Energy Storage Overview
Technologies & Applications

Presented by

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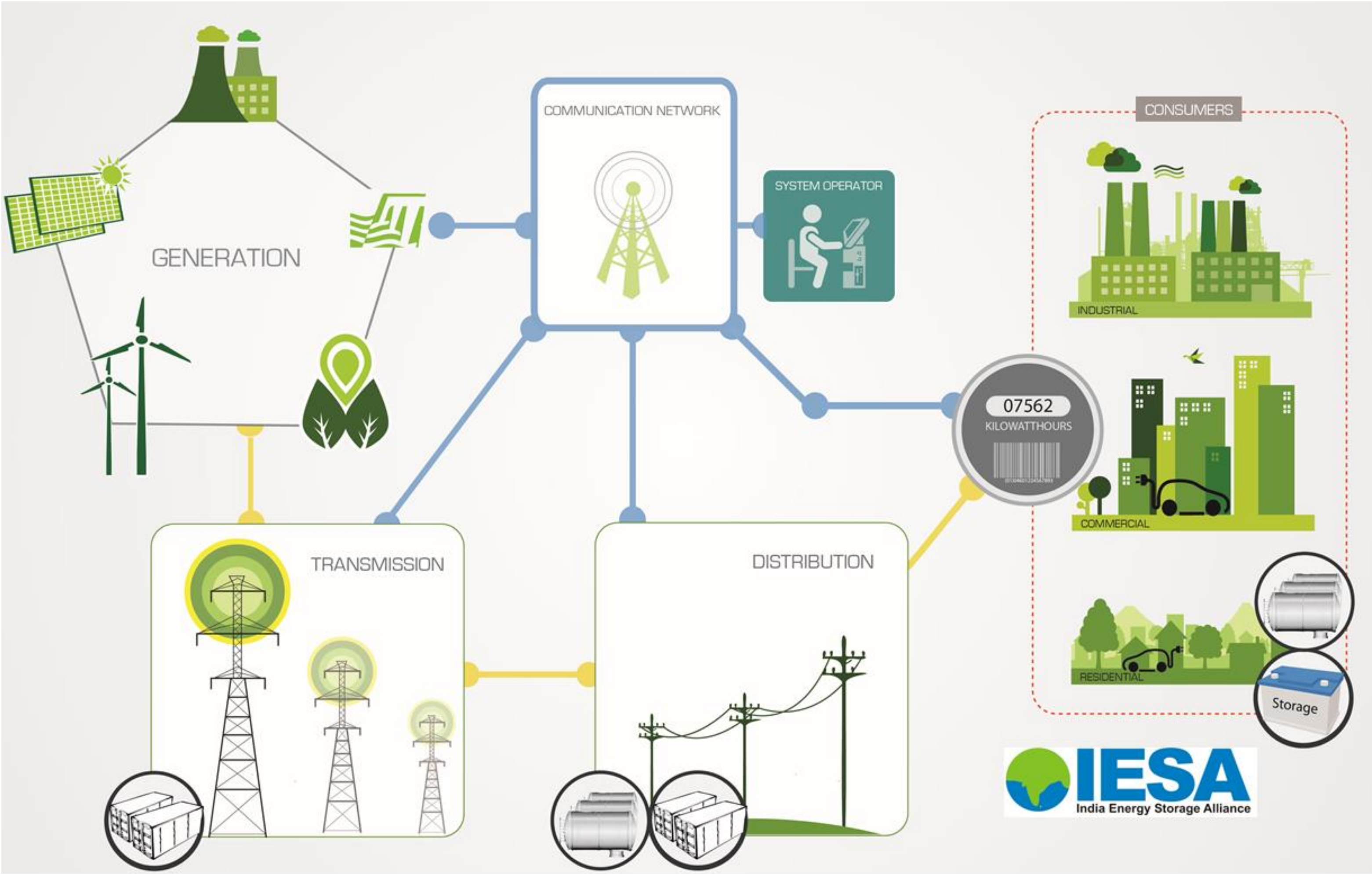
Outline

- Introduction
- Overview of key applications
  - Renewable Integration
  - Ancillary Services
  - Microgrids
  - Electric Transportation
- Overview of key energy storage technologies
  - Pumped Hydro, CAES
  - Electrochemical batteries
  - Capacitors & Flywheels
  - Fuel Cells

Role of Energy Storage in 21st century Grid



Energy storage could play a key enabling role in every aspect of modern grid including Generation, Transmission, Distribution and at Customer Premise (including electric vehicles)

Energy Storage Applications

Generation

- Energy Arbitrage
- Ancillary Services
  - Frequency Regulation
  - Spinning Reserves
  - Supplemental Reserves
  - **NEW** Ramping
- Capacity
  - Peak Energy
  - **NEW** Flexibility
- Reliability
  - Voltage Support/Reactive Power
  - Black Start
  - Frequency Response

