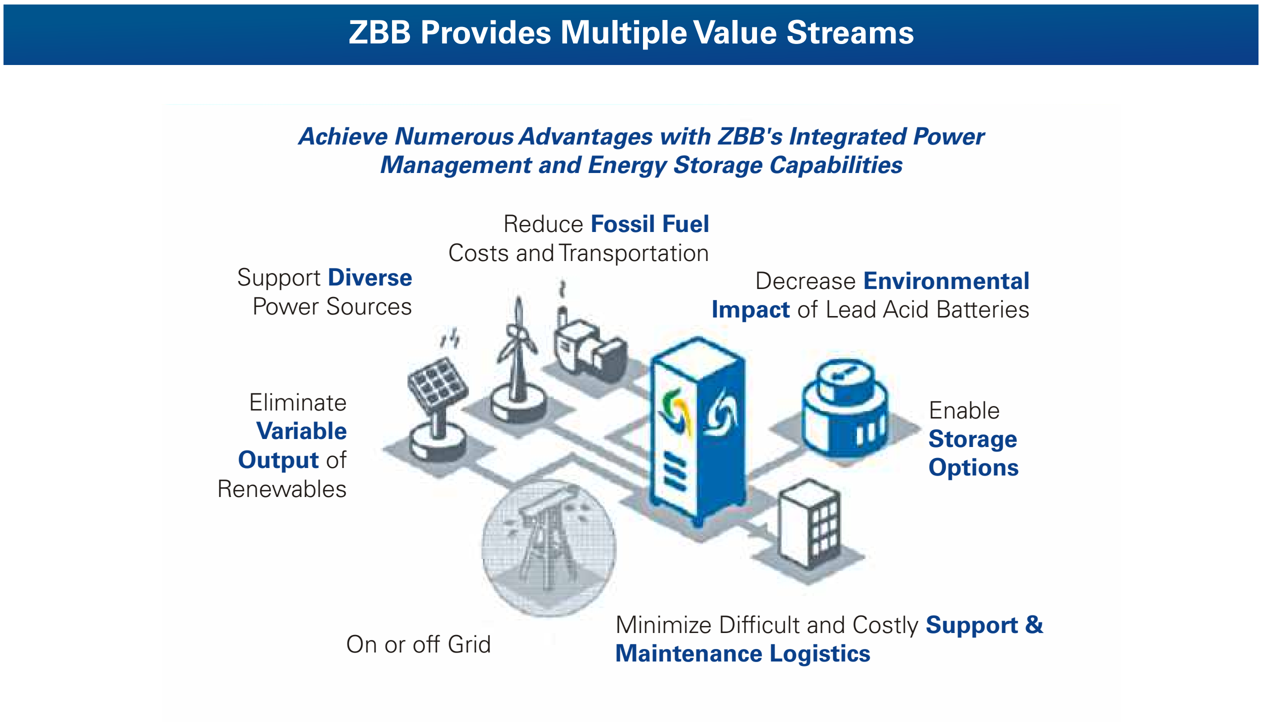
[48] Information provided by the ZBB Corporation.

As shown in Figure 16, the grid is designed to provide flexible use of energy resources, AC and DC types of demand and generation. It takes care of demand changes and matches supply. It is also designed to integrate in future with the main grid. Batteries cost just between 15 and 20 percent of total capital cost. They can be replaced every three to four years, with the rest of the power electronics designed to last over 20 years.

Figure 16: Micro Grid Implemented by the ZBB Energy Corporation



VRLA batteries are the most common storage technology being used in India. However, many solar PV systems backed by Lead Acid batteries require replacement within 1.5 years (500 cycles)[49]. Now, with technology advancements, energy storage technologies with a longer life and higher efficiencies are available (improved lithium-ion batteries, redox flow batteries, etc.).

The IESA estimates a potential storage demand of about 2600 MW for rural micro-grids including agricultural needs[50]. A rural micro-grid is an urgent need in India, driven by the following forces:

- India had set a target of 100 percent access by 2012, which has been delayed despite 95 percent achievement of the target on grid extension. This is due to the problems of power shortage and poor grid conditions at the tail end. The revised target is 2017.

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[49] As per discussions with off-grid users during an IESA event.

[50] June 2013 Market Assessment report of IESA.

- Regulators have pushed for one kWh per household/day as the availability target for any household[51]. With 80 million households not electrified[52], this means a storage capacity of 80 GWh (over 15 GW), just for residential loads[53].
- Village micro-grids need storage - they cannot operate without it.

Hence if a cost effective storage solution can be developed with improved life, cycle efficiency and costs lower than USD 0.1 per kWh/cycle, this segment can take off much faster.

3.3 ENERGY MANAGEMENT SYSTEMS FOR LARGE USER GROUPS

Residential, commercial or industrial complexes can have significant on-site generation, using variety of resources such as solar PV, solar thermal, diesel, gas, etc. These complexes need to manage and balance their energy needs, from on-site generation as well as procurement though grid (through independent procurement, bilateral deals or from exchanges, and balance from the distribution company). In order to manage and balance the energy needs and generation, these complexes would need Energy Management Systems (EMS), coupled with shared energy storage.

EMS can offer the following benefits to users:

- 24 x 7 power access
- High quality of power; reducing costs of process equipment degradation resulting from frequency variations
- Better integration of on-site renewables
- Reduced use of diesel and lower future energy cost inflation
- Meeting renewable power obligations
- Lower cost of grid power (composite of variable cost through improved procurement, demand charges, power factor penalties, etc.)

Investments in such systems including on-site renewable energy capacity could be made by third party investors.

Thermal energy storage systems can be designed and integrated for buildings (residential or commercial complexes) for meeting thermal energy requirements, especially air-conditioning.

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[51] EVI analysis with efficient appliances indicate that a fan, lights, TV and mobile charging loads can be ensured by the availability of 50 percent of the 1 kWh/day/household target.

[52] Assuming that those who have access to electricity are able to get the minimum of 1 kWh/day - which may not be correct.

[53] Assuming one day's storage, which may not be sufficient in villages.

Solar power can be stored using thermal energy storage technologies and be used for heating, cooling or process steam needs. The following are a few examples of thermal energy storage technologies for buildings

- Ice based storage systems are being used in more than 3,000 buildings worldwide across more than 35 countries. Ice can be created using vapor absorption systems and heat from solar collectors. It is then used to cool air during peak hours in the evenings, reducing expensive peak power and helping shave the peak demand. This is especially useful for commercial buildings such as malls, hospitals, cinema halls, hotels, etc.

  Underground storage of heat can be achieved by using boreholes or heated water or steam in accumulators, which is then used to provide the heating during winters. Worldwide more than 300,000 buildings have used such systems and Sweden has good experience in implementing such systems.

The European Solar Thermal Technology Platform (ESTTP)[54] is focusing closely on developing solar heating and cooling applications using such concepts. Such applications can provide significant economic benefit and target almost 50 percent of global energy needs. The ESTTP goal is to create an Active Solar Building standard to serve 100 percent of thermal needs of the building using solar thermal technologies. Similar standards can be developed in India.

The IESA estimates that large users could provide a potential demand for storage equivalent to 3,600 MW by 2020[55]. This segment needs high quality power with greater reliability. Storage duration may be shorter (between one and two hours) to protect against periods of grid shutdown or instability.

The Indian Smart Grid Roadmap (ISGM) sets out a 2014 – 2017 target for policies which will suit 'prosumers'[56] and promote two way interaction of load and grid such as building to grid (B2G), vehicle to grid (V2G)[57], roof-top generation, smart meters, net metering, dynamic time of day (TOD) tariffs and demand response, EV charging, etc. Such policies will pave the way for accelerated adoption of storage, especially if storage costs fall below USD 0.05 per kWh/cycle.

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[54] The European Solar Thermal Technology Platform, a European Commission initiative, brings together 600 stakeholders from the biomass, geothermal and solar thermal sector - including the related industries - to define a common strategy for increasing the use of renewable energy technologies for heating and cooling.

[55] The break down is Townships (510 MW), Shopping Malls (520 MW), Hospitals (870 MW), Hotels (420 MW), SEZs (560 MW) and other smaller units. Potential for solar roof-top application in these segments is close to 19000 MW at present and growing. Solar roof-top generation needs electrical storage and in future will integrate thermal storage as well.

[56] "Prosumers" mean consumers with the capacity to supply power using on-site captive generators and storage capacities.

[57] B2G: building to grid; V2G: vehicle to grid.

4 BUSINESS CASE ANALYSIS - INDIAN CONTEXT

For deployment and to chart out a clear roadmap for the energy storage sector, 'economic value' of energy storage needs to be established. To establish the economic value, there is a need to: (i) identify appropriate and specific end use applications; (ii) develop cost and performance simulation models for these applications; and (iii) based on the results, design and deploy actual demonstration projects to gather actual performance data on the ground.

To get some direction on the relative value of various parameters and future research, simulation was carried out for three important end use applications. A summary of the simulation results are presented below.

4.1 TRANSMISSION CONSTRAINED WIND CAPACITIES

Context

Wind energy projects in the state of Tamil Nadu (which is one of the major hubs of wind energy development in India) have been facing two major challenges, both of which are associated with the evacuation and transmission of power from high concentration wind resource areas:

- **Constrained transmission capacity**: Wind generators are being asked to back down during peak generation season by TANGEDCO (the state transmission utility) due to constraints in the transmission capacity. This is most prevalent during the monsoon season which is the peak season for wind energy generation. Generators end up with a revenue loss.

- **Underutilization of transmission capacity**: The transmission capacity available in most high wind resource areas is grossly under-utilized. For three-fourths of the year, wind generators operate below 60 percent of their capacity. Given that transmission capacity is usually linkedto peak capacity, the remaining 40 percent of the transmission capacity is utilized for only one-fourth of the year.

To address the problems of constrained transmission capacity for the evacuation of wind power and the deployment of wind energy in the state of Tamil Nadu, additional investments in transmission and evacuation are required. However additional transmission capacity leads to increased underutilization. This sub-optimal development of transmission capacity can be avoided through the deployment of energy storage solutions. In addition to deferring the need for transmission capacity enhancements, the use of energy storage capacity can improve the scheduling of power exported to the grid, leading to better grid management and a reduction in penalties/UI charges.

A hypothetical scenario was developed and analyzed to understand the gains associated with the deployment of energy storage solutions (the energy storage capacity was equivalent to 30 percent of the generation capacity of the wind turbine generator at a study site in Tirunelveli district, Tamil Nadu). More specifically, the simulation model studied the following:

- Increases in generation and revenue from the deployment of energy storage solutions.
- Savings from deferral of investment in transmission capacity enhancement.
- Costs incurred from penalties avoided through better scheduling of wind generation and transmission.

