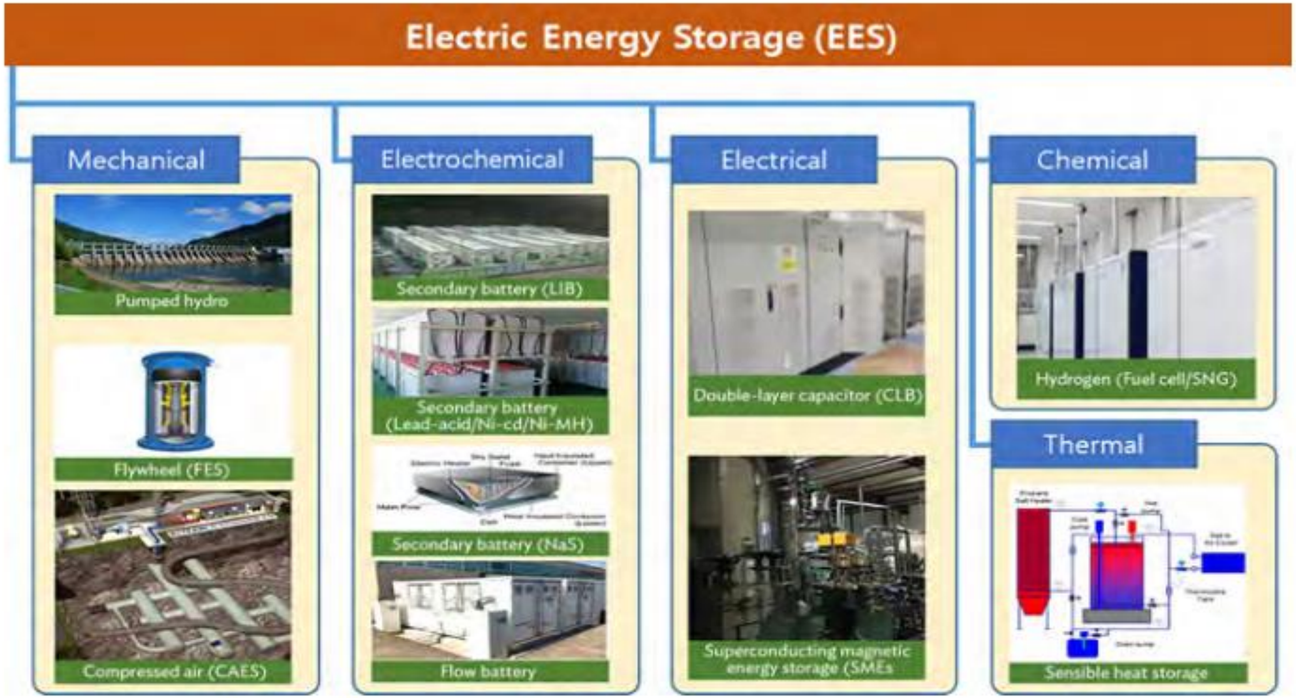
BATTERY ENERGY STORAGE SYSTEM (BESS)

Lighting up Lives!

ENERGY STORAGE SYSTEMS

Energy Storage System is a general term for the ability of a system to store energy using thermal, electro-mechanical or electro-chemical solutions.



*Mechanical, electrochemical, chemical, electrical, or thermal.
Li-ion = lithium-ion, Na–S = sodium–sulfur, Ni–CD = nickel–cadmium, Ni–MH = nickel–metal hydride, SMES=superconducting magnetic energy storage.

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Battery Energy Storage System

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- Battery Energy Storage System (BESS) is a technology developed for storing electric charge by using specially developed batteries.
- The underlying idea being that such stored energy can be utilized at a later time.
- A BESS typically utilizes an electro-chemical solution.

Why BESS over other storage technologies

BESS has following advantage over other Storage technologies as

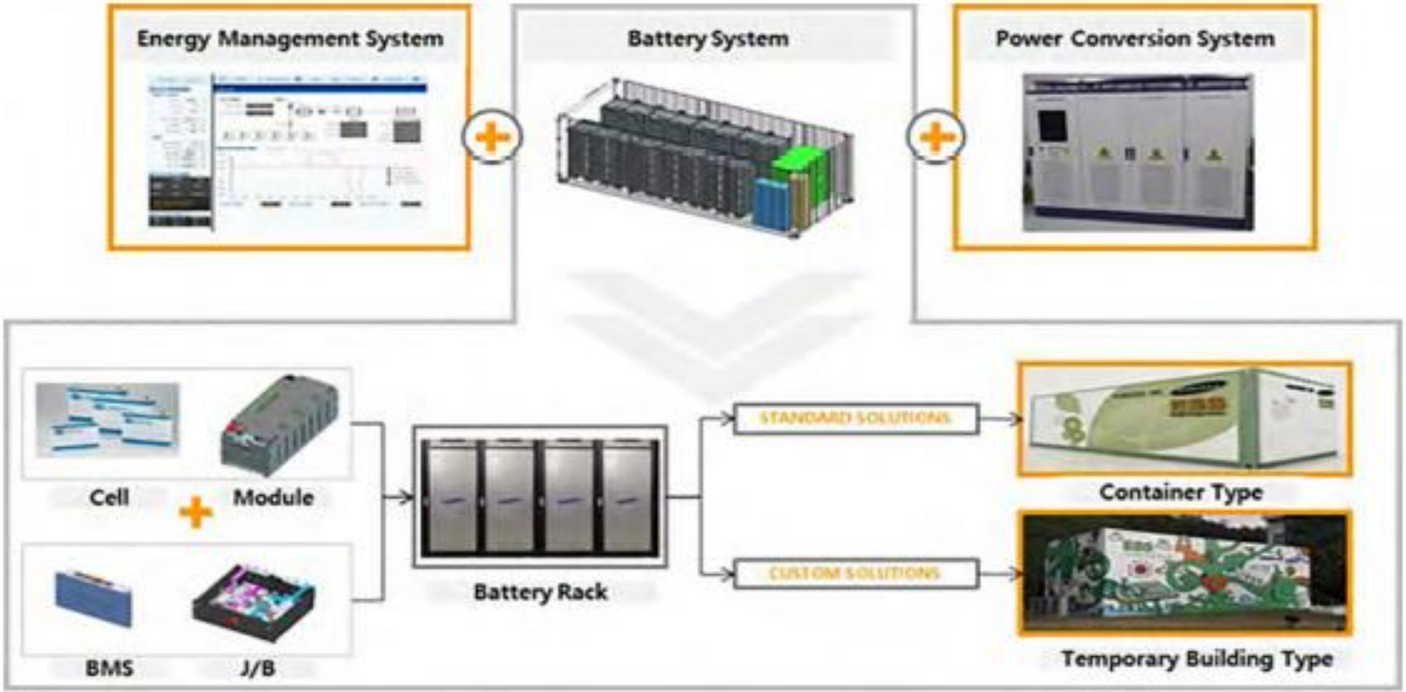
- It has small footprint and no restrictions on geographical locations that it could be located in.
- Other Storage technologies like Pumped hydro storage (PHS) and Compressed air energy storage (CAES) are only suitable for limited number of locations, considering water and siting-related restrictions and transmission constraints.

Energy and power densities of some technologies are as follows:

Technology	Power Density (W/l)	Energy Density (Wh/l)
PHS	0.1 - 0.2	0.2 - 2
CAES	0.2 -0.6	2 - 6
Li-ion Battery	1300 - 10000	200 - 400
Lead Acid Battery	90 - 700	50 - 80
NaS	120 - 160	150 - 300

- It is clear that BESS utilizing Lithium Ion technology offer high energy and power densities that are suitable for utilizing at distribution transformer level. The available space at the distribution transformer setup can be used to locate the BESS.
- Further the rated apparent power of distribution transformers are in the range of 160 kVA, 400kVA up to 1 MVA (for rural, urban and metropolitan respectively).

COMPONENTS OF BESS



BMS = battery management system, J/B = Junction box.

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DIFFERENTIATING CHARECTERISTICS OF DIFFERENT BATTERY TECHNOLOGIES

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	Energy density (kW/kg)	Round Trip Efficiency (%)	Life Span (years)	Eco-friendliness
Li-ion	1st 150–250	1st 95	1st 10–15	1st Yes
NaS	2nd 125–150	2nd 75–85	2nd 10–15	2nd No
Flow	3rd 60–80	3rd 70–75	4th 5–10	4th No
Ni-Cd	4th 40–60	4th 60–80	3rd 10–15	3rd No
Lead Acid	5th 30–50	5th 60–70	5th 3–6	5th No

Li-ion = lithium-ion, Na–S = sodium-sulfur, Ni–Cd = nickel-cadmium.