Transmission & Distribution

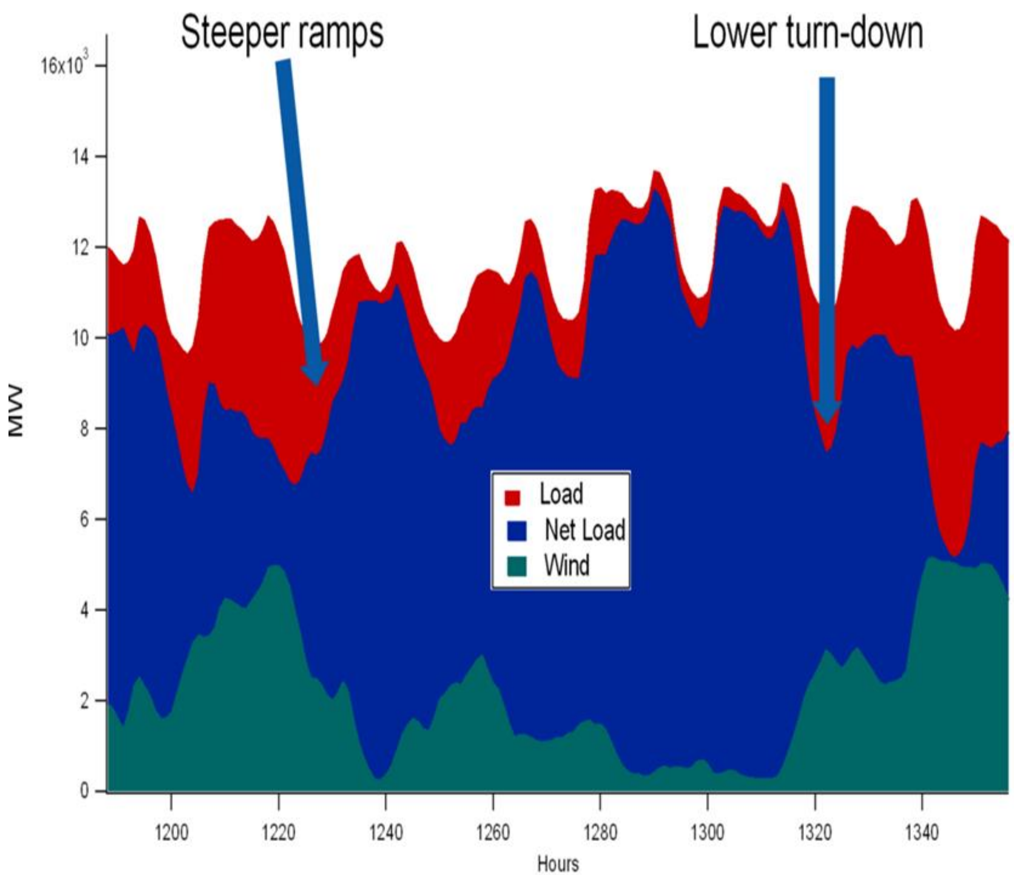
- **Upgrade deferral**
  - Reduce circuit and line overload
- **Grid resiliency**
  - Outage mitigation
  - Back-up power
- **Voltage support/power quality**
- **Congestion relief**

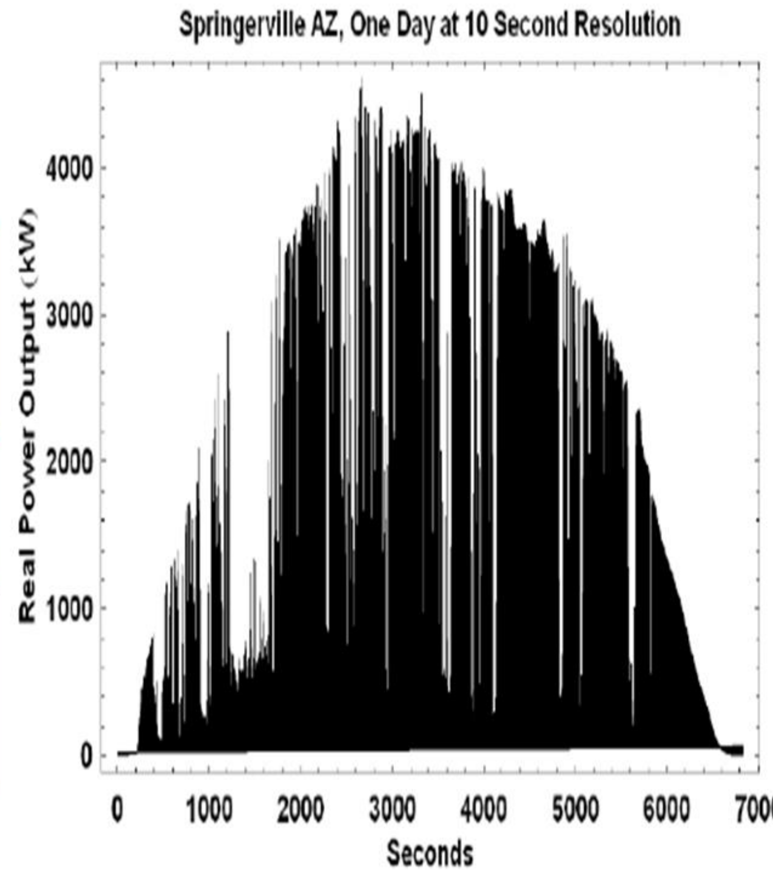
End-users

- Reduce Demand Charges
- Optimize Retail Rates
- Power Quality/UPS
- Onsite renewables

Wholesale Markets focused on "Generation" Applications and Demand Response , Utilities focused on "T&D"