Assumptions

The simulation model used assumptions based on real world data. The key assumptions were:

- **Wind generation**: Wind generation from S-95 model wind turbines[58] located in the Tirunelveli district in the state of Tamil Nadu was analyzed and modeled over a one year period[59].
- **Transmission capacity**: The available transmission capacity at Tirunelveli faces up to a 30 percent capacity bottleneck during the high wind season[60] and so to address this capacity gap, a storage capacity of similar power rating (30 percent, 0.63 MW) was proposed for storage design, with a four hour storage.
- **Energy storage technology**: Sodium-sulfur batteries[61] were chosen as the energy storage technology. The analysis was undertaken for the life of the wind turbine (i.e. for 20 years). The cost of storage was assumed at INR 10,500 per kWh (USD 166.4 per kWh). The life of sodium-sulfur batteries was assumed to be 4,000 cycles with a cycle efficiency of 90 percent.
- **Cost of supply**: It was assumed that the wind power generated would be supplied to commercial and/or industrial users connected to high tension voltage lines with net realization of INR 5.2 per kWh (U.S. cents 8.2 per kWh)[62] (escalating at 5 percent annually). It was also assumed that the generator also receives renewable energy certificates (REC), valued at INR 1.5 per kWh (U.S. cents 2.4 per kWh) for the power generated and sold.
- **Other savings**: To model the savings from investments in enhancing transmission capacity,

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[58] S-95 model wind turbine is a 2.1 MW wind turbine manufactured by Suzlon Energy Ltd.

[59] Wind data recorded at 10 minutes time intervals was used for the purpose.

[60] High wind season is between May and September.

[61] Sodium-sulfur battery technology has been in usage in Japan and U.S.in MW scale for wind farms.

[62] Currently tariff of INR 5.7 per kWh (US cents 9.0 per kWh) is applicable for these consumers in Tamil Nadu.

applicable state open access transmission charges[63] were taken as a proxy. The current open access charge, INR 4,692 per MW/day (USD 74.4 per MW/day), was assumed to represent the capital cost of the transmission network[64]. It was also assumed that with storage, better scheduling of power would be undertaken and a saving of about 0.5 percent of the tariff (INR 0.03 per kWh (U.S. cent 0.05 per kWh)) would be made from reduction in scheduling errors.

Results

The results the simulation model provided the following key insights:

- The introduction of energy storage technologies led to a net savings to the wind energy generator. 56 percent of the savings were due to the increase in power exports, 39 percent were from T&D capacity deferment and 5 percent was related to grid scheduling.
- The net present value of introducing the energy storage system is INR 16 million (USD 0.25 million), while the cost of the energy storage system was expected to be around INR 67 million (USD 1.1 million). The benefits covered only around 24 percent of the capital cost of the energy storage system.
- Energy storage solutions would become commercially viable for similar applications once their capital costs drop to INR1,250 per kWh (USD19.8 per kWh) or below.

Conclusion

At their current cost levels, it is not economical to invest in energy storage for this end use applications. For storage technologies to become viable for this end use application, the capital cost of the storage option has to come down from the current cost of INR 10,500 per kWh (USD 166.4 per kWh) to INR1,250 per kWh (USD19.8 per kWh), which is a reduction of about 80 percent.

However there is a huge focus on research to reduce the cost of storage internationally. For example, the Advanced Research Projects Agency-Energy (ARPA-E) has provided grants for projects which have the potential to reduce the cost of energy storage technologies by a factor of five, and experts believe it is possible to achieve this within a time frame of five years. Thus it is expected that similar models shall have much greater viability as the cost of storage decreases over time.

4.2 RURAL MICRO GRIDS USING SOLAR ENERGY

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[63] Transmission charge is determined by SERCs taking into account the capital costs and operating costs of the transmission infrastructure.

[64] This may not be accurate and needs to be properly estimated. EPRI report 'Electricity Storage and Technology Options' estimates these costs to be between USD 65 per kW per year and USD 390 per kW per year. For areas, where T&D deferral cost is high, this application may be viable even at today's storage costs.

Context

Stand-alone energy generation and distribution systems such as renewable energy based micro-grids have a huge potential for powering stand alone, off grid applications, especially for rural communities, remote commercial and industrial consumers and for meeting contingencies for breakdown of grid based supply. The default alternative for stand-alone applications has been diesel, which has a very high economic, financial and environmental cost. Therefore there is an increasing focus on renewable energy sources as the main source of electricity for stand-alone micro-grid going forward. For these applications (micro-grids), the cost of energy storage becomes all the more critical as the cost of the energy storage systems adds to the cost of an already expensive solar power system. In order to understand the effect of energy storage technologies on the cost of delivered power to the households on a stand-alone basis (through a micro-grid), an analysis was undertaken using a number of alternate energy storage technologies.

Assumptions

The simulation model used assumptions based on real world data. The key assumptions were:

- Micro-grid size and load: The simulation was undertaken for a typical village of 200 households. Each household had a connected load which consisted of 2 LED bulbs (with a load of 7 W each, operating for four hours per day), a fan (load of 40 W, operating for 10 hours per day) and a socket for other AC loads (with a total energy requirement of 40 Wh (running for one hour per day)).
- Energy storage technology: The following assumptions were made for the different energy storage technologies which could be used for the delivery of energy services when coupled with the solar plant and the distribution system for the micro-grid.

Table 6: Cost Assumptions of Various Storage Technologies for Rural Mini-Grids

	Units	VRLA Battery	Li-Ion	Vanadium Redox	Ultra Battery
Depth of Discharge (DoD)	Percentage	50	90	90	90
Battery Efficiency	Percentage	80	90	90	94
Cost of storage	INR/kWh (USD/kWh)	6,050 (95.9)	22,000 (358.7)	16,500 (261.5)	27,500 (435.8)
Life cycles	Number	500	2,000	10,000	10,000
Life	Years	5	27	27	27
Capacity of solar plant	kWp	36	32	32	31
Cost of solar plant	INR/Wp (USD /Wp)	182 (2.9)	235 (3.7)	211 (3.3)	261 (4.1)

Result

The estimated cost of energy delivery from various energy storage technology options was calculated using simulations of the levelised cost of energy (LCOE), including the cost of micro-grid and storage. The results of the simulation are highlighted in Table 7 below.

Table 7: Cost of Generation for Micro-grids using Various Energy Storage Technologies

	Units	VRLA Battery	Li-Ion	Vanadium Redox	Ultra Battery
Cost of energy delivered	INR/kWh (USD/kWh)	98.03 (1.55)	51.22 (0.81)	29.36 (0.47)	33.59 (0.53)
Cost of storage of energy supplied	INR/kWh (USD/kWh)	76.80 (1.22)	31.26 (0.50)	9.39 (0.15)	13.94 (0.22)
Cost of energy per household per day	INR/day (U.S. cents/kWh)	47.44 (75.2)	24.79 (39.3)	14.21 (22.5)	16.26 (25.8)
Cost of energy for household lighting load per day	INR/day (US cents/kWh)	8.23 (13.0)	4.30 (6.8)	2.47 (3.9)	2.82 (4.5)

The results of the simulation point to a number of interesting observations:

- The cost of generation from the solar plant came out to be around INR 20.0 per kWh (U.S. cents 31.7 per kWh), while the cost of energy storage (over and above this cost) varied between INR 9.4 per kWh (U.S. cents 14.9 per kWh) to INR 76.8 per kWh (U.S. cents 121.7 per kWh).

- The default fuel source for micro-grids is diesel, which had a landed cost of electricity of over INR30 per kWh (US cents 47.5 per kWh)[65]. Solar based micro-grids are competitive with diesel-based micro-grids when used with Li-Ion, Vanadium Redox and Ultra Battery technologies. At current price levels, solar micro-grids with VRLA batteries are not competitive based on the simulation.

- Currently, most rural micro-grids only cater to lighting loads, which cost between INR 2.5 per day (U.S. cents 3.9 per day) and INR 8.2 per day (U.S. cents 13.0 per day) for these households. The cost of lighting from micro-grids, without VRLA batteries, is comparable to the cost of current sources (i.e. kerosene) - INR 5.0 per day (U.S.cents 7.9 per day).

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[65] Cost of generation from diesel generator will be higher than INR 30 per kWh due to increased inefficiencies when run at part loads and varying loads.

Conclusion

The main conclusion that can be drawn from this analysis is that VRLA batteries, though the most expensive option, are most widely used for these applications. The other technologies though have the advantage (over VRLA batteries) are not popular due to their higher capital cost and being further along in terms of the stage of commercialization.

It is expected that the cost of solar and storage will continue to decrease with scales of economy, reduced cost of capital (about 10 percent post tax) for rural communities and technology developments. The cost of storage is expected to reduce to below INR 5,000 per kWh (USD 79.2 per kWh) within a time frame of three to five years. With these reductions, the landed cost of electricity from solar based micro-grids may fall to about INR 10.0 per kWh (U.S. cents 15.8 per kWh), with storage accounting for INR 2.2 per kWh (U.S. cents 3.5 per kWh). At this cost, solar based micro-grids would be extremely cost-competitive, even with the national grid (assuming that the cost of power from grid escalates at five percent annually and accounting for distribution and tail end losses).

4.3 LARGE COMMERCIAL AND INDUSTRIAL USERS FACING POWER SHORTAGES

Context

The commercial and industrial sectors suffer from regular grid outages, poor quality of power(especially during peak demand periods), and significantly higher cost of grid based power. In states such as Tamil Nadu, the distribution companies have stopped sanctioning any increase in demand loads for C&I consumers due to lack of adequate generation capacities. As a result, C&I consumers end up relying on and consuming expensive diesel-based power generation to meet their unmet demands. The cost of grid supply is also higher in many states due to Time of Day (ToD) tariffs[66]. Any intervention which can help these consumers lower their cost of energy delivered is likely to generate a huge demand and lead to significant foreign currency savings for the economy.

Renewable energy technologies coupled with energy storage technologies have the potential to help the C&I segment reduce its energy costs. Energy storage solutions allow C&I users to:

- Store energy during off peak demand periods and consume this energy during peak demand periods or during periods with grid outages, there by reducing energy costs (peak demand charges, peak hour power costs, diesel costs etc.)
- Procure power from the energy exchange during the night (when the cost of power is lower) and use the same during peak demand periods and grid outages.
- Generate and store onsite renewable power from solar plants and use this energy during grid outages and peak periods.

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[66] Under the ToD regime, the C&I segment is charged premium tariffs during peak hours and a discounted tariff during off peak hours.

To understand, analyze and map the benefits of energy storage for the C&I sectors, a simulation model for a business case was developed.