Value Levers for BESS in Power Systems

Ancillary Services	▪ BESS can provide Ancillary Services support (frequency and voltage support) ▪ Black start
Transmission Infrastructure Services	▪ Transmission congestion relief and upgrade deferral ▪ Technical loss reduction ▪ Right of Way (RoW) constraint management
Distribution Infrastructure Services	▪ Ramping for self-scheduled portfolios / avoiding RE curtailment ▪ Distribution upgrade deferral ▪ Reliability enhancement: outage mitigation ▪ Managing large scale EV charging stations across distribution network ▪ Peak shaving and energy support
Avoided Renewable Curtailment	▪ RE energy time-shift (arbitrage) [hourly BESS support] ▪ Capacity firming of RE generation [Sub-hourly BESS support]

Battery Energy Storage Systems are more flexible than other conventional options, as they do not have locational constraints, have very fast response times and can be deployed in both large and small scales.

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GRID APPLICATIONS OF BESS

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Grid Applications	Technical Considerations
Electric energy time-shift : • It involves purchasing inexpensive electric energy, available during periods when prices or system marginal costs are low, to charge the storage system this stored energy can be used or sold at a later time when the price or costs are high. • Similar time-shift duty can be provided by storing excess energy production, which would otherwise be curtailed, from renewable sources such as wind or photovoltaic.	Storage system size range: 1 – 500 MW Target discharge duration range: < 1 hour Minimum cycles/year: 250 +
Regulation: • It involves managing interchange flows with other control areas to match closely the scheduled interchange flows and momentary variations in demand within the control area. • It helps in maintaining the grid frequency.	Storage system size range: 10–40 MW Target discharge duration range: 15 min to 1 hour Minimum cycles/year: 250–10,000
Black start : • Storage systems provide an active reserve of power and energy within the grid and can be used to energize transmission and distribution lines and provide station power to bring power plants on line after a catastrophic failure of the grid. • Storage can provide similar start-up power to larger power plants, if the storage system is suitably sited and there is a clear transmission path to the power plant from the storage system's location	Storage system size range: 5–50 MW Target discharge duration range: 15 minutes to 1 hour Minimum cycles/year: 10–20

USE CASES

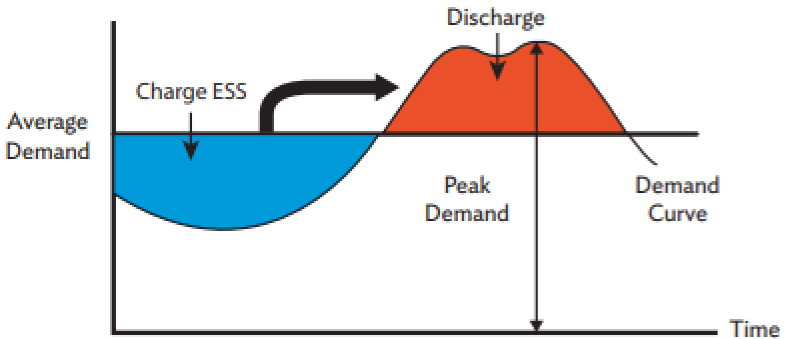
RENEWABLE ENERGY INTEGRATION:

CHALLENGES FACED BY RENEWABLES WITHOUT BESS	CHALLENGES THAT CEN BE ENCOUNTERED WITH BESS
Network owners may be penalized for insufficient reinforcement of network capacity to accommodate all network connection requests.	More grid connections can be made under existing network capacity as surplus power can be stored
Distribution system operators may have trouble with system stability and may be forced to curtail renewable in-feed to avoid over-voltage conditions.	Smoothing of renewable in-feed reduces forecast errors, and the need to procure spinning reserve. Surplus power can be stored at consumers' homes instead of being fed into the grid.
Network reinforcement and curtailment costs are ultimately recovered from end consumers in the form of higher tariffs.	Higher network capacity utilization reduces the burden on consumers as curtailments are reduced and network reinforcement is minimized.

USE CASE - DEMAND SIDE MANAGEMENT

PEAK SHAVING

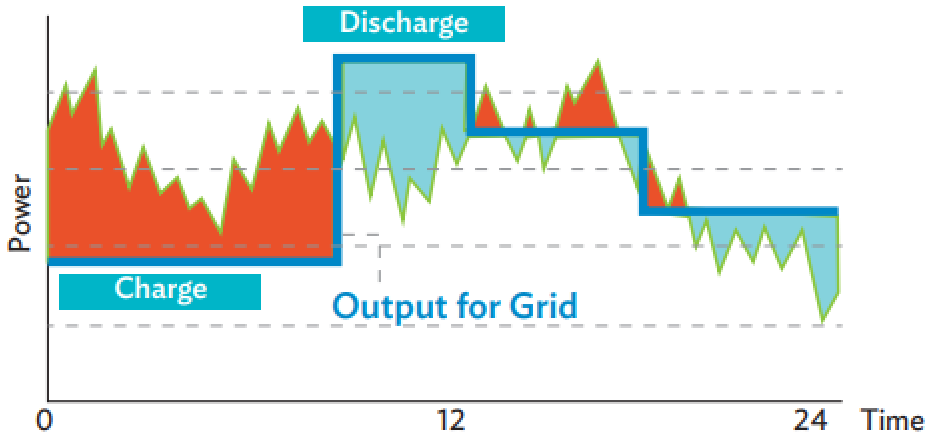
- The reduction of electric power demand when network capacity is stressed is known as peak shaving
- Helps defer investments in network expansion or network reinforcement.
- Helps the utility meet demand without having to ramp up expensive peaking generators.
- Customers that install on-site power generation share in those savings by receiving reduced power tariffs or in some cases capacity payments (such as in the United Kingdom [UK]).
- Peak-shaving generators use special equipment to monitor the electric grid and start up quickly. This equipment provides the added benefit of backup power in case of rolling backups and grid outages



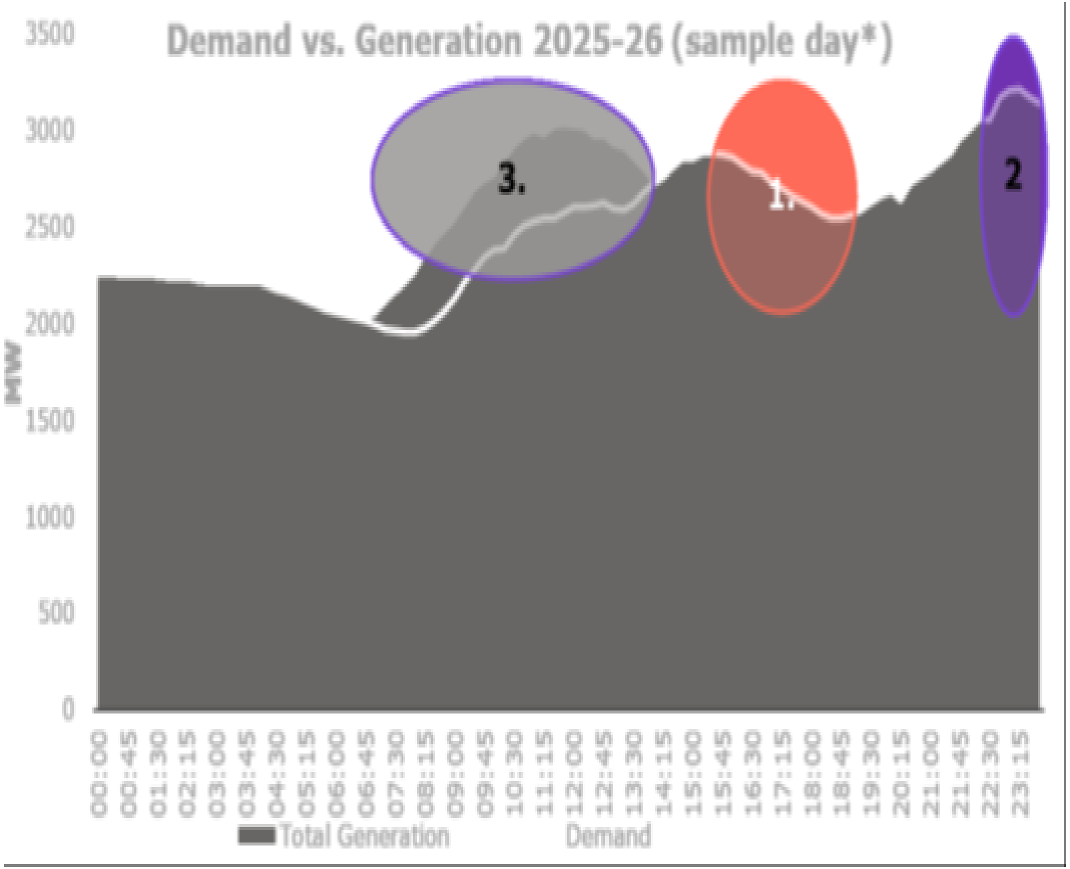
USE CASE - DEMAND SIDE MANAGEMENT

LOAD LEVELLING

- It is the process of shifting demand away from peak hours to off-peak hours.
- Behind-the-meter energy storage allows for load leveling without any changes to the consumer load profile.
- Reducing peak-time usage of grid-supplied electricity – saves energy costs , reduces overuse charges, prevents blackouts by means of the UPS feature of generators, complies with carbon dioxide (CO2) reduction regulations.