Challenges in integration of renewables





Source: Dr. Michael Milligan NREL / AWEA : Dr. Jay Apt, CMU

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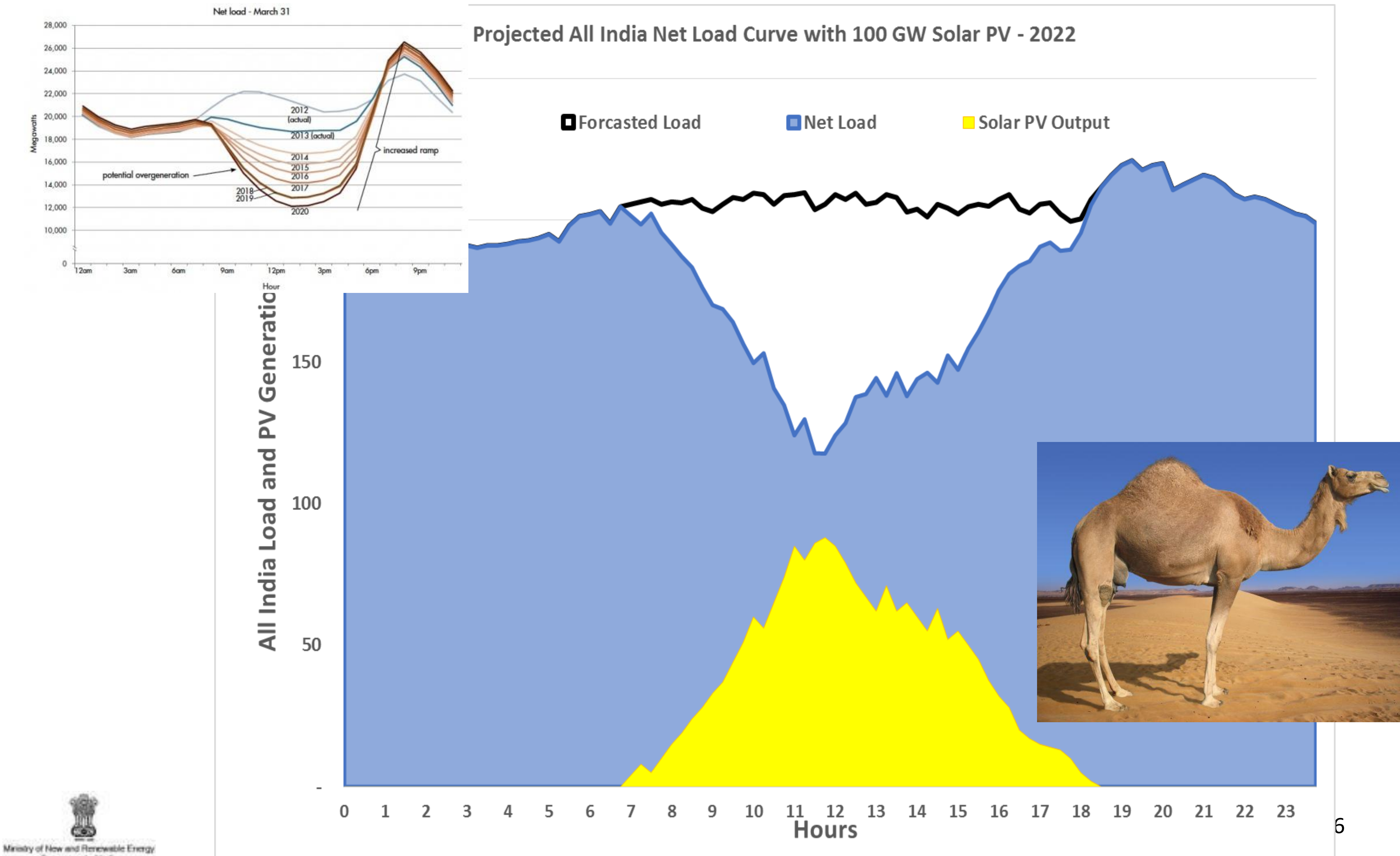
Need for storage for solar integration



Ministry of New and Renewable Energy
Government of India

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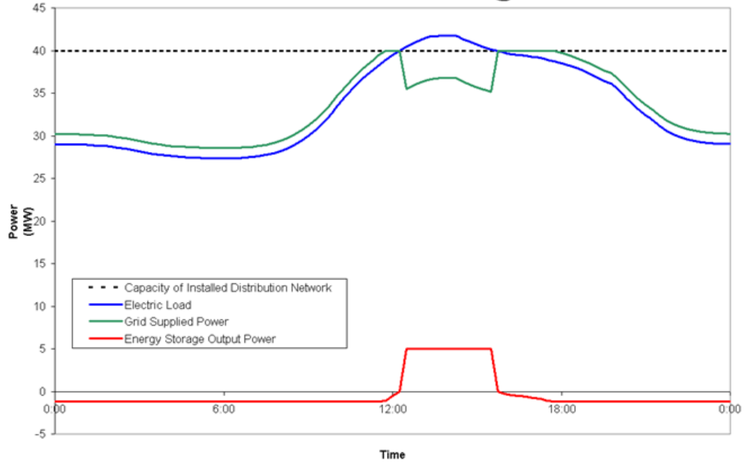
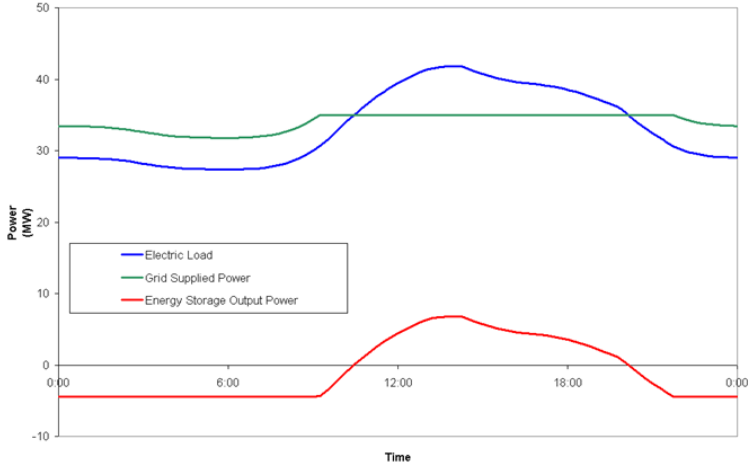
Energy Storage Applications