Assumptions

The simulation model used assumptions based on real world data. The key assumptions were:

- An industrial establishment in Maharashtra was analyzed, with a 5 MW connected load, 2 MW of on-site solar capacity, peak load of ½ hour every day and peak to average load ratio of about 2.
- It was assumed that during peak hours (18:00 - 22:00 hours), electricity will not be available from the grid and the industrial establishment shall have to source electricity from diesel generation sets at a cost of about INR 18 per kWh (U.S. cents 28.5 per kWh).
- The state of Maharashtra also provides significant opportunities for cost savings from 'time-shift', 'peak shaving' and 'renewable energy' use due to its high energy tariffs. The demand charges for electricity supply are INR 190 per kW/month (USD 3 per kW/month).
- The current[67] tariff for electricity is INR 6.33 per kWh (U.S. cents 10 per kWh) for industrial consumers, with an additional peak hour tariff premium of INR 1.1 per kWh(U.S. cents 1.7 per kWh) and an off peak hour (night) tariff discount at INR 1.0 per kWh (U.S. cent 1.6 per kWh).
- Solar power costs for on-site solar are expected to be lower than INR 7 per kWh (U.S. cents 11.1 per kWh) if accounted for with capital subsidy or REC benefits.
- Electricity was available at about INR 2.75 per kWh (U.S. cents 4.4 per kWh) (annual average of 2012) on the Indian Energy Exchange during the night.
- A Vanadium Redox storage system is assumed with a cost of about INR 16,500 per kWh (USD 261.5 per kWh). No subsidies were assumed for storage investments.

Results

The main conclusion that can be drawn from this simulation is that these applications are economically viable at present, however under the following conditions:

- The solar power is used to meet peak hour load, replacing diesel.
- The balance energy (not available from solar) for meeting the energy requirements from peak hour loads is supplied from the storage system which stores off-peak power in the night, at a lower tariff.
- Of the total savings, 85 percent was contributed by solar power and 15 percent by peak hour power substitution with off peak grid power. For this scenario the present value of benefits breaks even with costs.

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[67] The data pertains to April 2013.

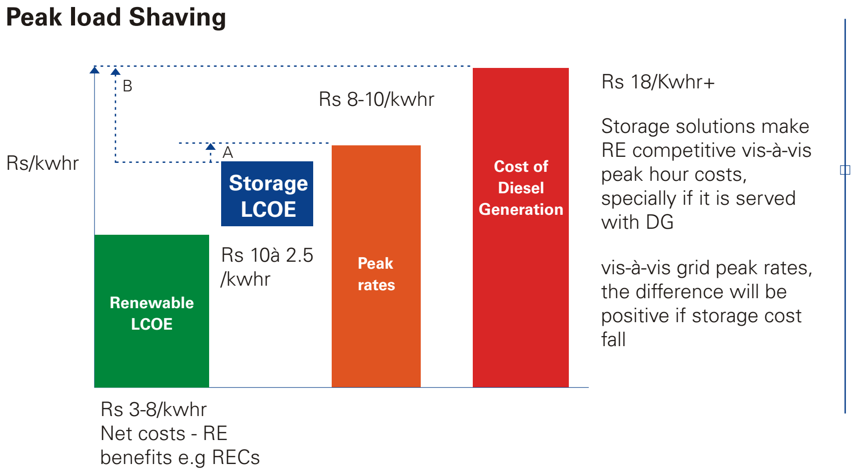
- Returns improve when the system uses short term power from the grid at a minimum price[68] to meet peak hour loads.
- If accelerated depreciation benefits (available for storage integrated with solar PV systems) can also be availed as a part of the investment, significant additional benefits (about 30 percent of investment cost) can be realized.

Conclusions

The key conclusion from the simulation is that storage coupled with renewable energy capacity has a high probability of being viable in states such as Tamil Nadu[69], Andhra Pradesh, and Rajasthan, which have high tariffs for commercial consumers, peak power deficits, and excellent solar or wind generation potential. This viability of storage options for various applications will increase when tariff inflation is also factored into the simulation model.

In most Indian states, the grid regulators expect peak power tariffs to be between INR 2.2 per kWh and 2.5 per kWh (between U.S. cents 3.5 per kWh and U.S. cents 4.0 per kWh) higher than off peak hour tariffs. For storage systems to step-in and be viable within this price differential, the cost of storage has to fall below INR 3,500 per kWh (USD 55.5 per kWh). If such price levels can be achieved, storage systems have the potential to become an integral part of the energy management system for commercial and industrial establishments. Figure 17 summarizes the cost benefit of energy storage for peak shaving.

Figure 17: Cost-benefit of Energy Storage Systems for Peak Shaving



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[68] March –April 2013 IEX analysis about INR 2.5 per kWh (U.S. cents 4.0 per kWh) which translates to INR 5.5 per kWh (US cents 8.7 per kWh) after accounting for various open access charges and losses.

[69] The analysis doesn't account for impact of poor power availability/reliability/quality on the industry. A FICCI study assesses that over 30 percent of cost escalation is felt by Industries in Tamil Nadu, Odisha and Andhra Pradesh and 61 percent of firms face 10 percent or higher loss of production due to power issues. EPRI report on 'Electricity Energy Storage Technology Options' estimates the cost of momentary shortages in the U.S., for small C&I customers to be USD 120 per kW. Such estimations need to be done for Indian Market as well.

5 RECOMMENDATIONS AND NEXT STEPS

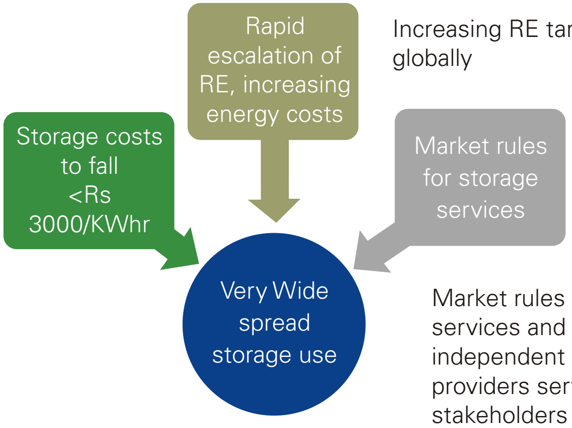
As discussed in the previous sections, research and discussions from the stakeholder consultation workshop indicate that India will need energy storage systems for accelerated deployment of renewable energy and meeting its RPO targets. Currently, lead acid batteries are predominantly used as the energy storage medium for residential and industrial consumers and pumped hydro for grid connected storage. Lead acid batteries have limitations of life, depth of discharge and efficiency and pumped hydro is limited by specific locations and the need for creating dams. New technologies need to be evaluated and business models need to be developed to ramp up addition of energy storage in India.

Many storage technologies with capital cost levels of less than USD 500 per kW and less than USD 0.10 per kWh/discharge cycle (electrical storage) are available and can be employed in India. Detailed work needs to be done to put a value to storage in various applications and develop appropriate policies to scale up. The emerging factors for wide spread use of energy storage technologies has been presented in Figure 18.

Work also needs to be done to provide detailed market analysis and signals to attract competitive storage technologies to participate in the Indian market.

Figure 18: Emerging Factors for Wide Spread Use of Energy Storage

Analysis indicates wide use of energy storage on back of falling storage costs and escalating power prices



Likely scenario with increasing energy needs and limited fossil fuel reserves, apart from environmental costs of fossil fuels

Increasing RE targets, DSM measures etc, globally

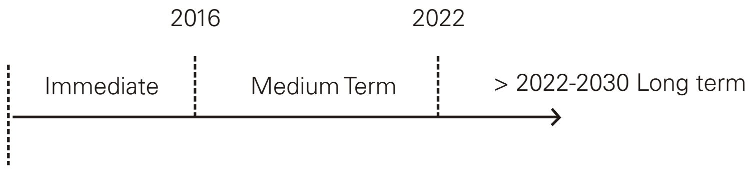
R&D programs such as ARPA-E designed to have manifold reduction in costs (<$100/kWhr) and manifold improvement in performance.

Market rules for pricing ancillary services and payments to independent storage service providers serving multiple stakeholders

Priority area for action were identified based on research of successful programs on storage globally, drivers of Indian requirement for energy storage, and detailed stakeholder consultations with global technology delegations, potential users, policy makers and equipment vendors. Following framework was used identifying issues and developing recommendations:

Strategic Dimensions and Roadmap Development

Information and Analysis for market	Scenarios underlying ESS use-→Market Potential--→ specific applications, use cases→economic value of ESS
Application	Use case -→pilot projects --→scale up of effective pilots--→wider replication (programmatic approach).
Technology development	Joint/shared research potential (storage, controls and rest of the system, applications); base research for India.
Policy	Policies to support research, technology development, deployment (procurement of storage resources by utilities, participation in energy and regulation markets/ancillary services, aggregation as storage service provider etc.).
Localization	As scale up happens, identification of well located manufacturing zones with appropriate policies.
Institutional Structure Capacity build up	Integration with Smart Grid Mission Centers of excellence; Training as part of overall smart grid roadmap



This section outlines briefly the outcome of this work.

5.1 AREAS FOR FURTHER WORK

The following areas need deeper research to be ready for 2016-17 when many drivers such as decline in renewable energy costs, inflation in fossil fuels, drop in storage costs and acceleration of smart grid implementation, come together to help accelerate adoption of storage technologies.

1. Market Research and Analysis
2. Technology Development
3. Application Demonstrations
4. Policies
5. Financing

5.1.1 Market Research and Analysis

'Value' of storage in modern energy systems is application and location specific. Further research and tools are needed to analyze this value, guide developers to identify viable applications and guide policy makers to evolve rules for developing a market based storage services market.

There follows a list of 'assessments' and 'tools' needed in the immediate future (2014-15):

- Detailed market assessment and estimation of 'economic value' for key energy storage applications. This may also cover business models through which storage services may be provided, aggregating revenue streams from a number of beneficiaries (value stacks). This knowledge can be used to develop appropriate policy regime for energy storage in India. Economic value estimates will help in prioritizing various applications[70].

- A detailed assessment of storage technologies, which is based on direct discussions with technology suppliers, feedback from users or demonstration sites around the globe and experts from well-known global R&D programs, to understand current and expected future price-performance of technologies. This assessment will be useful for developing India's own storage technology development strategy.

- Development of simulation, analytical and control tools to design, schedule, dispatch and earn revenue from energy storage devices, specific to Indian context. Some important types of tools/models[71] are:

    - Long term resource portfolio planning
    - Production simulation (generation, transmission)
    - Load flow analysis (near term grid stability)
    - Dynamic simulation (short term grid variability and load balancing)
    - Technical screening of storage solution (technologies and services)
    - Cost and value analysis tools (life cycle analysis of ESS solutions)

- Modeling of 20/30 percent Renewable Energy use scenarios, related impact on the grid and the requirement of energy storage. This will facilitate preparation of a strategic roadmap for energy storage in India.