BENEFITS OCCURRED FROM BESS



1.Benefits from Ramping Support
Inability of thermal generators in the portfolio in supporting rapid decline in RE/uptake in demand.
BESS can discharge quickly to "even out" the generation.

2.Benefits from Energy Arbitrage
BESS will run at slots with peak demand and help in peak reduction. The BESS will charge when the energy cost is low and dispatch during peak (high cost)

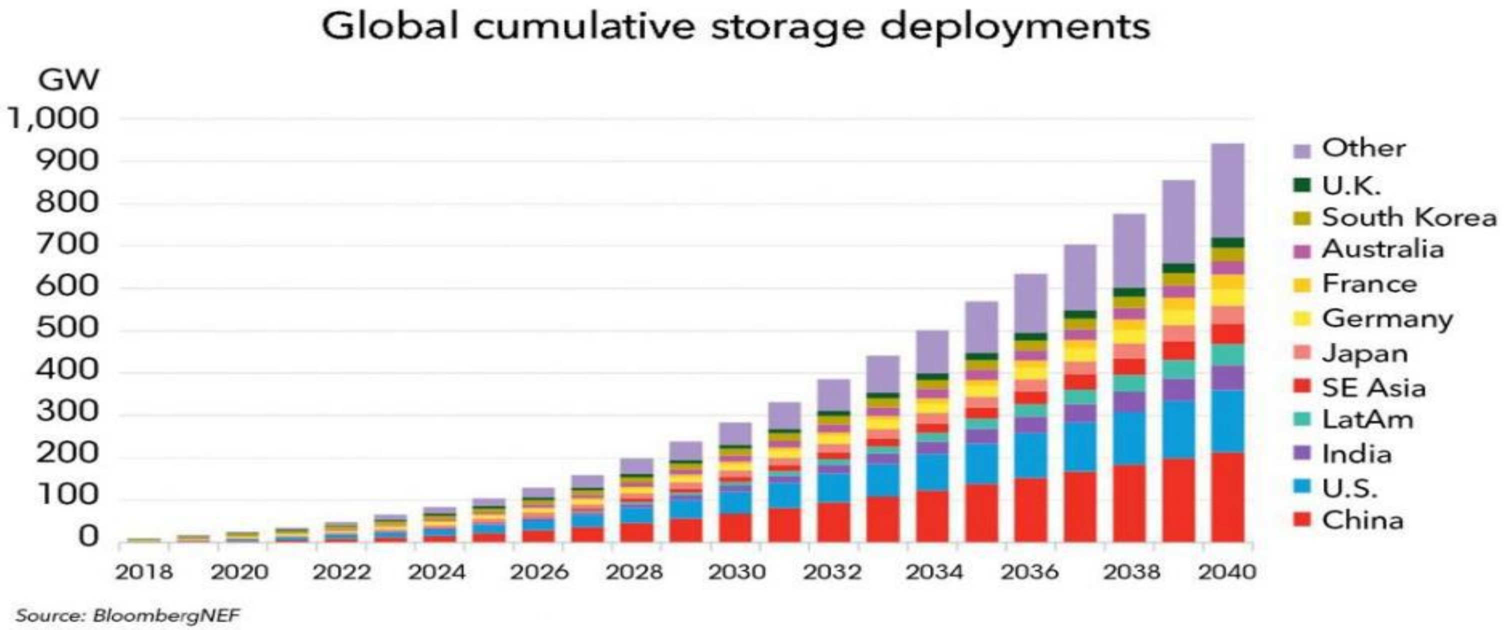
3.Excess Generation
As the country shifts to more RE generation, there will be excess of generation which can be used to charge the BESS at lower cost

4.Capacity Deferral
The battery system is optimally located to defer distribution capacity enhancements.

Global storage market trends

Drivers:
- Global movement towards renewables
- Cost & performance improvements
- Financial backing for storage companies

Challenges:
- Outdated regulatory and market design
- Perception of high prices
- Lack of standardization



BESS System Cost Projections

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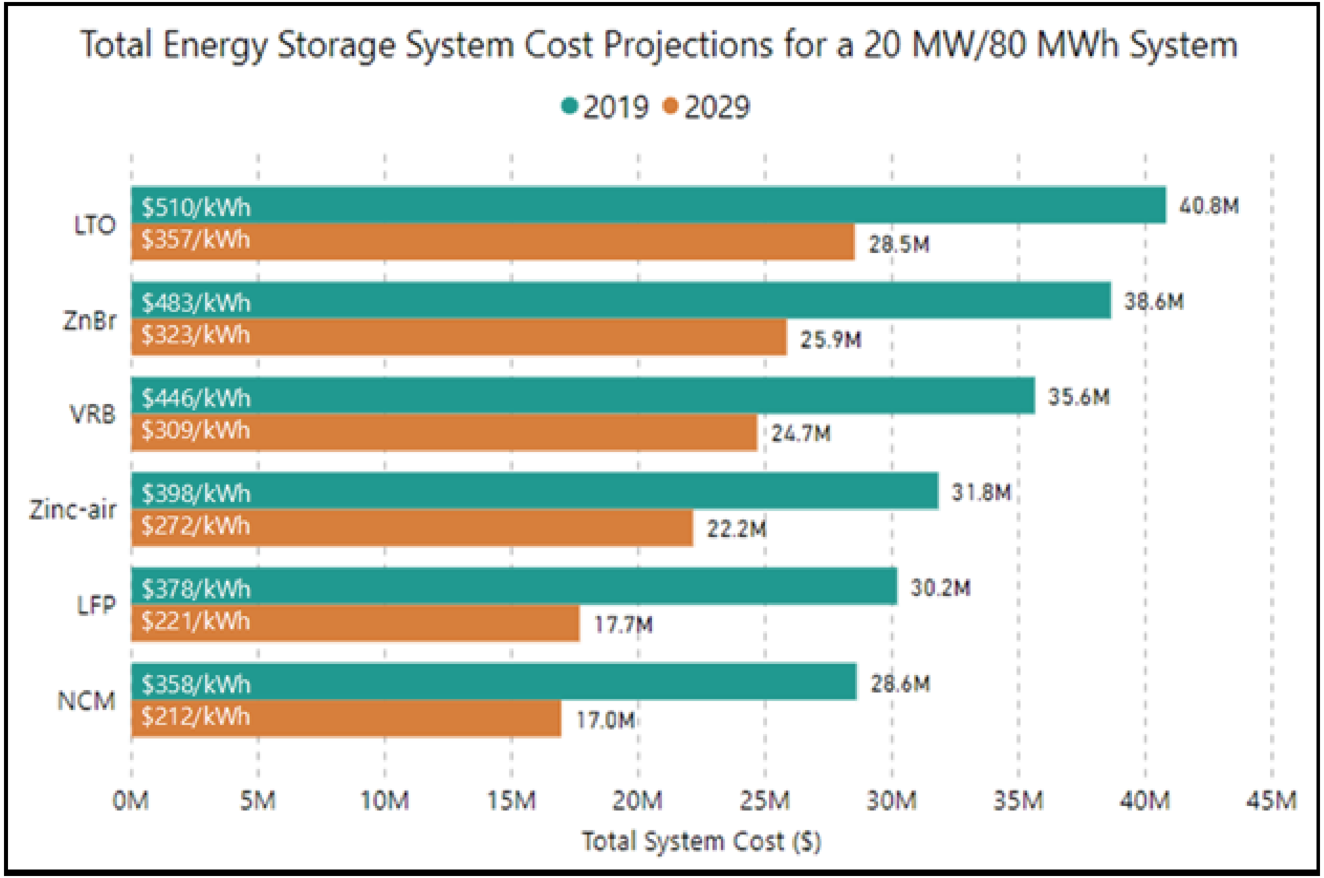