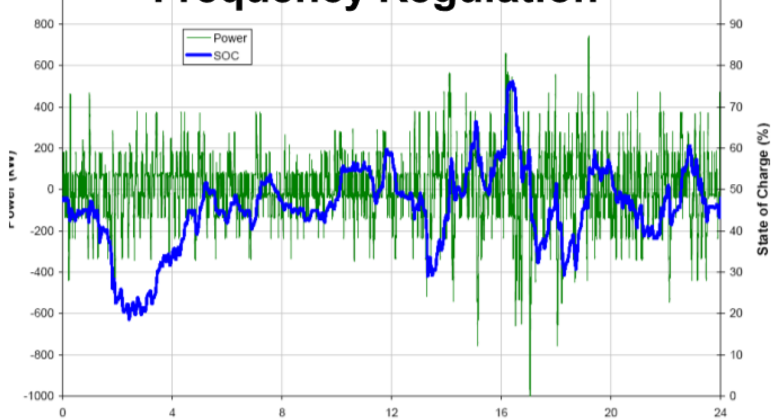
Peak Shaving



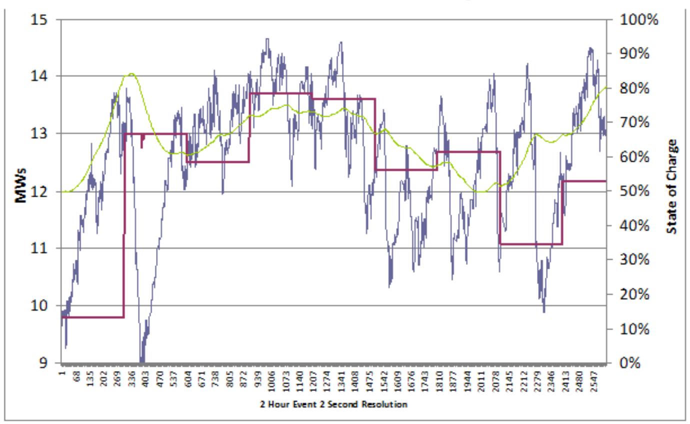
Load Levelling



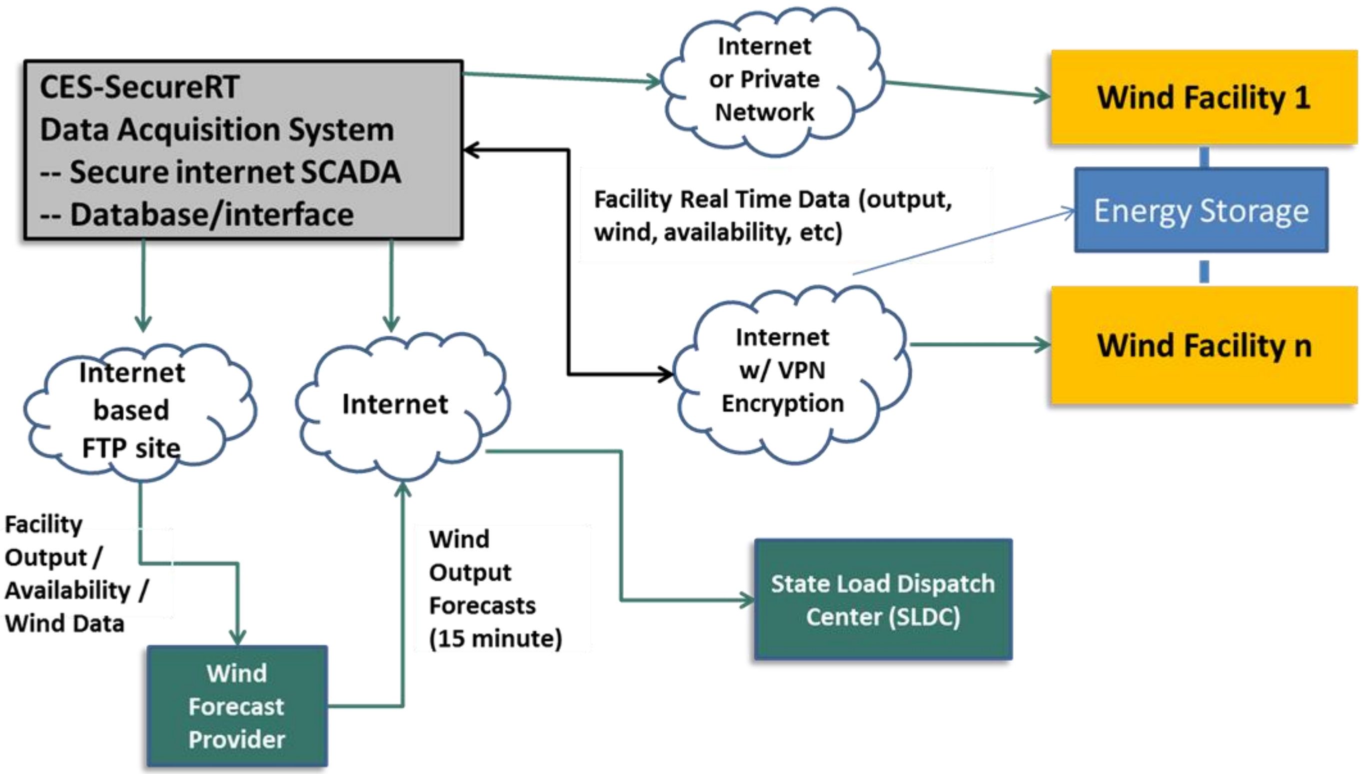
Frequency Regulation



Wind Firming



Renewable scheduling with Advanced Wind Forecasting and Energy Storage




Source: AES Energy Storage


Source:Ecoult


Source: S&C Electric

Customized's Market Operations Center currently actively manages over 3000 MW of generation, energy storage and demand response resources to maximize profits for our clients.