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[70] Annex-5: Principles for estimating 'value' of storage.

[71] A number of such tools exist and have been cited by EPRI in their handbook.

5.1.2 Technology Development

India, offers a very attractive opportunity to commercialization of emerging storage technologies. To accelerate adoption, following actions are needed in the immediate future (2014-2017):

- Identifying a Centre of Excellence for Energy Storage from amongst the leading academic or research organizations in India. This Centre of Excellence could anchor activities relating to 'research' as well as 'technology development'. The Centre could also demonstrate important applications of storage.

- Establishing standards for use of energy storage and related use cases/applications (e.g. standards for integrating distributed generation resources like roof tops; standards for micro-grids, standards for grid connection of renewable farms, forecasting and scheduling standards, etc.). Establishing standards of performance testing of storage technologies and vendors, so that users have increased confidence while choosing a supplier.

- Development of a Research and Development program for energy storage, using internal capability as well as joint research with other countries. This program would focus on improving costs, efficiency, life, energy density and such other parameters for key energy storage technologies and help develop supporting systems (e.g. battery management systems, energy management systems) to integrate storage solutions with the grids. With such basic research India can become an important player in this strategic area. The program could be run in a PPP mode with part assistance coming from government sources and part from private sources. It could competitively invite solution providers to develop solutions for a given 'performance' or 'result' in specific applications (e.g. storage for 90 percent reduction in ramp rates of power generated in a large wind or solar farm).

5.1.3 Application Demonstration

Demonstration of new technologies is critical to provide confidence to all stakeholders and help them make right decisions.

- Demonstration is needed for following important applications:
  - Grid Integration of renewables and Optimization
    - Utility scale RE farms
    - Distributed generation (roof top and other on-site systems)

    - Rural micro-grids
    - Energy Management Systems for large users
    - Management of aggregated storage systems in a (smart) grid – B2G, V2G

- The location and use case for the application would be arrived at in line with Market Assessment and Value Analysis described earlier.
- The results from the pilot will help develop overall recommendations on the policies required to accelerate adoption of storage technologies. The designing of pilot would include the following:
    - Goals for each pilot; use case
    - Identification of a host for the pilot along with financing (public, private contributions)
    - Establishing, in dialogue with technology suppliers, performance and economic models for the pilot for suitable technologies, including revenue models which will justify investment in the pilot
    - Validating the assumption of demand model for the application and refine the demand model
    - Monitoring and Verification (M&V) protocol for validating the performance, benefits and impacts of the ESS application.
    - Sharing of the results from the pilot

5.1.4 Policies

Initially policies are needed to maximize the participation of storage in different potential revenue streams and making them monetizable. Market rules need to be developed so that public support needed to make storage viable comes down rapidly.

Some of the important policy areas are:

- *Policies supporting 'Prosumers'*
    - Participation of distributed energy storage systems (DESS) in grids both as 'loads' and 'generators' (bi-directional use).
    - Rules for providing multiple services using the same storage capacity as generators/load.
    - Rules for aggregation of storage capacities and participation in providing services.
        - V2G, B2G and Vehicle to Building (V2B)

- *Energy Market related Policies*
    - Rules for participation of storage service providers in the energy markets; Energy (reserve) capacity, ancillary services. Payment mechanism for the same.
    - Dynamic pricing for peak loads; peak load management using storage
    - Policies to encourage utilities and transmission companies to use storage or procure resources from storage service providers. Procurement obligations (e.g. in California).
- *Fiscal benefits and incentives to implementers of storage solutions (which may taper off as market adopts storage and storage costs fall)*
    - Capital subsidies
    - Interest cost subvention
    - Custom duties, Value added tax (VAT)
    - Income tax
    - Accelerated Depreciation
    - VGF/shared investments (PPP) for demo project
    - Technical Assistance for demo project
    - Use funds from National Clean Energy Fund (NCEF)
    - Public benefit charge
- *Policies supporting micro-grids*

  Micro grids (rural, residential complexes, C&I customers), energy management systems

    - Separation of 'wire' and 'distribution' – micro grid operators or storage service providers to be allowed to serve a group of customers with energy management solutions. Pricing rules for micro-grid operators.
    - Policies supporting group procurement of micro grid services, by a group of customers.
- Policy for encouraging localization in manufacturing of storage component.

Stakeholder consultations reveal that if policies for RPOs, Open Access, Peak Load pricing, Power Quality and Reliability, Grid Integration, Merit Order Dispatch, and Forecasting and Scheduling of renewables are implemented strictly, it will accelerate adoption of storage technologies.

5.1.5 Financing

To carry out the initial research, policy development, part financing of demonstration projects and establishing the Centre of Excellence, financing could be obtained from the following sources:

- NCEF has a large corpus ~ USD 2 billion and permits use of the funds for
  - Advanced technologies in renewable energy including critical energy evacuation infrastructure,
  - Integrated community energy solutions,
  - Basic energy sciences',
  - *Pilot and demonstration projects for commercialization, etc.*

  Financial support to Energy Storage will qualify under these categories.
- UI pool account funds can also be used for storage solution integrating 'large renewable farms' or 'on-site RE' capacities to the transmission or distribution grids.
- Public benefit charge' or State Green Funds could be used to support demonstration projects implemented by 'utilities' for frequency or voltage regulation, ancillary services, scheduling renewable power, integrating electric vehicles to the grid or supporting village micro-grids, in conjunction with financial support from other programs.

5.2 PREPARING A ROADMAP[72] FOR INDIA'S STORAGE EFFORTS

California (USA)[73], EU[74] and Japan have developed detailed roadmaps for storage applications. This report is creating a Case for Action for India. As an important area for future energy systems, and a key component of India's own Smart Grid Roadmap, India needs to develop a Roadmap for energy storage capabilities in India, with detailed milestones and actions in three time buckets (2013-2017, 2018-2022), 2022-2030. The roadmap could be created by 2014 end, supported by research work as identified above.

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[72] IEA has defined an approach for preparing technology roadmaps. A Roadmap would typically cover Goals, Milestones, Gaps and Barriers, Action areas, Priorities and Timelines.

[73] 2020 Strategic Analysis of Energy Storage in California.

[74] EASE/EERA supported Energy Storage Technology Development Roadmap towards 2030.

Energy Storage Forum

It was also recommended to create an expert industry forum with members from electricity service providers, utilities, renewable energy generators, research laboratories, representatives from ministries, regulators, and storage system suppliers. This forum will facilitate setting and roadmap with clear goals, design of pilots, use of research grants, sharing of knowledge, development of policies and implementing the roadmap for development of storage solutions in India. This forum would also establish linkages and collaboration with other expert groups (U.S., Europe, Japan, etc.).

Energy storage is associated with several programs developed by Government in the areas of rural electrification, smart grids, energy efficiency, electric vehicles, renewable energy, etc. Accordingly the forum should have representatives from Ministry of Power, Ministry of New and Renewable Energy, Department of Science and Technology, Ministry of Heavy Industry, etc. Policies and rules would be needed to use part of the funds from these programs to support the Energy Storage Roadmap. One of these ministries could play the role of an anchor.

Annex 1

Energy Storage Technologies[75]

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
Chemical	Battery	Lead Acid						Euro 50-150/ KWhr			5 MWhr Vernon Plant by Exide at California. 8MWhr BEWAG plan at Berlin. 1.4 MWhr Metlakatla plant. Cost Lower than Li or Ni (most expensive LI NI batteries can be 13 times more than LA batteries)
			Flooded Cell				1500 cycles				Robust but requires more maintnenance effort
			VRLA		25-45 Whr/kg	60-95%; 20% self discharge /m	<1500 cycles		Available	Widely used	Industry players claim to have achieved 10 yr of life, however actual experience is of 500-1000 deep discharge cycles (1.5-3. yrs); low maintenance effort needed. Temperature sensitive-can't be exposed to high temperatures and energy rating falls at lower temperatures (< 20 deg C) Pose problems of loss of efficiency when continuously used in partial charge state.
			Ultra battery			94%+	10000 cycles+				This combines a VRLA battery with an asymmetric capacitor, improving the power rating, efficiency as well as response time of the battery. Has flat performance curve over 10%-90% discharge depths.

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[75] Source: EVI Research

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
Chemical	Battery	Ni Cd and other Ni family		1KW-2000 KW	20-120 whr/kg (dahlen 2003)	~70%, Ni-Zn 80%; Na-NiCl2 90%	1500+ deep cycles	2005 (Golden valley-BESS cost was $30 million ~ $1100/KW. Typically 2 times the cost of Li batteries and 4 times the cost for LA batteries. Recent range Euro 200-750/KWhr	Available	Limited	Ni and Cd electrodes and KOH as electrolyte. **High energy density and better cycle life than LA**. More expensive. Cd content is controlled. Use is declining due to toxicity issues. Aplication for a 27 MW Battery Bank for 15 min storage in Golden Velley Electric Association plant in Alaska. Batteries provided by SAFT. Toxicity of Cd has resulted in Ni-MH replacing Ni-Cd.Urban Electroc Power(UEP) is developing Ni-Zn, flow assisted batteries under ARPA-E a battery, to be manufactured in India with HBL, with 10000 cycles life and $400/KWhr costs, 85% round trip efficiency, 20 Whr/kg density, DOD 90%. They are also developing MnO2-Zn batteries with $100/KWhr costs and 2000+cycle life. **Specially being used for Industrial Complex peak demand shaving (20%-40%)**
		Na-S		100-1000 KW	100-1000 KW	90% +	2500-4000 cycles with deep discharge 15 yrs life	Euro 170-500/ KWhr.	Developed for last 20 yrs	Mostly used in Japan> 300 MW under impleme-ntation	Molten sodium (cathode) and sulfur (anode) separated by aluminum ceramic electrolyte which only allows sodium ions to pass.High power density, high efficieny.Long discharge cycle capability (8 hrs). Can rapidly discharge and at multiples of rated power High temperatures creates a safety issue. 2 Plants in Japan at 9.6 MW and 64 MWhr capacity are in operation - one at a water treatment plant and one at a utility operated by Hitachi. Also used in a wind farm of 51 MW at Rokkasho island. AEP Installations in US for 6 MW x3 each at West Virginia and Ohio. Long Island bus depot installation 1 MW (2006)

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
Chemical	Battery	Li-Ion		1KW-10 KW	100-150 Whr/kg (Investire 2003). Can go up to 200 Whr/kg with nano-composite materials	90-100%	10000 cycles+	Euro 150-420/KWhr;	Available	Popular in small scale applications. Also Electric vehicles	Nano Powders and Nano Composite elctrodes are being used to increase capacity. Li batteries now account for 50% of small battery market. Tesla has developed a battery for BEV 200 KW. SAFT SATCON 100 KW/1 min storage for stabilizing grid. Limited environmental issues. LiO2 can be recycled. EU has taken up an initiative POMEROL to reduce the cost of LI batteries to < Euro 25/KW
		Metal air batteries	Li-Air		High-110-420 Whr/kg for metal air batteries of various kinds	50%-very low		Lowest cost batteries	Electrically rechargeable cells are developing	Limited at large scale	Metal air batteries in general consume the metal (anode) and convert into metal oxide which is removed. Recharging s difficult and most common applications are one time use only.
			Zn Air								
			Iron-Air								This is the most developed of all metal-air batteries. Very low environmental footprint
	Flow batteries										Flow batteries as a class offer advantages of being able to scale up discharge time by using higher elctrolyte storage capacity and charge caryring capacity. However they can be noisy and require energy for pumping.
		ZnBr		1000 Kw-5000 KW	37 Whr/kg	75%		ZBB system Euro 900/KWhr	Early phase of commercialization	Limited used	Two dfferent electrolytes flow past carbon plastic composite electrodes in 2 compartments separated by a polyololefin membrane. ZBB system being tried in US DUIT facility at 500 KWhr scale.