- LTO: Lithium Titanate
- NCM: Lithium Nickel Manganese Cobalt Oxide
- LFP: Lithium Iron Phosphate
- ZnBr: Zinc Bromide
- VRB: Vanadium Redox Battery

Costs will keep reducing over the next decade

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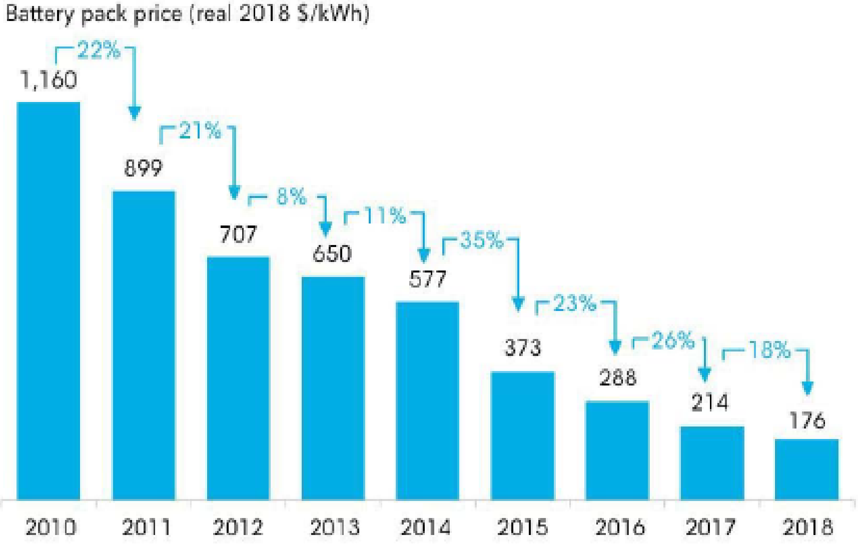
Total energy storage system project cost is expected to decrease by 30-40% by 2029 across all battery technologies

The primary drivers of the cost reductions include:

- Increased production capacity
- Supplier diversity
- Incremental performance improvement
- Reduction in project development and engineering costs

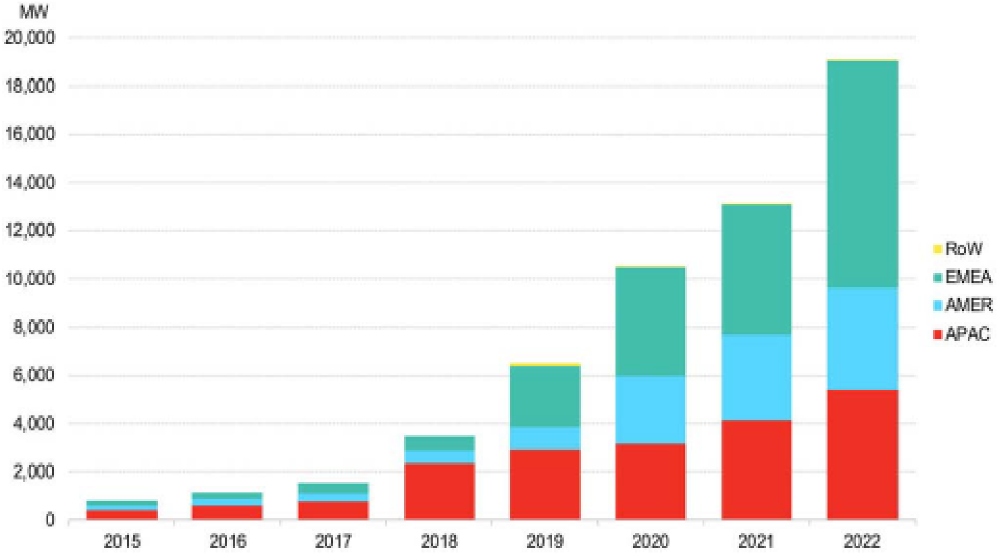
The trajectory of storage cost has similarities with historical solar cost trends

Lithium-ion battery price survey results: volume-weighted average



Source: BloombergNEF

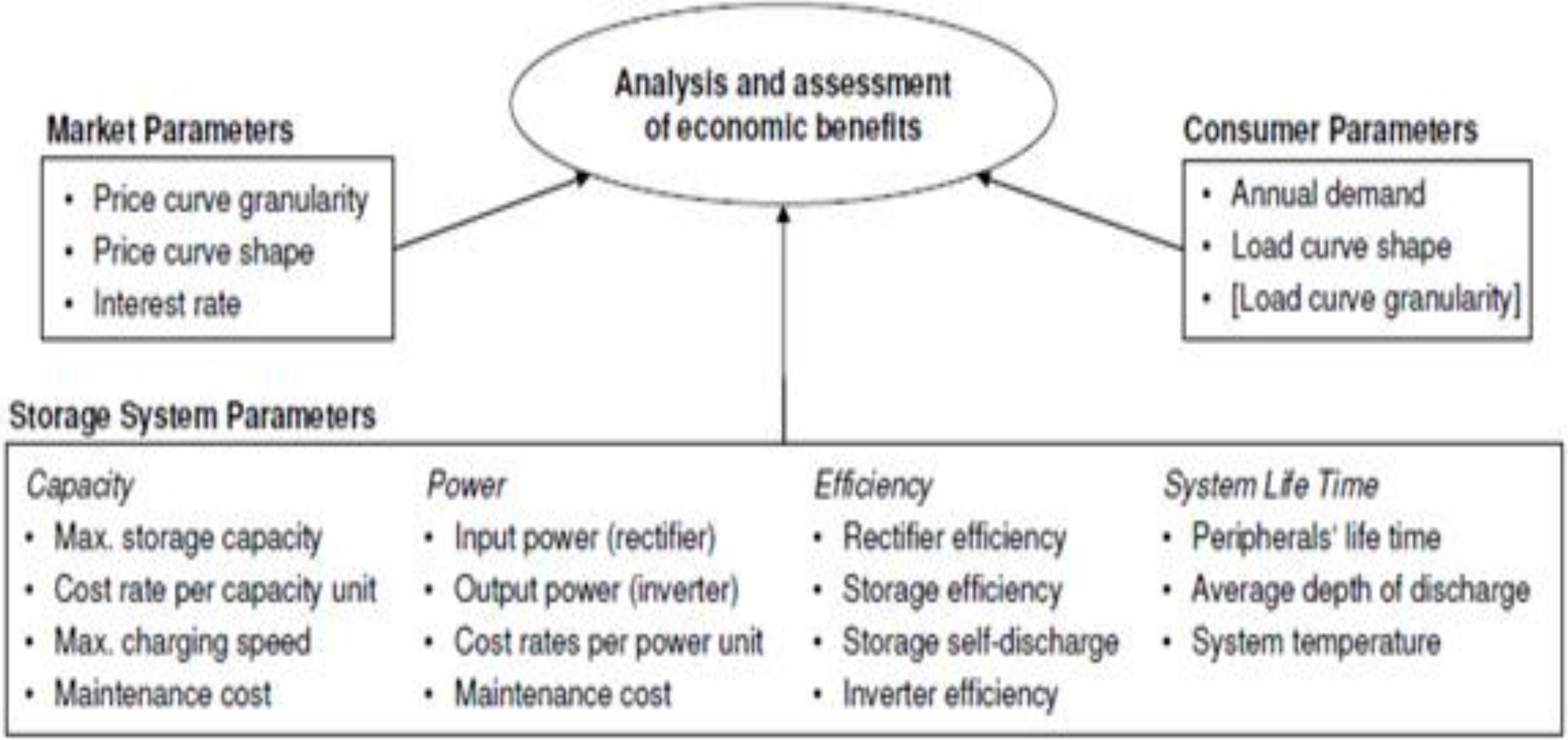
Global Cumulative Storage Deployments, 2016-2030 (GWh)



85% cost reduction since 2010 due to technology improvements, economies of scale, manufacturing competition

Similar trajectory to PV deployment in early 2000s

Parameters for determining the BESS economics



Cost Analysis: Cost Breakdown

1. Capital cost or plant financial carrying charges

    a. Storage System footprint and space requirements (Energy andPower density).
    b. BESS (batteries, power converters, etc.)
    c. Facility infrastructure (communications and control, environmental control, grid interconnection, etc.)