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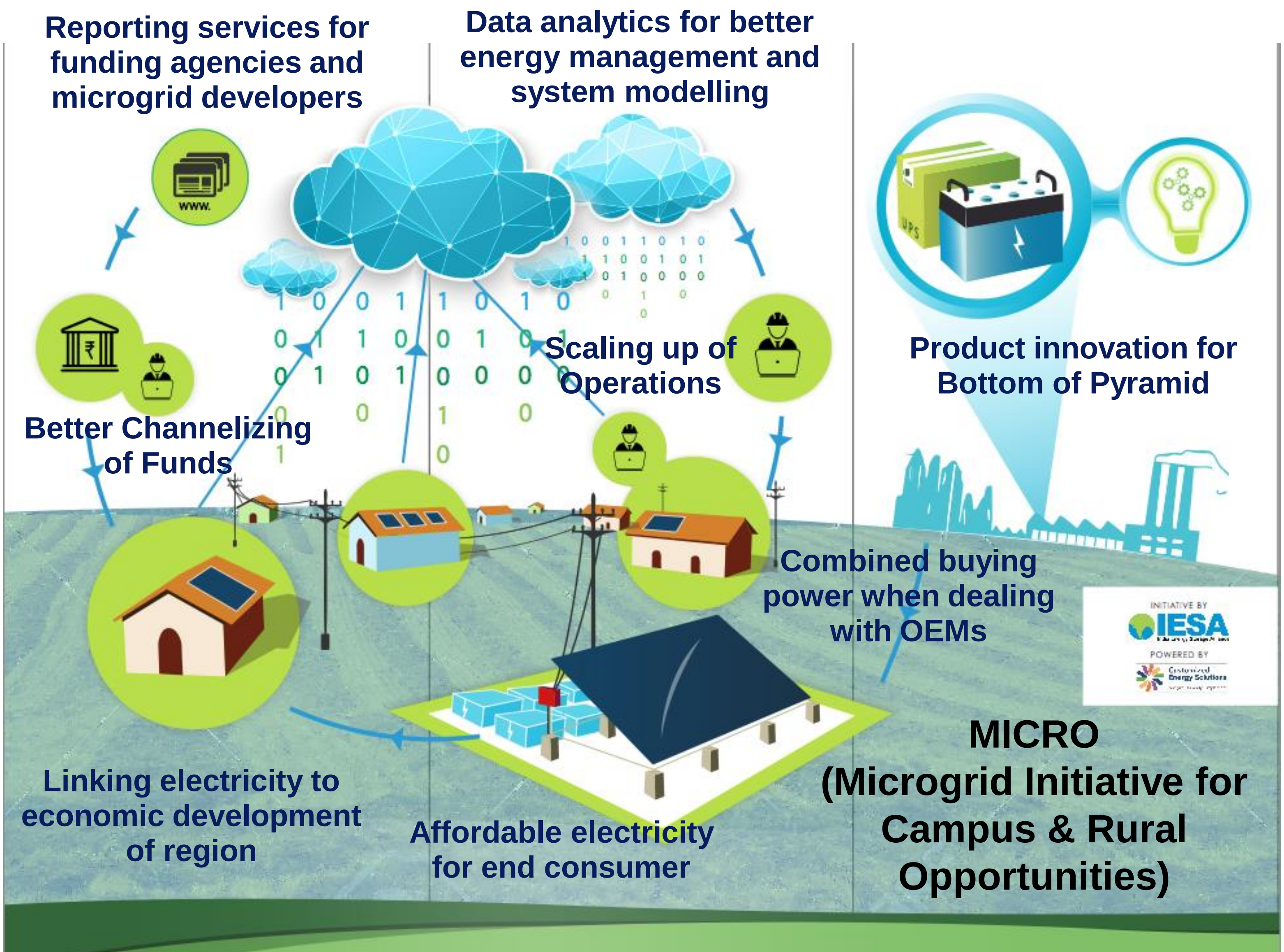
Microgrids for energy access



Smart Townships and Cities

- **Indian Government is working on developing 100 Smart Cities.**
- **20 smart cities are already identified for initial funding**
- **In addition over 300 Ultra Modern Townships with 5 – 50 MW of peak demand could drive need for storage in India.**

US DOE Smart Grid-
Energy Storage Demonstration Projects 2008

Major projects include: CAES demonstration (NY and CA), Renewable Integration (CA, TX, NM), Peak Shaving, Community Energy Storage and demonstration of new technologies.

Visit www.energy.gov for additional details.

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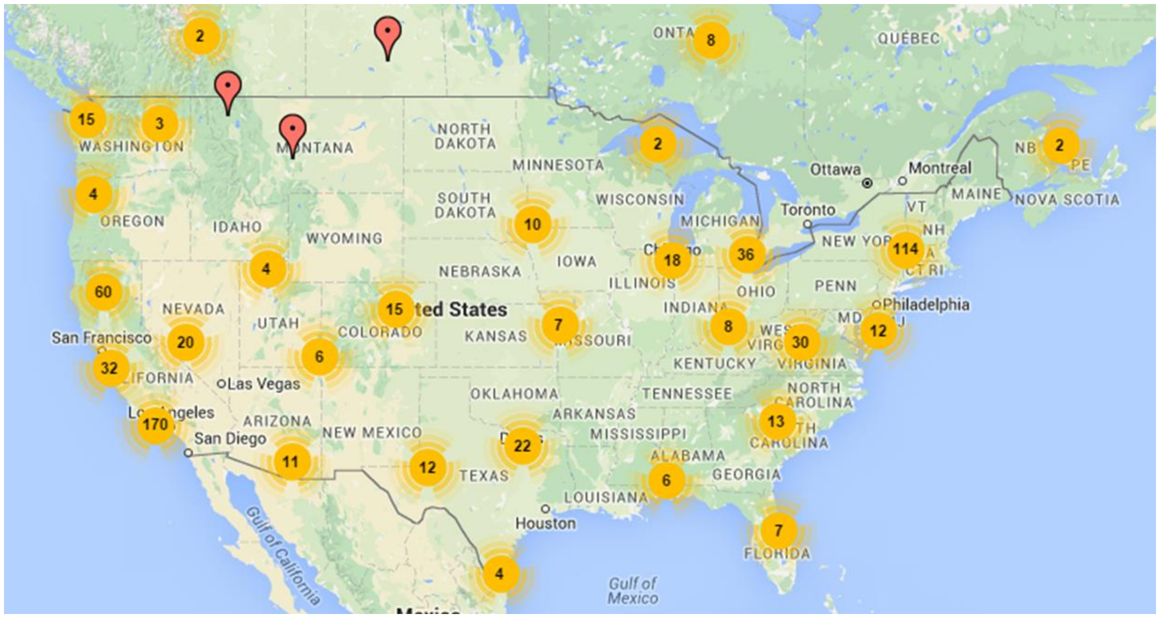
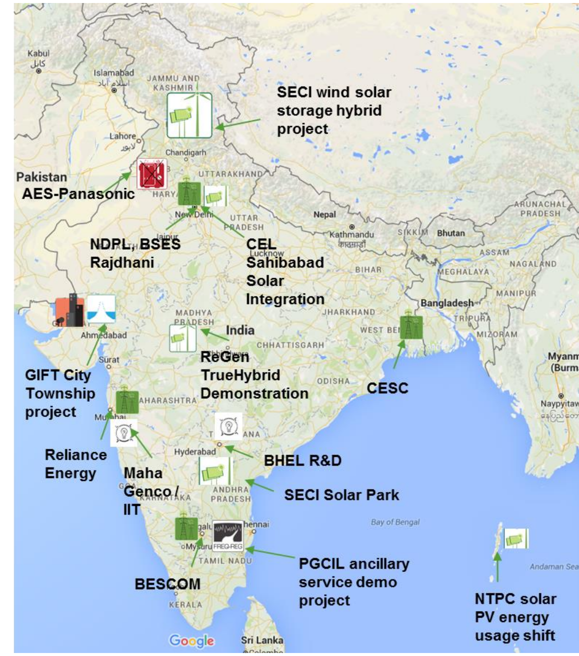
Current Status of US & India Projects