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
Chemical		VRB (vanadium Redox)		up to a few 100 KW		85% Can be discharged fully without reducing life.	Japan-14000 cycles without reduction in capability	$500-1280/kWhr	Early Phase of commercialization	Limited	These have the best life and 100% discharge ability. This is being tried in many wind farms, e.g Sorne Wind Farm (Ireland). The system will provide pulses of 3 MW for 10 minutes/hr. United Technologies is developing Vredox batteries with $250/KWhr cost and 85%+ efficiency
		Na-S (sodium polysulfide) / Bromine redox flow				60%+			Very early stage	No commercial scale deployment	Energy and power densities are independent. Can scale up for large applications.High power density. Immature technologies, high maintenance costs
		Cerium Zinc				75%, lab scale			Very early stage	No commercial installtion so far	Largest Cell voltage (2.43 V) and power density for a unit electrode area. Developed by Plurion
	Fuel cells	PEM (Proton Exchange Membrane)		100KW-500KW		System efficiency for electricity conversion into hydrogen, storage, transportation and reconversion through fuel cells: 60-70% loss; 30% effy		DOE, 2011 has reported, a cost level of $49/KW for a 80 KW system with 500,000 volume of production. Targets $35/KW ove time	Most common fuel cell. Still lot of active research is being done	small systems (a few KW). Freedom Car USA	H+ ions move through membrane and combine with O- ions at Cathode. Micro-CHP applications. Solidpolymer as electrolyte; porous carbon with platinum iside as electrodes. Platinum as a catalyst - sensitive to CO content in the incoming fuel. Also needs fine control over water content, temperature etc. PEM has been tried in 27 buses in CUTE (Clean Urban Transport for Europe). 250 Kw x 2 systems; acceleration performance same as Diesel. 20.4-31.5 Kg/100 KM. EU invested Eurom300 million in Hydrogen and Fuel Cell technologies, in FP6. A packaged solution has been developed by a team in an Indian Management Instititue which has

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
											worked on a solution at $6/watt cost level, using PV to generate hydrogen and then using this hydrogen to generate power when needed. The cost is stil high to make a significant dent
		SoFC (Solid Oxide Fuel cells)		1kW-2 MW		85% in CHP mode			Bloom energy most celebrated start up. R&D	Deployed in some commercial applications. Internet companies~ $100/KW	Oxygen ions move to anode and combine with Hydrogen. Electrolyte is Yitrium stabilized Zirconia. Operate at 1000 Deg Cent. Advantage of low cost of material as expensive catalysts such as platinum are not needed. Can use almost any hydrogen bearing fuel, as the fuel is reformed internally and hydrogen generated. Corrssion issues due to high temperature
		AFC (Alkaline fuel cells)		10-100 KW		60%-70%		$125/KW	R&D	Military/ space	Acqueous solution of Potassium Hydroxide in a matrix. OH ions moves through the membrane and combines with H2 at Anode. Operate at 90-100 deg cent. Very sensitive to CO Impurity in the fuel
		PAFC (Phosphoric Acid Fuel Cells)		100-400 KW		70%+ efficient when used in co-generation mode; else 37-42% in generating electricity alone (EERE, HFCIT 2007)		$4-4.5/KW	Commercialized	Distributed generation being used commercially.	Electrolyte is phosphoric acid in a lithium-aluminum soaked matirx. Catalyst is carbon supported platinum. Operates at temperature of 190-200 Deg C. Tolerant of hifh impurity (both CO_2, and CO). Good CHP Potential. First fuel cell technology to be commercialized

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
		DMFC (Direct Methanol Fuel cells)				85% in CHP mode; else 50%			R&D	Pilot	Fuel is methanol Anode catalyst draws hydrogen from methanol, elimniating the need for reformer. Good potential for vehicle use (high temperature of 650 deg cent); technology is very young at present. Temperature range 50-120 deg cent
		Molten Carbonate Fuel cells (MCFC)				50-60%			R&D	distributed generation pilots	Electrolye is a mix of sodium/potassium carbontate in a mix of Li(OH)2.Operates at 620 deg cent. Has the ability to reform the fuel
		Molten Carbonate Fuel cells (MCFC)				50-60%			R&D	distributed generation pilots	Electrolye is a mix of sodium/potassium carbontate in a mix of Li(OH)2.Operates at 620 deg cent. Has the ability to reform the fuel
	Bio-fuels								Available	Limited so far but potential pathway for extensive use	Commercial fuel companies suggest that they can create fuel at cheaper prices if cude prices > $55/bbl. Shipboard production of gasoline using nuclear power would cost < $6/gallon when the cost in 2010 was almost twice. US Navy estimates that terrestrial production using wind power could cost petrol < $1/gallon. In iceland a plant exists to use geothermal energy to produce 2.0 million litres methanol

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
Electrochmical	Hydrogen	Underground hydrogen storage							Available	Not widely used although	can be stored in salt domes, caverns, abandoned oil fields. By using a turbo-expander the cost of compressing and storing underground (at 200 bars) is 2.1% of energy content. Wind energy storage since 2007, in Ramea, Newfoundland and Labrador. A similar project in Utsira, a Norwegian island. Total cycle loss, till the point of use at~ 7%. 50 KWhr of energy is needed to produce 1 kg of Hydrogen. Wind Hydrogen Ltd (Scotland Facility of 5 MW---> 50 MW) will operate a wind--> H2 facility. Hydrogen will generate electricity for 4 hrs/day. Hydrogen will be generatd over 10 hours/day. Hydrogen for transport diversifies electricity mix usage. Hydrogen is being developed for direct use in IC engines (eg. BMW, Ford)
		Alternate storage in Active Carbon or Carbon nanotubes									
		Absorption in Metla Hydrides and Fullerines									

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
	Hydrogen--> methane								Available	methane infrastructure is commonly available	Using sabatier process, conver into methane. Methane then can use the existing transportation and storage infrastructure
	Oxy-Hydrogen								Available	limited	DC current used to generate HHO which mixed with fuel is burnt and releases energy
	Hydrogen peroxide								Available	limited	Energy used to produce H2O2 . It is used as a propellant for engines/turbines.
Electric	Capacitors	Tesla's (capacitor) Tower							Developed in 1930s	Not used, although may russian pilots exist for wireless and single wire transmission.	Sets up storage between earth and stratosphere and can transfer power at demand at any point of the globe without needing a wire transmission
		Nanoscale capacitor									Energy stord is proportional to area and voltage squared and inversely proportional to the distance between electrodes. Hence nano-scale capacitors (made of carbon) can store large amounts of electrcity

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
		Super capacitors		2 Kw-250 KW	5KWhr/kg ; MIT reports 60 kWhr/Kg	85-98% (Willer, 2003)	> 300,000 cycles	200-1000 Euro/KW (2002)	Developing	Widespread at small scale	Electrochemical capacitors; store energy in the electrical double layer at the electrode-elctroylte interface. Activated carbon electrode increase the surface area- 1000-2000 m2/g. Distance between internal electrode layer and surface layer is measurable in angstroms, hence increase the capacitor capacity. Electrolyte (water, sulfuric acid or KOH; organic systems: solvents-acetonitrile, propylene carbonate; salts: tetraalkyle ammonimum salts giving) High power density, high cycle life (> 100,000), quick recharge, high efficiency (> 90%). Low energy density (compared to batteries), sloped voltage curve requiring power electronics. Expensive. EPCOS (Germany 5000 F, 2.5 V). Panasonic, NESS (Korea) are high capacity ECs. Mostly used as Starting Power sources right now. Can be used on HEVs as regenerative braking system. Sacramento Regional Transit District, USA is using 1 MW system for regenerative system for its rail system (cost will be 50% of conventional DC sub-system). Long life cycle and high efficiency
	Suprconduting magnet energy storage (SMES)					97%. Extremley rapid discharge times		Euro 350/KW	Developed up to 10 MW, otential to go up to 2000 MW	Power quality applications. Japan, USA	High power, quick recharge. Temperature of coil ~ -269 deg cent. Low energy density, large parasitic losses. Expensive. First SMES device 10MW/30 MJ installed at Bonneville Power Station by Pacific Intertie). Currently viable at MW scale (10s of MW) with seconds of discharge. To stabilize transmission system.

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
Thermal Energy Storage (TES)	Molten Salts					99%+	High		Available	Used mostly with CSP (therma)	Normally thermal energy, most often solar, is collected and stored for a few hours to a few days in molten salts (nitrates of sodium, potassium, calcium, lithium, mixed in a eutectic mixture). The salts are kept between 288 (storage tank side)-568 deg cent (solar collector side). Seasonal Thermal Energy Systems (STES) enable thermal energy storage during summers for heating use in winters.The Drake Landing Solar Community in Alberta, Canada has now achieved a year-round 97% solar heating fraction, a world record.
	Concrete and ceramic blocks, hot bricks etc						High		Available	Limited use in Buildings	These blocks can be heated to high temperatures (1200 deg cent+) and thetrefore a small blokc can store large quantity of thermal energy, releasing it over time. Good for residential buildings etc.
	Steam						High		R&D	CSP thermal	Steam accumulaor stores solar thermal energy and converts into electrical power using steam engine. Terrajoule, USA has set up a deomsntration plant 100 KW (24x 7) supply capability at $2/peak solar capacity. The peak solar collection capacity is 300 KW plant. Thus a 100 KW (24x7 Plant) is ecpected to cost $600,000 with this technology which is very attractuve to most process industries. Also expected to use only 0.7 acres of collection area/land which 50%-705 less than PV.