2. Total operating cost:

    a. Cost for charging the system
    b. Labor associated with plant operation
    c. Plant maintenance
    d. Replacement and repair cost
    e. Decommissioning and disposal cost

Cost Analysis: Utilizing Used Li-Ion Batteries

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- A new 15 kWh battery pack currently costs **$990/kWh to $1,220/kWh** (projected cost: 360/kWh to $440/kWh by 2020).

- The expectation is that the **Li-Ion** (EV) batteries will be **replaced** with a fresh battery pack once their efficiency (energy or peak power) **decreases to 80%**. Based on various forecasts for market penetration of PHEVs and EVs over the **next 10 years**, a large number of PHEVs and EVs will be approaching this 80% efficiency level by 2020. These batteries can be **recycled** or used in other less demanding applications for the rest of their useful life provided a business case can be made for their secondary use.

- The **minimum goal** for a selling price for a Used Li-Ion Batteries is less than **$150/kWh** for 25,000 units at 40 kWh.

Benefit Analysis: Revenue Generating Applications

1. Electric Energy Time-Shift
2. Load Following
3. Renewables Energy Time-Shift
4. Renewables Capacity Firming

Benefit Analysis: Electric Energy Time-Shift

- Basic concept: *Buy low / Sell high*
- Key elements:
  - Round trip efficiency
  - Hourly prices
  - Discharge duration
- For about 900hrs/year the price is $100/MWhr* (peak time)
- For about (8760-900)=7860hrs/year the price is $50~$60/MWhr* (off-peak time)

Decision making process: If the cost for wear on the storage system, plus the cost for charging energy, plus the cost to make up for storage losses exceeds the expected benefit, then the transaction is not made.

- The generic benefit estimate for Electric Energy Time-Shift ranges from $400/kW to $700/kW (over 10 years).

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Benefit Analysis: Renewables Energy Time-Shift

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- Similar concept Electric Energy Time-Shift but with emphasis on the renewable energy source.

- Instead of selling off-peak energy in real-time (when generated), that energy is stored and used at a later time when energy prices are high.

- Peak time 12:00 pm – 5:00 pm

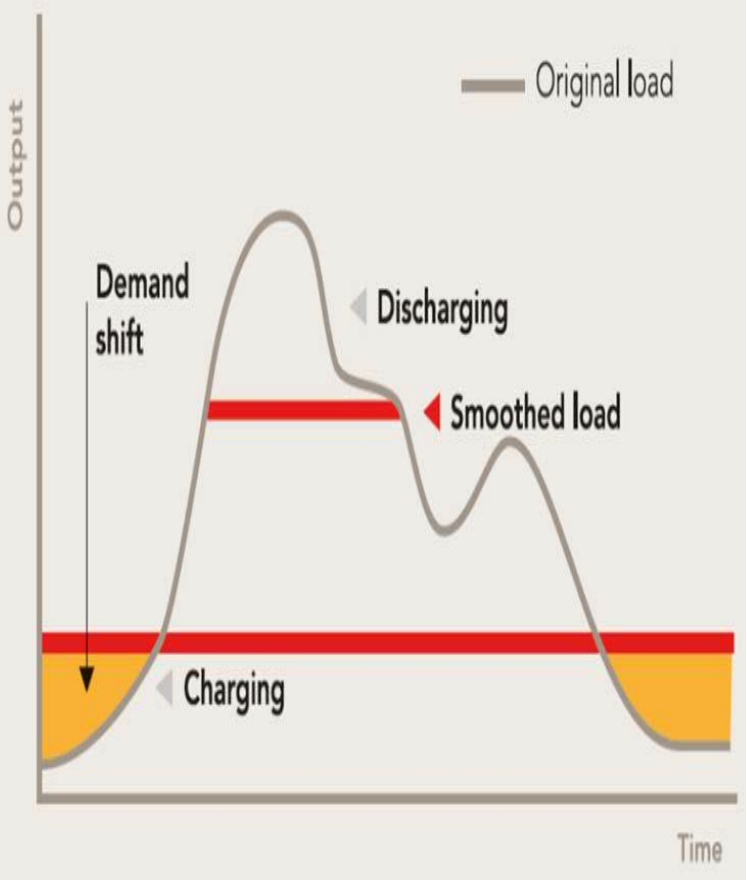
- Storing low-priced energy from the grid *and* directly from renewable energy generation means that there is more energy output from the renewable energy plus storage system than could be delivered if only energy from renewable energy generation is stored.

- The generic benefit estimate for Renewables Energy Time-Shift ranges from $233/kW to $389/kW (over 10 years).

Benefit Analysis: Load Following

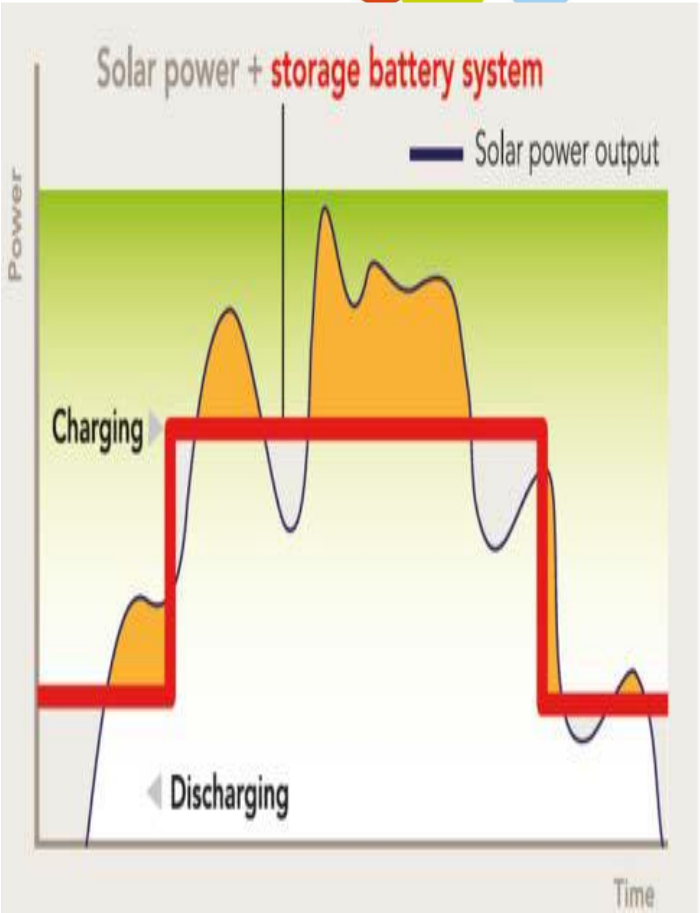
The benefit consists of two possible scenarios:

- ❑ Marginal cost: Cost for fuel and variable maintenance
  - ✓ Low end cost $20/MW per hour (hydroelectric plant)
  - ✓ High end cost $50/MW per hour (combined cycle generation)
- ❑ Capacity cost: Cost for additional generation capacity
  - ✓ A simple cycle combustion turbine costs $60/kW- year
  - ✓ A combined cycle plant costs $120/kW-year
- ❑ The generic benefit estimate for Load Following ranges from $359/kW to $710/kW (over 10 years).



Benefit Analysis: Renewables Capacity Firming

- A well-optimized, solar generation facility can have a 0.80 capacity credit.
- Whereas another solar generation facility might be firmed with a capacity credit of 0.40 (*i.e.,* distributed, flat panel PV modules with a suboptimal and fixed orientation, regular dust accumulation, shading by surroundings, high ambient temperatures, high level of cloudiness, etc.).
- Adding storage to distributed fixed-orientation PV is assumed to increase the capacity credit from 0.40 to 1.0.
- The renewables capacity firming benefit estimated for adding storage to renewable energy generation is incremental. Consequently, the financial merits of adding storage to renewables generation, the incremental benefit is compared to incremental cost (to add storage).
- The generic benefit estimate for Renewables Capacity Firming ranges from $709/kW to $915/kW (over 10 years).