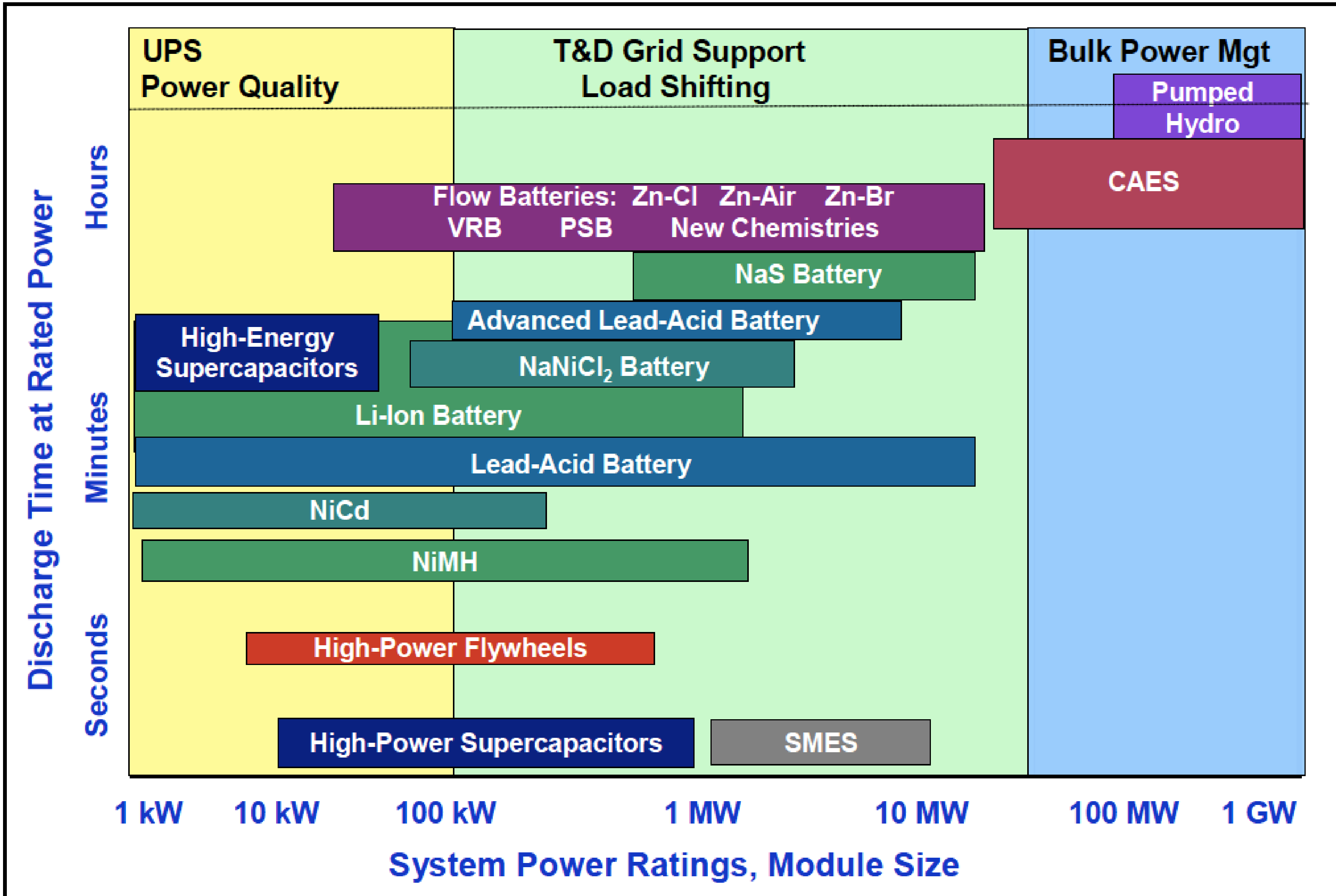
Source: US DOE Energy Storage database & India Energy Storage Alliance

- US drivers
  - Ancillary services
  - Solar –storage integration for peak load & demand charge management
  - Microgrids for resilient grid / campus
  - Diesel minimization in islands
- India drivers
  - Diesel minimization for islands & C&I
  - Renewable integration
  - Energy access
  - Ancillary services for Grid reliability & power quality

Energy Storage Landscape 2016

* In addition Thermal storage, ultra capacitors and fuel cells are also part of energy storage ecosystem