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Development	Development	Remarks
Thermal Energy Storage (TES)	Cold storages						High		Available	Smulation to be done for large scale p	This methiod uses the cold storage capacity to cool, to decrease the temperature (be 1-2 deg cent) in the night using cheap power and use the extra cold temperature to reduce cooling power consumption in the day, by swtiching off the chillers for hours. This results in peak load shaving and power arbitrage benefit. Being studied for a large scale implementation in Netherlands (50,000 MWhrs of energy storage possible)
	Ice								Available	Limited use (3500 buildings worldwide)	With high specific heat of fusion of water, ice can store 93 kWhr of energy/m3 or 26.T of HVAC Hrs. Low cost, less space than water. In 2009, used in 3300 buildings and 35 countries. Night conversion, day time use for ACs. Also being used in Pune.
											A ground storage heat pump, pumps heat into the ground and uses it whe needed. Inter-seasonal storage also possible. Heat is reatined in aquifers or earth (around a network of boreholes), flooded mines or caverns, lined pits filled with gravel and water. Germany, Netherland and Sweden have extensive experience in the technology. More than 300,000 systems worldwide with 80% + systems in Swedem. "Zonnige Kempen", Westerlo (Belgium). Social housing project with BTES in combination with solar panels and asphalt collector.Wiggenhausen-Süd solar development at Friedrichshafen features a 12,000 m3 (420,000 cu ft) reinforced concrete thermal store linked to

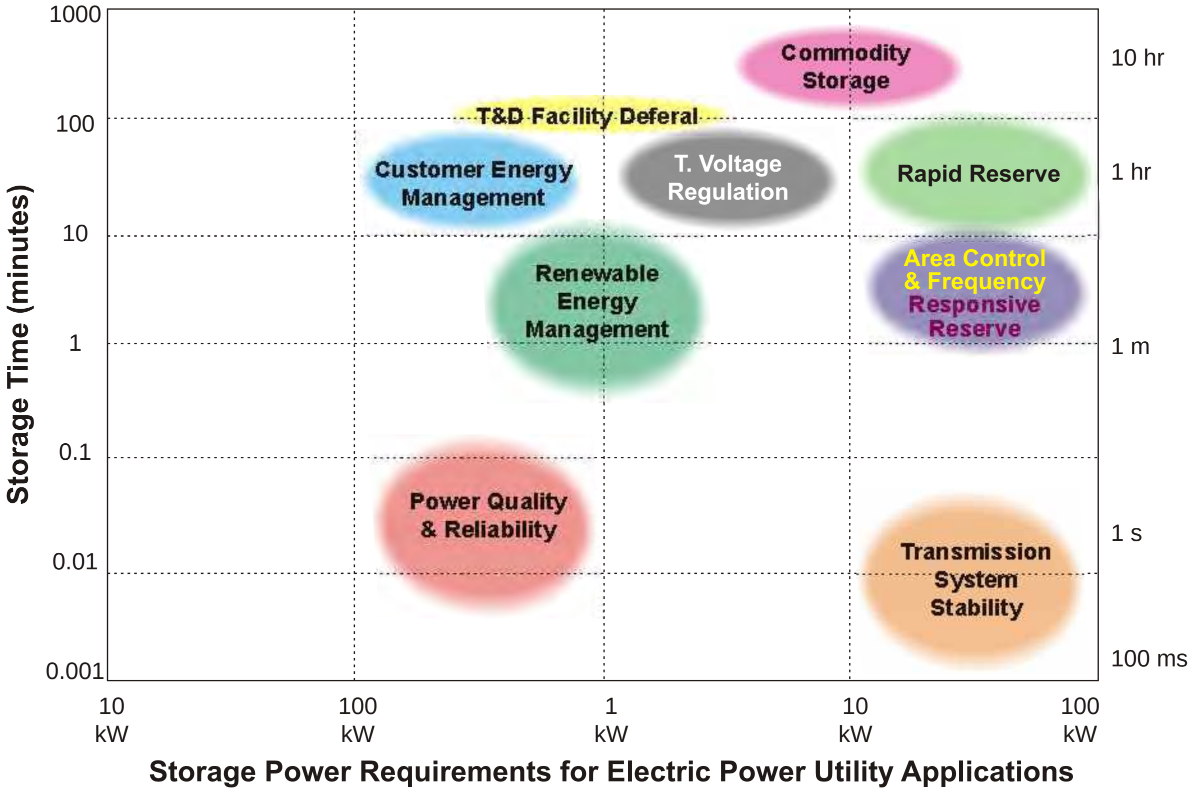
Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
											4,300 m2 (46,000 sq ft) of solar collectors, which will supply the 570 houses with around 50% of their heating and hot water Excellent application for buildings.
	Cryogenic liquid air or nitrogen					25%-50% when the input energy is electrical energy. If a waster heat surce is used, Ac-AC efficiency of 70% can be achieved.			not commercialized	limited	Energy is used to generate liquid air (temp < -195 deg cent; air liquifies to 1/1000th of its original volume and can be kept at atomospheric temperatures) or nitrogen and then expanded using heat to power engine (Dearman engine) or turbine. Used for cars and is also being used at a power station in UK. A 300kW, 2.5MWh storage capacity pilot cryogenic energy system developed by researchers at the University of Leeds and Highview Power Storage that uses the liquid air as the energy store, and low-grade waste heat to boost the thermal re-expansion of the air, has been operating at a 80MW biomass power station in Slough, UK, since 2010 and claims efficiency of 70%.
	Solar pond								Available	Limited	A solar pond is simply a pool of saltwater which collects and stores solar thermal energy. The saltwater naturally forms a vertical salinity gradient also known as a "halocline", in which low-salinity water floats on top of high-salinity water. A tranlucent water body can have bottom at 90 deg centigrade and top layer at 30 deg centigrade. Example- Sinai Solar lake in Egypt. This approach is very useful for developing countries making it possible to collect lot of solar energy at very low cost

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
	Thermal Energy Storage in Closed Greenhouses										In passive heat storage, heat is transferred in summers through air and is absrobed and returned to building in the winters. In active heat storage, heat collected in summers, through active collection is used for heating in winters.The more recent “Zero Heating Energy House”, completed in 1997 in Berlin as part of the IEA Task 13 low energy housing demonstration project, stores water at temperatures up to 90 °C (194 °F) inside a 20 m3 (710 cubic feet) tank in the basement] and is now one of a growing number of similar properties.“Jenni-Haus” built in 1989 in Oberburg, Switzerland has three tanks storing a total of 118 m3 (4,200 cubic feet) providing far more heat than is required to heat the building.
Kinetic	Flywheel			100 KW-2000 KW (lowe speed); High speed 1 KW-250 KW	50-100 whr/kg	90%; discharge times of 30 minutes in DUIT. Beacon power plant of 200 flywheels can take 20 MW up or down for wind power variation.	a few yrs (normally low life)- Beacon power system life at 20 yrs	Euro 1050/KW	Available	Most used in germany. Costs high	Flywheel coupled with motor-generators. Successful at low power KW scale. High cycle life, quick recharge, Potentially dangerous modes on failure. Large standby losses. Low speed wheels (up to 10000 rpm) made with steel, magnetic bearning are used to reduce rotationa/standby losses. High speed flywheels made of exotic grpahite and glass composites. Normally used for providing bridging power to back-up generators. **Beacon Power USA 2 KW, 3 Hrs (is the only known model for long duration discharge cycle**. A coming led ring technology (PCRT) to reduce srface cracks from development

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Develop-ment	Develop-ment	Remarks
	Gravitation potential energy device										These devices have been proposed to generate massive energy storage using a weight say 100 T+ lifted to a large height- 100 m+ (possible in underground cavenrs which can store a potential energy of 5 MWhr approx and can be used to generate eletricity by lowering and running a dynamo.This may be one of the most environment friendly means of high efficiency storage with potentially very long life.
	Springs										Traditional mechanical forms of energy storage. However not useful for large scale storage. Spring and Hyrdaulic accumulators can be combined however.
Pumped Hydro	Hydroelectric-large pump hydro					70%-85%	High	$140-$700 (Goldisthal plant in Germany-1000 KW)	Available, although site limitations exist	~90 GW+ capacity in thwe world and 30 GW+ under planning	Many plants in Washington, Orgaon, Wales. Much more efficient than batteries in terms of energy density. Huge power and energy capacity. Requires special locations, expensive to build. 90 GW of capacity in the world already. Old Mineshafts and coastal areas are potential alternative locations being looked at
	Hydraulic Accumlators										
	Micro Pump Hydro										

Energy Storage Technologies	Level1	Level2	Level3	Power Rating	Energy Density	Efficiency	Lifetimes	Cost	Development	Development	Remarks
Compressed gas systems	Air				80%			Euro 400/KWh	Limited, site restrictions, gas availability	2.7 GW planned	Use of underground caverns, abnadoned mines. Compressed air is released and converted into energy using standard gas turbines. A plant runs in Alabama since 1991. Much more efficient than batteries in terms of energy density. Disadvantages: slow start; requires special location, expensive to build and maintain, and requires gas supply. The energy consumption for gas turbineshas been seen to be reduced by up to 60% using this method. The first system was constructed in 1978 for 290 MW at Germany Hundorf. Second plant was at Alabama in US. A plant is being planned by Shell wind energy and Luminant in Texas. Several plants under planning in Japan, Italy, Russia etc
	Smaller hybrid CAES system-above ground				80%			$700-750/KW			Pipes (48" dia, 2400 psi pressure) keep the compressed air. (capacity < 50 MW).
	Compressed Co2 (sequestered)				80%			$700-750/KW			Walker Architects (2008) published an application based on sequestered Co2

Annex 2 Comparative Performance of Electrical Energy Storage Technologies[76]



Data from Sandia Report 2002-1314

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[76] Source: Energy Storage Association. Website: www.energystorageassociation.org

Annex 3

Generic List of Electrical Energy Storage Applications[77]

Application	Description	Time scale of Operation
Application	Description	Time scale of Operation
Load Leveling/Arbitrage	Purchasing low-cost off-peak energy and selling it during periods of high prices.	Response in minutes to hours. Discharge time of hours.
Firm Capacity	Provide reliable capacity to meet peak system demand.	Must be able to discharge continuously for several hours or more.
Operating Reserves Regulation	Fast responding increase or decrease in generation (or load) to respond to random, unpredictable variations in demand.	Unit must be able to respond in seconds to minutes. Discharge time is typically minutes. Service is theoretically "net zero" energy over extended time periods.
Contingency Spinning Reserve	Fast response increase in generation (or decrease in load) to respond to a contingency such as a generator failure.	Unit must begin responding immediately and be fully responsive within 10 minutes. Must be able to hold output for 30 minutes to two hours depending on the market. Service is infrequently called.
Replacement/ Supplemental	Units brought on-line to replace spinning units.	Typical response time requirement of 30-60 minutes depending on market minutes. Discharge time may be several hours.
Ramping/Load Following T&D Replacement and Deferral	Follow longer term (hourly) changes in electricity demand. Reduce loading on T&D system during peak times.	Response time in minutes to hours. Discharge time may be minutes to hours. Response in minutes to hours. Discharge time of hours.
Black-Start	Units brought online to start system after a system-wide failure (blackout).	Response time requirement is several minutes to over an hour. Discharge time requirement may be several to many hours.[3]
End-Use Applications TOU Rates	Functionally the same as arbitrage, just at the customer site.	Same as arbitrage.
Demand Charge Reduction	Functionally the same as firm capacity, just at the customer site.	Same as firm capacity.
Backup Power/ UPS/Power Quality	Functionally the same as contingency reserve, just at the customer site.	Instantaneous response. Discharge time depends on level of reliability needed by customer.