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Storage project costs accrue to goods and services provided by three parties

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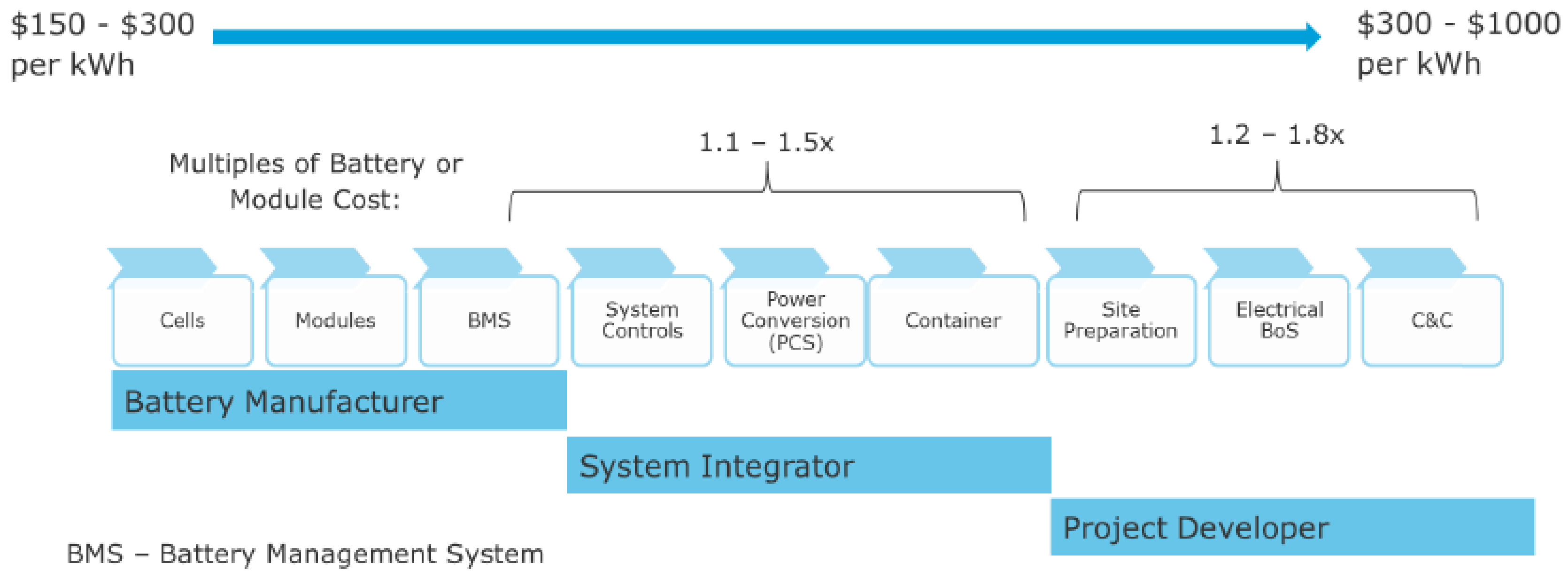


BMS – Battery Management System

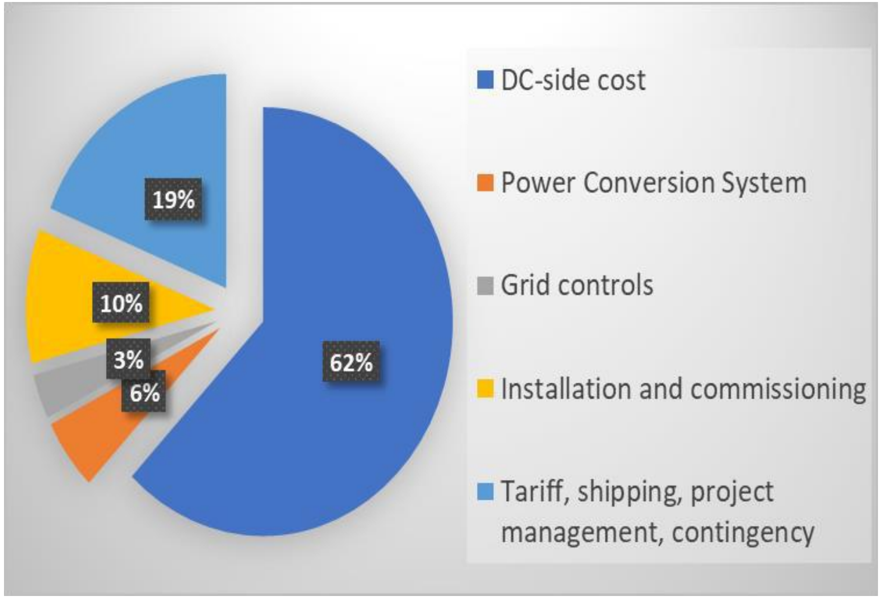
C&C – Construction & Commissioning

BoS – Balance of System

CAPEX WALKTHROUGH

Technology	Cost Range
DC Side Modules and BMS ($/kWh)	$200 -$500
Power Conversion System ($/kW)	$70 -$110
Grid management control system ($/kW)	$20 -$50
Electrical BoP, installation, commissioning ($/kW)	$80 -$200
Services, tariffs and contingency ($/kWh)	$50 -$100
Preventative maintenance cost ($/kW-year)	$3 -$7
Capacity Maintenance Cost	Based on amortized dc-side replacement cost at $100-$250/kWh based on overbuild/augmentation schedule OR Annual contract
Equipment insurance fee	0.5% -1.0% Capex per year

CAPEX WALKTHROUGH



- DC-side cost is 60-65%
- PCS and control costs ~10%.
- BoP and Project development costs are 20 –30%

CASE STUDY

Unique experiment: South Australia's Battery Farm

Hornsdale Power Reserve (HPR), the 129MWh battery energy storage system (BESS) deployed by Tesla and developer Neoen in South Australia in 100 days duration was found to have had a positive impact on the local network.

The system went into operation in November 2017. Aurecon, an independent engineering and infrastructure advisory company, issued a case study report based on HPR's performance on its first 365 days of service.

Description

- It is the world's largest lithium ion battery system in existence to date
- HPR has a 100MW discharge capacity and shares a 275kV network connection point with Hornsdale Wind Farm (300MW).
- Of the 100MW capacity, 70MW is reserved for system security services contracted to the South Australia government, while Neoen can use the remaining 30MW and 119MWh of storage capacity to participate in market opportunities.
- Aurecon's experts found HPR to have supplied numerous benefits to the system throughout the year, including removing the need for network upgrades and additional capacity. It also responded effectively to stress events on the local network.

System Operation

- The first year of operation included a “large system security event” , when an inter-connector between the grids of Queensland and New South Wales was tripped, islanding the Queensland region. Using fast frequency response (FFR) services, HPR was able to stabilize grid frequency to within the accepted range of 0.15Hz either side of 50Hz. Aurecon said HPR “performed as required”, providing significant frequency support to all connected National Electricity Market regions.

- HPR also participates in six further Frequency Control Ancillary Services markets for AEMO, including managing total deviation of frequency and Rate of Change of Frequency. From operational data provided, Aurecon said the system is providing “very rapid and precise response to FCAS regulation signals”. This is in particularly stark contrast to the much slower and less precise responses provided by steam turbines, which have been the traditional means of balancing this part of the network.

- Aurecon said HPR has greatly increased the competitive dynamic of the FCAS markets, highlighting that in 2016 and 2017 FCAS constraints meant 35MW of capacity had to be kept aside, adding close to AU$40 million in regulation costs in that time.

- In addition to frequency regulation, the system also participates in AEMO and ElectraNet’s System Integrity Protection Scheme (SIPS), which offers protection against the loss of the locally-sited Heywood Interconnector if multiple generators fail. It’s a direct response to the 2016 blackout which eventually inspired the deployment of HPR, and Aurecon acknowledged that HPR plays a significant role in injecting energy into the network. It is required to discharge up to 100MW in under 150ms. If this step fails, the system is then used to help provide load shedding to the network.

Pilot on Grid Connected BESS at Transmission Voltage

Implemented in collaboration with Power Grid Corporation of India Ltd. (CTU)

Augmenting the system with capabilities to demonstrate array of use cases (on Advanced Lead and Lithium -ion) including:

a. Dynamic Frequency Regulation
b. Voltage/Reactive Power Support
c. Load Following
d. Peak Shaving
e. RE Capacity Firming
f. RE Time Shift
g. Integrated Applications

- This pilot shall test the techno-economic effectiveness of grid-connected BESS in providing dynamic frequency regulation and other ancillary services.