Mapping Storage Technologies

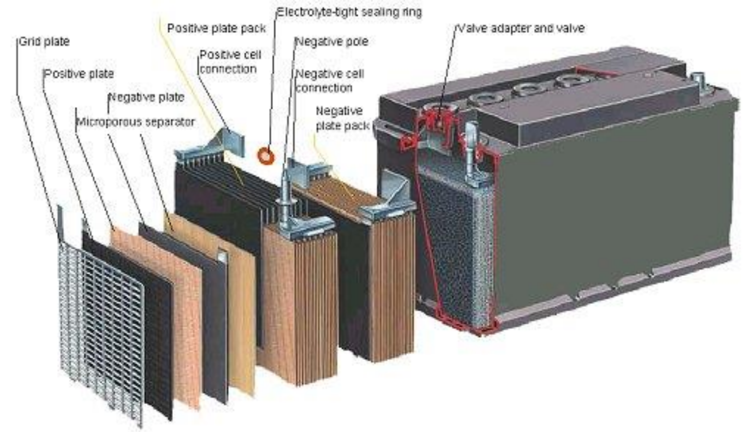


EES Selection Criteria

- Power Rating and Energy Capacity
- Round Trip Efficiency
- Service Life
  - Cycle Life
  - Calendar Life
- System Cost
  - Cost per Unit Power ($/kW)
  - Cost per Unit Energy ($/kWh)

Advanced Lead Acid

Lead-Acid batteries consist of two electrodes: Lead and lead-dioxide immersed in sulfuric acid.



Lead Acid

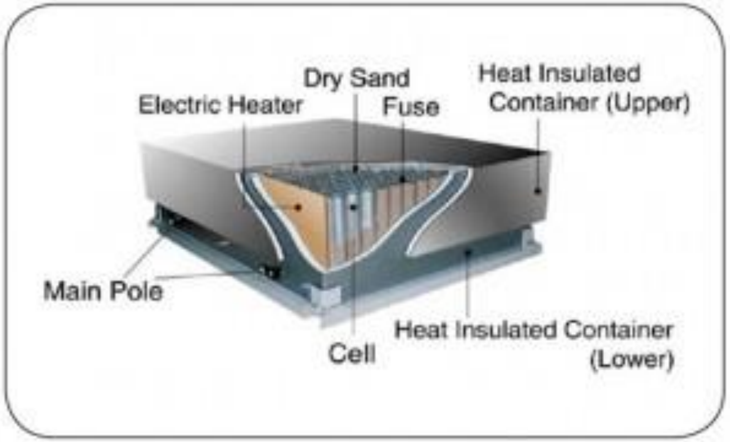
Performance measure	Cycle Life	Energy Efficiency (%)	Price Point ($/kWh)
Market leader	1200	80	200
Best in class	2000	85	300

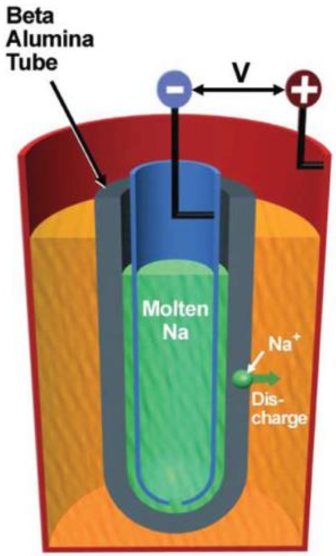
Sodium based battery - NAS

Sodium-sulfur (NaS) batteries use molten sodium and sulfur electrodes separated by a ceramic electrolyte

Sodium Based

NGK FIAMM GE SHARP AQUION ENERGY





Performance measure	Cycle Life	Energy Efficiency (%)	Price Point ($/kWh)
Market leader	4000	70	500
Best in class	6000	85	750-1000

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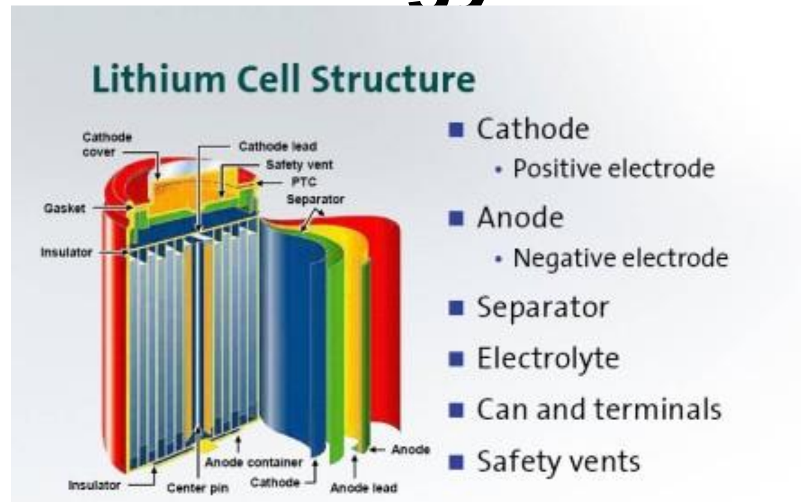
Li-ion Battery Technology

Li-ion battery uses graphite as the anode material and $LiFePO_4$ or $LiCoO_2$ or Lithium titanate or lithium nickel manganese cobaltate as the cathode.