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[77] Source: EPRI-DOE (U.S.) Handbook of Energy Storage for Transmission and Distribution Application 2003.

Annex 4 Cost Benefit Analysis Framework For Business Case Of Energy Storage Technologies

For better understanding of the business case for deployment of energy storage technologies, a framework for cost benefit analysis was been made. The framework created is only an approximation and does not include benefits like frequency regulation etc. In order to understand the exact benefits, a detailed model needs to be developed with all possible benefits included and quantified. Based on the framework, three different business models have been analyzed in the report. The framework for each of the three renewable energy models has been described below:

A. Transmission Constrained Wind Capacities

At present, the transmission & distribution (T&D) infrastructure capacity of utilities is not sufficient to evacuate entire power generated during peak periods. So, currently, various wind farms (e.g. in Tamil Nadu) are not able to inject the entire power generated during peak period of generation. Part of generation from wind farms is lost, and this means losses in revenue for the developers. To address the problem of constraint in T&D infrastructure, utility needs to invest in developing additional T&D capacity.

By using energy storage capacity, such investments in developing additional capacity can be avoided (in part or full). During peak periods, surplus power generated (in excess of T&D capacity) can be stored in energy storage capacity. The stored power can be exported to grid during off-peak periods when there is no constraint on T&D capacity.

Cost Benefit Analysis Framework:

	Parameters	Description
Benefits	Increase in Revenue	With storage capacity, wind farms can inject more power into the grid to be sold off.
	Savings in scheduling penalties	With storage capacity, developers can better schedule power injection to grid. Any surplus than scheduled power can be stored in storage capacity and any shortfall can be compensated from the storage capacity. In this way, the developer can avoid paying penalties for injecting excess/lower power.
	Decrease in transmission charges	Transmission charges are applicable on the developer, based on connected capacity. With storage capacity, connected capacity is lower as excess wind capacity is stored. With decrease in connected capacity, transmission charges are lower.
Costs	Cost of initial investment	Initial investment will be the incremental capital investment for the wind project due to storage capacity. The cost of incremental investment is based on current market trends.
	Cost of replacement during project life cycle	The incremental cost of storage for the entire project life of a wind farm needs to be analyzed for an understanding of cost and benefit of the storage technologies. Few storage technologies have a life of less than 20 years and need to be replaced during the project life of a wind farm.
	Additional O&M expenses	Storage technologies require additional operations & maintenance over regular O&M of wind farms. O&M cost is considered as a percentage of capital cost.

Estimation methodology:

A sample wind power project site in Tamil Nadu has been selected for conducting a cost benefit analysis of energy storage technology. Based on the wind speed data collected at the site, generation for 2.1 MW wind turbine is estimated.

Based on the capacity of the nearest sub-station, power injection that is feasible at the substation and losses due to under capacity of sub-station are estimated.

Similarly, power injection to grid is estimated in case energy storage capacity is available with the wind turbine. Based on the estimates, the necessary increase in power injection is calculated. Benefits due to energy storage capacity are estimated on the basis of the increase in power injection and also on:

- The current market rates of third party power sale in Tamil Nadu,
- Transmission charges by Tamil Nadu State Electricity Board (TNEB)
- Scheduling charges by Tamil Nadu State Electricity Board (TNEB)

Based on the benefits and cost estimations, Net Present Value (NPV) is calculated. Also the feasible cost of energy storage technology is determined to attain at which point energy storage technology becomes commercially attractive.

Assumptions used in the Model

Wind Turbine Capacity		
Capacity of Turbine	2.1	MW
Life of the project	20	Years
Export restriction level	30%	
Maximum power export	1.47	MW

Storage Capacity Requirement		
Battery Capacity	30%	
Average storage time	7.9	hrs
Capacity of battery	5.00	MW Hrs
Saving in transmission capacity	0.63	MW
Minimum State of Discharge (SoC)	10%	
Battery Input Signal	1.47	MW
No of cycles per year	177	cycles

Storage Technology		
Battery Technology	Na-S	
Battery Cost/kWh	166.4	USD/kWh
	10,500	INR/kWh
DOD	90%	
Cycle Efficiency	90%	
Life	4,000	Cycles
	22	Years
Cost of replacement of storage technology	10,500 (166.4)	INR/kWh (USD/kWh)

Balance of System (BoS)		
BOS for battery management, PCU etc.	INR/W	
(US cents/W)	12	
(19)		
Life of BoS	Years	10
Replacement cost of BoS	INR/W (US cents/W)	12 (19)

Current Tariff		
Tariff of power sale to third parties in Tamil Nadu	5.2 (8.2)	INR/kWh (US cents/kWh)
Annual escalation	5%	
REC (Floor Price)	1.5 (2.4)	INR/kWh (US cents/kWh)
Period of REC Mechanism validity	10	Years

Other Charges		
Cost of Transmission	4,692 (74.4)	INR/MW/day (USD/MW/day)
Losses in transmission etc.	15%	
Savings due to better scheduling	0.03 (0.05)	INR/kWh (U.S. cent/kWh)

Cost of O&M		
Increase in O&M	2.0%	% of storage cost
Annual Escalation	5%	

Results

Power Export to Grid		
Without Battery Bank	4.38	million units
With Battery Bank	4.61	million units
Increase in export	0.23	million units
Savings during first year	2.78 (44.1)	INR million (USD thousand)
Present Value of savings	15.88 (251.7)	INR million (USD thousand)

Initial Costs		
Storage system	58.33 (924.4)	INR million USD thousand)
Storage Management system (BOS)	7.56 (119.8)	INR million USD thousand)
Total cost	65.89 (1044.2)	INR million (USD thousand)
Present value of cost	67.20 (1065)	INR million (USD thousand)
NPV of incremental cash flows	-51.32 (-813.3)	INR million (USD thousand)

Sensitivity analysis of NPV against tariff and Cost of Technology

Sensitivity of NPV in INR million (USD thousand) with varying Tariff and Cost of technology										
		Tariff in INR/kWh (U.S. cents/kWh)								
		5 (7.9)	6 (9.5)	7 (11.1)	8 (12.7)	9 (14.3)	10 (15.8)	11 (17.4)	12 (19.0)	13 (20.6)
Cost of storage technology INR/kW (USD/kWh	2,000 (31.7)	-45.35 (-718.7)	-29.57 (-468.6)	-13.8 (-218.7)	1.98 (31. 4)	17.75 (281.3)	33.52 (531.2)	49.3 (781.3)	65.07 (1031.2)	80.85 (1281.3)
	3,000 (47.5)	-100.76 (-1596.8)	-84.99 (-1346.9)	-69.21 (-1096.8)	-53.44 (-846.9)	-37.66 (-596.8)	-21.89 (-346.9)	-6.11 (-96.8)	9.66 (153.1)	25.44 (403.2)
	4,000 (63.4)	-156.17 (-2475.0)	-140.4 (-2225.0)	-124.63 (-1975.1)	-108.85 (-1725.0)	-93.08 (-1475.1)	-77.3 (-1225.0)	-61.53 (-975.1)	-45.75 (-725.0)	-29.98 (-475.1)
	5,000 (79.2)	-211.59 (-3353.2)	-195.81 (-3103.2)	-180.04 (-2853.2)	-164.26 (-2603.2)	-148.49 (-2353.2)	-132.71 (-2103.2)	-116.94 (-1853.2)	-101.17 (-1603.3)	-85.39 (-1353.2)
	6,000 (95.1)	-267 (-4231.4)	-251.23 (-3981.5)	-235.45 (-3731.4)	-219.68 (-3481.5)	-203.9 (-3231.4)	-188.13 (-2981.5)	-172.35 (-2731.4)	-156.58 (-2481.5)	-140.8 (-2231.4)
	7,000 (110.9)	-322.41 (-5109.5)	-306.64 (-4859.6)	-290.87 (-4609.7)	-275.09 (-4359.6)	-259.32 (-4109.7)	-243.54 (-3859.6)	-227.77 (-3609.7)	-211.99 (-3359.6)	-196.22 (-3109.7)
	8,000 (126.8)	-377.83 (-5987.8)	-362.05 (-5737.7)	-346.28 (-5487.8)	-330.5 (-5237.7)	-314.73 (-4987 .8)	-298.95 (-4737.7)	-283.18 (-4487.8)	-267.41 (-4237.9)	-251.63 (-3987.8)
	9,000 (142.6)	-433.24 (-6865.9)	-417.47 (-6616.0)	-401.69 (-6365.9)	-385.92 (-6116.0)	-370.14 (-5865.9)	-354.37 (-5616.0)	-338.59 (-5365.9)	-322.82 (-5116.0)	-307.04 (-4865.9)
	10,000 (158.5)	-488.65 (-7744.1)	-472.88 (-7494.1)	-457.1 (-7244.1)	-441.33 (-6994.1)	-425.56 (-6744.2)	-409.78 (-6494.1)	-394.01 (-6244.2)	-378.23 (-5994.1)	-362.46 (-5744.2)
	11,000 (174.3)	-544.07 (-8622.3)	-528.29 (-8372.3)	-512.52 (-8122.3)	-496.74 (-7872.3)	-480.97 (-7622.3)	-465.19 (-7372.3)	-449.42 (-7122.3)	-433.65 (-6872.4)	-417.87 (-6622.3)

B. Commercial and Industrial (C&I) Segment Facing Power Shortage

Currently, most industries and commercial consumers purchase electricity from utilities and a few consumers purchase on open access market as well. These consumers face restrictions in load during peak grid hours, grid outages and higher cost of power during peak hours. Deploying energy storage capacity can help consumers better manage their energy requirements and also increase solar energy use. Consumers can utilize energy storage capacity in the following way:

- Store energy during periods when grid and solar power are available
- Store energy during off-peak periods when the tariff is lower than other periods
- Purchase electricity during off-peak periods at a very low rate and store

Stored energy can be utilized

- During grid outages, partially offsetting expensive diesel power
- During peak grid periods to compensate for load restrictions
- During peak grid periods when the tariff is higher

Cost Benefit Analysis Framework:

	Parameters	Description
Benefits	Saving in diesel consumption	With energy storage capacity, electricity is stored during grid and solar available period. The energy saved is used during grid outages, partially offsetting diesel consumption. Difference between diesel savings and cost of energy stored is the net saving due to energy storage capacity. Also, electricity can be purchased on open access during nights when the cost of electricity is low. Electricity purchased at a lower price can be stored and used during outages. Difference between diesel savings and cost of energy stored is the net saving due to energy storage capacity.
Costs	Cost of initial investment	Initial cost of investment is based on current market trends.
	Cost of replacement during project life cycle	In the case of an energy storage system with solar plant, cost of storage for the entire project life of the solar plant needs to be analyzed in order to understand the cost and benefit of the energy storage technologies. Few storage technologies have a life of more than 25 years and need to be replaced during the project life of wind farm.
	O&M expenses	O&M expenses are considered as a percentage of capital cost.