- The pilot shall also be crucial in providing inputs to finalize standards for BESS grid interconnection.

- The pilot is helping establish detailed site acceptance standards for grid-connected BESS

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Pilot on Grid Connected BESS at Transmission Voltage

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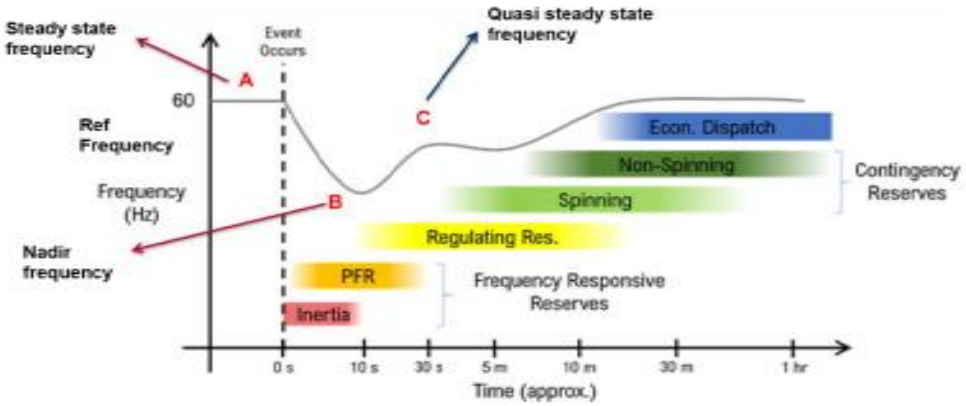
Value of BESS in Primary and Secondary Frequency Response –Southern Region

GTG-RISE, with the support of PRDC Ltd, carried out simulation studies for frequency regulation with BESS. It involved assessing the performance/impact of grid connected BESS response in arresting grid frequency events in the inertial/primary time frame and determining optimal sizing of BESS for grid stability.



- Simulation indicated that a 1200 MW (1 hr) BESS was equivalent to ~3000 MW of spinning reserves required in the Southern Region for primary response.
- Deployment of 1200 MW BESS yields significant benefits in releasing the 3000 MW of spinning reserves for participation in the day-ahead market.
- Benefits outweigh cost of 1200 MW BESS by a factor of 3 as restrictions on scheduling beyond MCR can be relaxed for all conventional plants with BESS deployment.

Pilot on Grid Connected BESS in Distribution Network

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Establishing business case for a distribution utility in Delhi for its 20 MW BESS

Conceptualization & Pilot Implementation

- Stacked economic benefit assessment of 20 MW BESS deployment in Distribution system
- Develop Market Framework for BESS in Distribution

Market & Regulatory Framework

- Preparing a business case for deployment of BESS in distribution
- Business model formulation and SLA conditions
- Business case approval from DERC

Key Activities

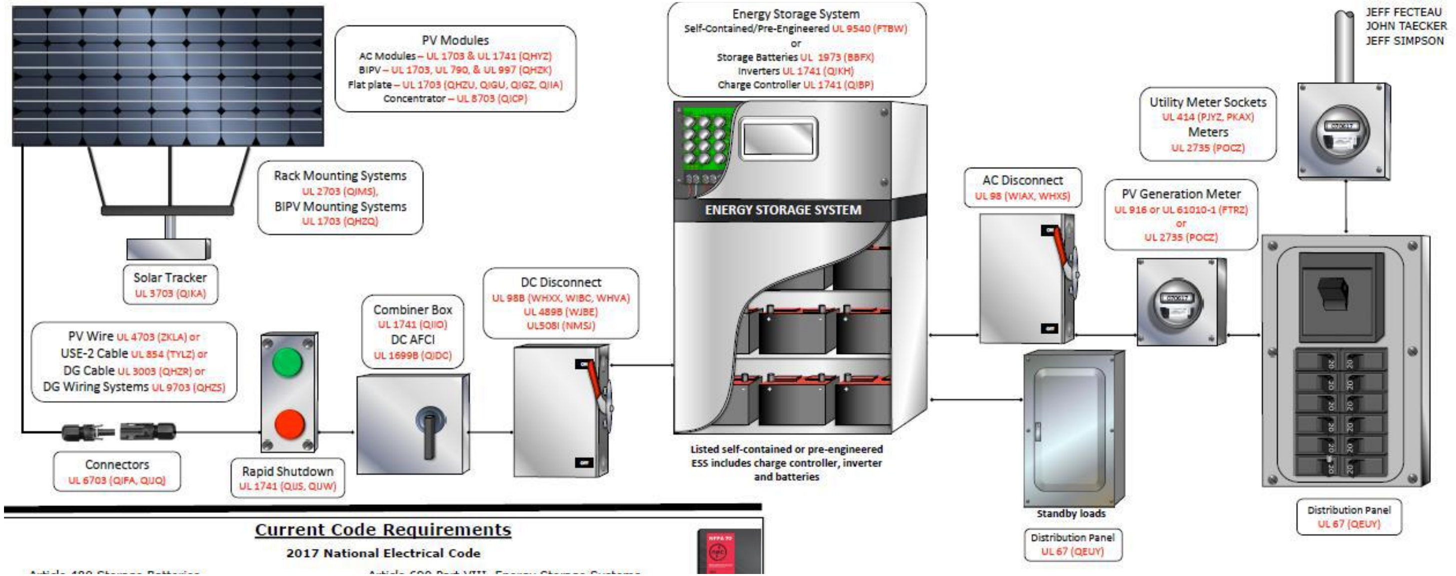
- ❑ Technical (load flow) modeling of the interconnected network in **standard load flow modeling tools** to evaluate capacity deferral of the associated network infrastructure (Transformer, feeder, Capacitor bank etc.)

- ❑ Simulation modeling (**Python based optimization model integrated with Open DSS**) to estimate stacked economic benefits from ramping support, energy time-shift, CAPEX deferral and other potential applications for optimal utilization of BESS

Compliance and Safety

For most projects, individual components of the BESS are required to meet electrical and/or safety code and standard requirements.

Battery, Cells, Modules and Racks	Battery Container	BESS
• UL 1642 • UL1973 • UL 38.3	• NEC/NFPA 70 (U.S) • SPE 1000(Canadian)	• UL 9540 • NFPA 855 • NFPA 1



AC/DC Convertor

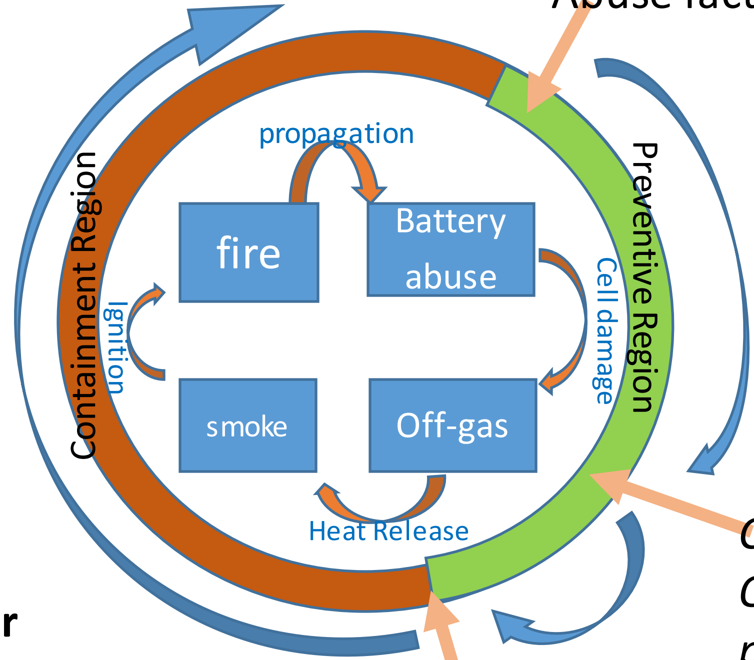
UL 1741
IEEE 1547(Invertor only)

Defining the hazard: What is “thermal runaway”?