Estimation Methodology:

For an estimation of the benefits that can stem from energy storage technology, Maharashtra has been considered, given that the commercial and industrial tariffs here are high. Based on the energy storage capacity, estimation can be made of the electricity stored in the capacity during the off-peak period and sun hours (solar energy). Savings can be estimated on the basis of the electricity stored and difference between off-peak power and the cost of diesel power/peak period.

Based on the benefits and cost estimations, NPV is calculated.

Assumptions

Load & Consumption		
Peak Load	5	MW
Peak Load to average load ratio	2	
Peak load average hours/day	0.5	hours
Consumption/day	61.3	MWh
Consumption during peak hours	10.2	MWh
Solar power		
Cost of roof-top solar power from RESCO	7 (1.1)	NR/kWh (U.S. cents/kWh)
Installed capacity of solar	2	MW
Average sun hours/day	4.5	hours/day
Annual generation	3285	MWh
Annual deration	0.50%	

Parameters of Selected Energy Storage Technologies

		VRLA Battery	**Li-Ion**	**Vanadium Redox**	**Ultra Battery**
Depth of Discharge (DoD)		50%	90%	90%	90%
Battery Efficiency		80%	90%	90%	94%
Cost of storage	USD/kWh INR/kWh	95.9 6,050	348.7 22,000	261.5 16,500	435.8 27,500
Life cycles		500	2,000	10,000	10,000
Life	Years	1	5	27	27

Tariff of Utility Power		
Energy Charges	6.33 (10.0)	INR/kWh U.S. cents/kWh)
Monthly charge	190 (3.0)	INR/kV/Month (USD/kW/month)
Off-Peak Power rate	5.33 (8.5)	INR/kWh (U.S. cents/kWh)
Off Peak Hours	8	hours
Peak rate	7.43 (11.8)	INR/kWh (U.S. cents/kWh)
Peak Hours	4	hours
Annual escalation	5%	
Open Access		
Off-peak Power procured from the exchange	2.75 (4.4)	INR/kWh (U.S. cents/kWh)
Cross-subsidy surcharge	0.76 (1.2)	INR/kWh with subsidy etc (U.S. cents/kWh)
Open Access Charges	4,944 (78.4)	INR/MW/day (USD/MW/day)
Wheeling charges	0.11 (0.2)	INR/kWh (U.S. cents/kWh)
Transmission losses	4.85%	
Wheeling losses	6%	
Cost of Electricity from Diesel		
Cost of power from Diesel Generator	18 (28.5)	INR/kWh (U.S. cents/kWh)
Annual Escalation	5%	

Results

NPV of net savings for energy storage solutions in INR million (USD thousand)	VRLA	Li-Ion	Vanadium Redox	Ultra Battery
Solution – Off-peak power + Storage	-973.20 (-15.4)	-282.1 (-4.5)	92.1 (1.5)	-25.8 (-0.4)
Solution – Off-peak power + Solar + Storage	-986.6 (-15.6)	-295.6 (-4.7)	78.6 (1.2)	-39.2 (-0.6)
Solution - Solar + Storage	-716.8 (-11.4)	-253.1 (-4.0)	43.8 (0.7)	-50.1 (-0.8)
Solution - Open access power + solar + storage	-998.4 (-15.8)	-311.5 (-4.9)	62.7 (1.0)	-56.5 (-0.9)

C. Rural Electrification using Solar Energy

With the current cost of energy storage technologies, the energy cost for rural electrification projects using solar (with VRLA battery) is quite high (about INR 19/day/household (U.S. cents 30.1/day/household)). The cost of electricity generated from solar mini grids with these new technologies has been estimated using a levelized cost method. Cost of energy storage technologies is estimated at which solar power form micro grids can be competitive to cost of power from utility grid.

Assumptions used in Model

Individual House Load Profile & Energy Demand per day

SL No.	Detail Description	Load in Watt	Quantity in Nos.	Duty Cycle (hours/day)	Energy (Wh/day)
1	LED Lamp	7	2	6	84
2	CFL	0	0	6	0
3	Fan	40	1	8	320
4	Power Socket	40	1	2	80
5	Other AC Load				0
6	**Total**				**484**
7	No. of households in village	200			
8	Total energy demand per day per village				96,800

Detail Design of Solar Plant			
	Detail Description		
1	Total Energy Demand per day	Unit (kWh)	96.80
2	Losses on DC side		93.10%
3	Temperature Losses		5.00%
4	Battery Efficiency		80.00%
5	Inverter efficiency		90.00%
6	Distribution Line efficiency		95.00%
7	System Efficiency		60.50%
8	**Total energy demand from the array per day**	**kWh**	**160**
9	Sun hrs	kWh/sqm/day	4.5
10	Array Capacity	kWp	36
11	Autonomy	day	1
12	Depth of Discharge		50%
13	Battery capacity in kWh	kWh	287
14	Battery DC Voltage	Volt	240
15	**Battery capacity in Ah.**	**Ah**	**1,195**

Results

Parameters of Storage Technologies					
		VRLA Battery	**Li-Ion**	**Vanadium Redox**	**Ultra Battery**
Depth of Discharge (DoD)		50%	90%	90%	90%
Battery Efficiency		80%	90%	90%	94%
Cost of storage	USD/kWh	95.9	348.7	261.5	435.8
	INR/kWh	6,050	22,000	16,500	27,500
Life cycles		500	2,000	10,000	10,000
Life	Years	1	5	27	27
System cost	INR/Wp	182	235	211	261
	(USD/Wp))	(2.9)	(3.7)	(3.3)	(4.1)

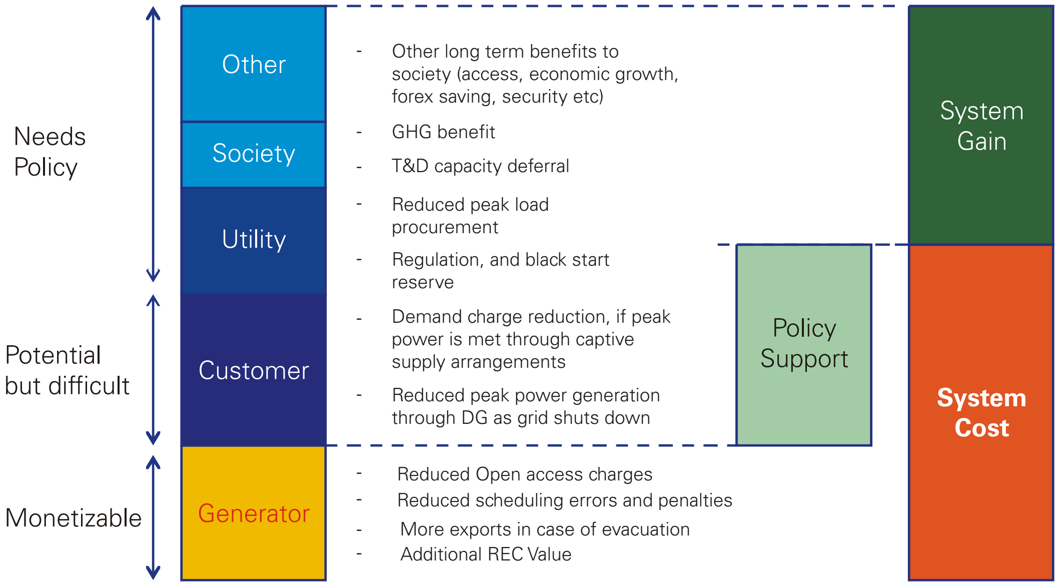
Results

		VRLA Battery	Li- Ion	Vanadium Redox	Ultra Battery
Cost of energy	INR/kWp (U.S. cents/kWp)	47.44 (75.2)	24.79 (39.3)	14.21 (22.5)	16.26 (25.8)
Cost of storage of energy supplied	INR/kWh (U.S. cents/kWh)	8.23 (13.0)	4.30 (6.8)	2.47 (3.9)	2.82 (4.5)

Annex 5 Principles for estimating 'value' of storage

Energy storage, at different times, can play different roles, for a variety of stakeholders. For example it may play the role of 'generator' and provide energy at peak periods to a group of consumers, can act as contingency reserve for transmission system operators, provide frequency regulation (control of ramp up or down of power) for generators. Depending on the contractual commitments and priorities, therefore, the same storage capacities will have many revenue streams and economic values. Not all of them will be 'monetizable', depending on the policy regime. The following diagram explains this logic in terms of 'value' stacks for a storage capacity.

value Stack of Storage - storage at evacuations



If economic value from more value streams can be utilized the application may not need any policy support – will be viable on market principles

While evaluating various potential use cases for a storage capacity and its value stack, following key principles should be used:[78]

1. Assessing storage requirements and its value based on location of the storage resource in the grid.
2. Avoiding double counting of benefits

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[78] In line with EPRI/DOE Handbook of Electricity Storage 2013.

3. Distinguishing between monetizable services and benefits and indirect/non monetizable benefits.
4. Carrying out simulation of value only after identifying technically feasible and potentially cost effective use-cases.
5. Delaying policy analysis until effective use cases with their impacts are modeled and understood.

Steps for modeling value of Energy Storage:

1. Identify grid requirements, location, and potential use of ESS to meet the requirement
2. Translate grid requirement to ESS specifications, define solution value
3. Develop feasible use cases (technically feasible and monetizable anchor services, coupled with secondary services, frequency and duration of services, hierarchy of services based on terms of contracts). These often would be location specific.
4. Assess grid impacts (baseline scenario, vis-à-vis scenario with ESS) and incidental benefits.
5. Estimate the break-even price/performance at which storage becomes viable in the application. Develop a business case for the investor in ESS.

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