Application of Abuse factor

Abuse factor examples:
-Temperature of +250°F (+120 C)
-Failure of grid, transformer, inverter, breakers, and fuses

Second order thermal runaway impacts:
-High heat, causing cascading failure
-Fire



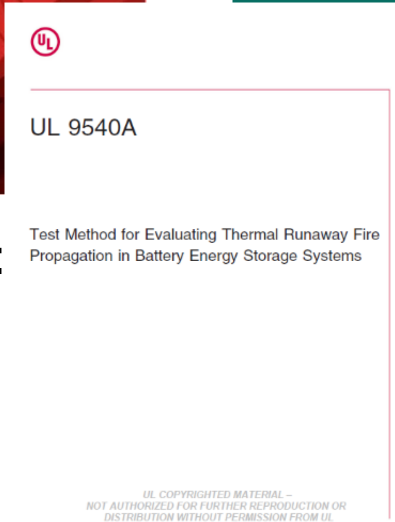
Cell vents – Opportunity for preventative actions

Opportunity for containment actions

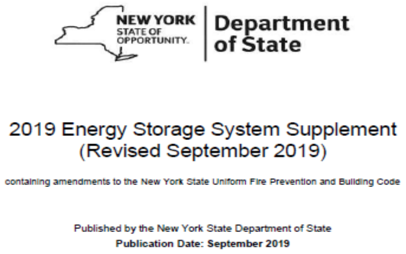
Oneset of thermal Runaway

Managing the hazard: Standards to prevent thermal runaway

- **NFPA 855**
- **IFC 2018 (and 2021)**
- **UL Standards**
  - UL 1642 (cell)
  - UL 1973 (module)
  - UL 1741 (inverter)
  - UL 9540 (system)
  - UL 9540A (test method)
- **2019 New York Code Supplement**


UL 9540A

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

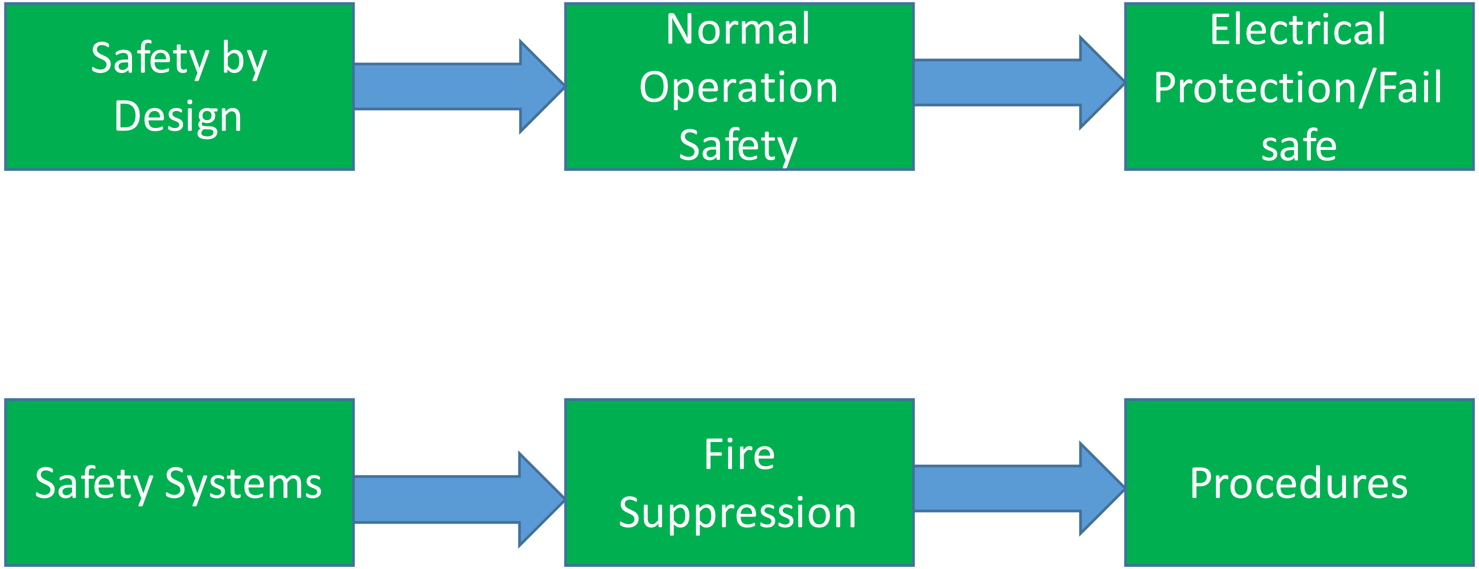

NEW YORK STATE OF OPPORTUNITY. Department of State

2019 Energy Storage System Supplement
(Revised September 2019)

containing amendments to the New York State Uniform Fire Prevention and Building Code

Published by the New York State Department of State
Publication Date: September 2019

Managing the hazard: Concentric Layers of Protection



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Income vs Degradation

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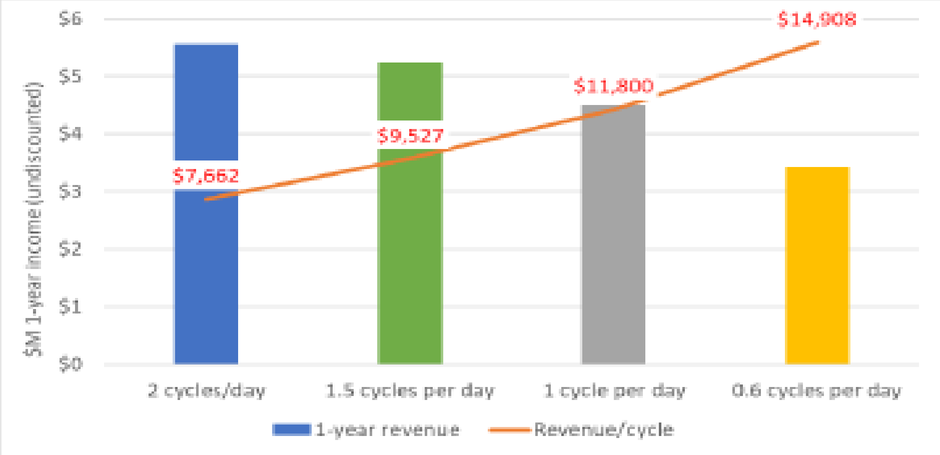
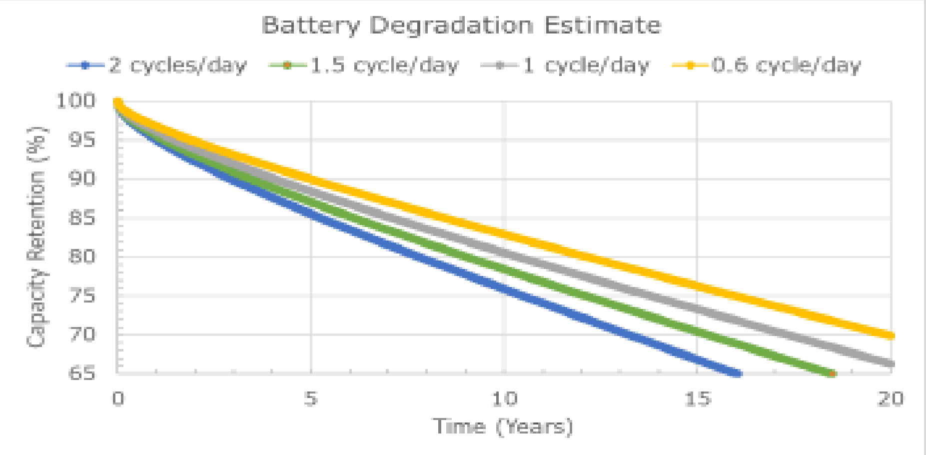
Battery XT is DNV GL battery degradation modeling tool. Battery XT combines predictive analytics of DNV GL testing data with mathematical models of cell electro-chemistry to predict degradation behavior under real-world operating profiles, project and site conditions. ES-Grid dispatch profiles can be used as Battery XT inputs

Typical warranties account for 1 to 1.5 cycles/day for a system expected to last 10 yrs.

As cycling limitations are imposed, the system prioritizes cycling only when it is increasingly valuable to do so.

BESS Dispatch and Operations Simulations used to create degradation profiles





2 cycles/day,70% in 13.1 Yr. , cycles/day,70% in 17.8 Yr.
1.5 cycles/day,70% in 15.6 Yr.

Future Work

- Apply different methods to evaluate an investment in BESS:
  - Rate of Return
  - Payback time
  - Net Present Value
  - SWOT analysis
- Evaluate a system with and without an BESS (comparative study)
- Hardware testing of a BESS (eGRID)

Thank You!