Li-Ion Batteries

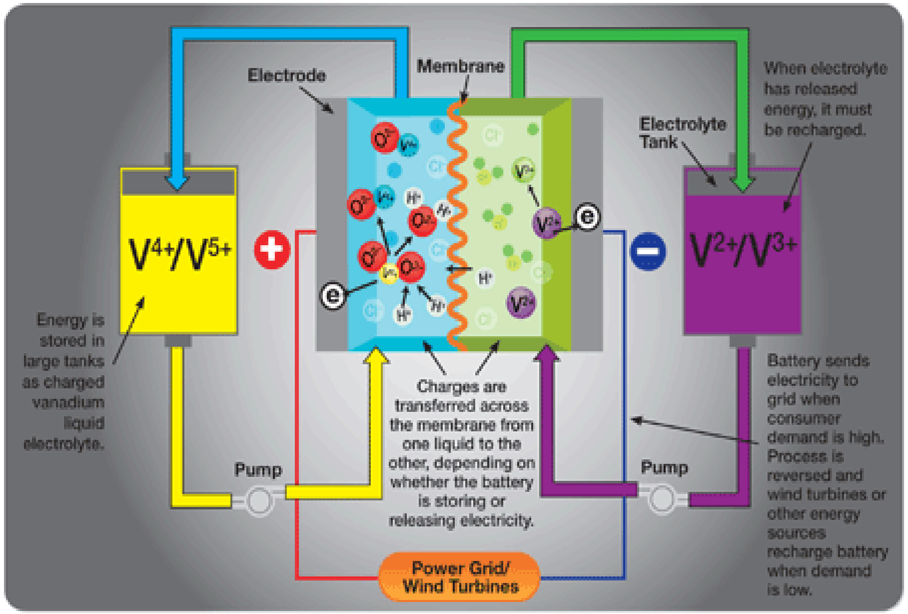
SONY, AES Energy Storage, HITACHI, MITSUBISHI, LG Chem, Panasonic, BYD, TESLA, electrovaya, SAMSUNG, altairnano, microvast, saft, ATL, LG Chem, TOSHIBA, NEC, Kokam

Performance measure	Cycle Life	Energy Efficiency (%)	Price Point ($/kWh)
Market leader	2000	90	400
Best in class	6000+	95	1000

Flow Battery Technology

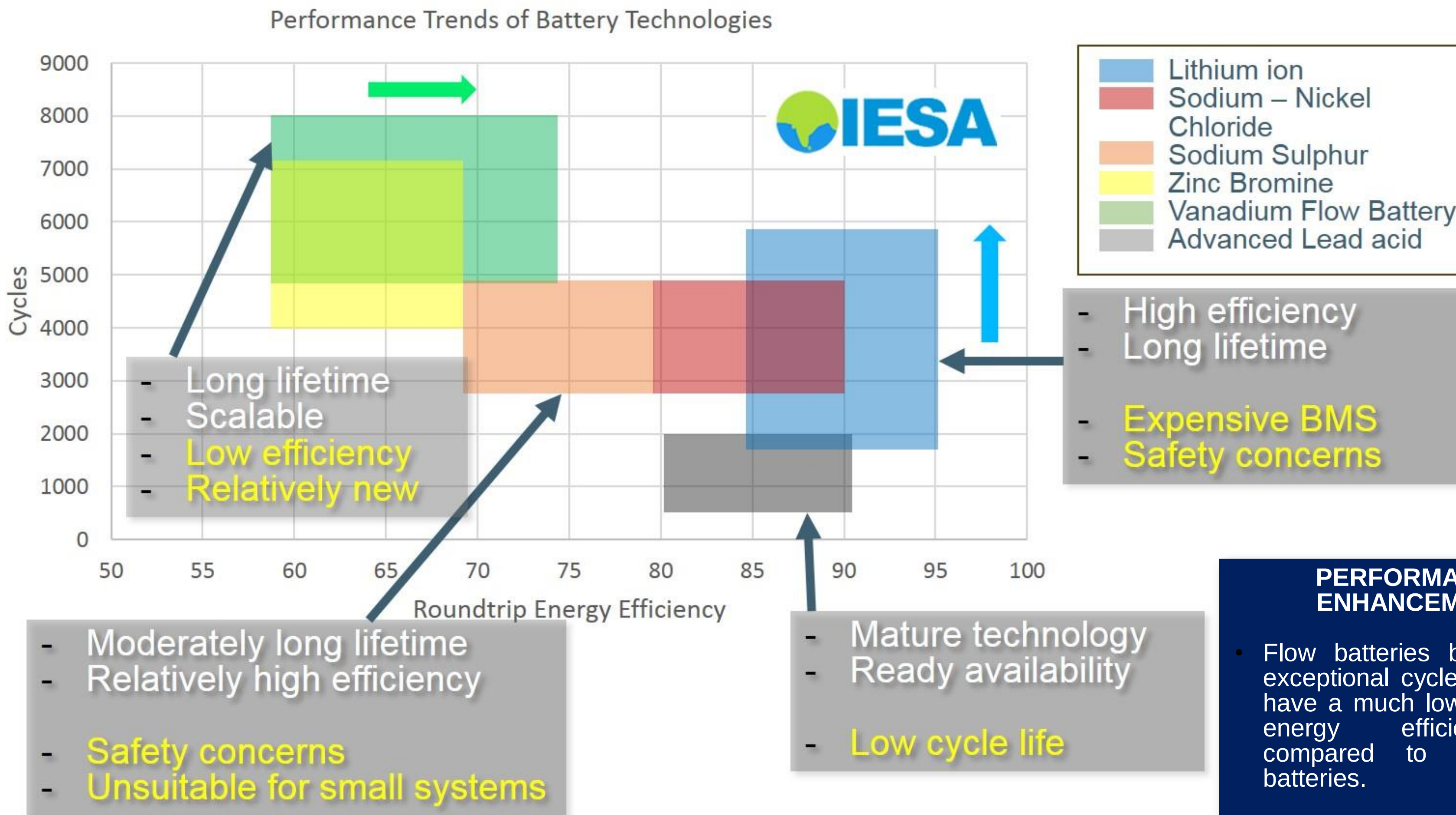
Flow batteries use liquid electrolytes with fixed cells to store and regenerate power. Various flow battery chemistries exist such as vanadium redox, zinc-bromine, iron - chromium etc.

Flow Batteries



Performance measure	Cycle Life	Energy Efficiency (%)	Price Point ($/kWh)
Market leader	5000	60	500
Best in class	10000	70	1000

Future Advances in Energy Storage

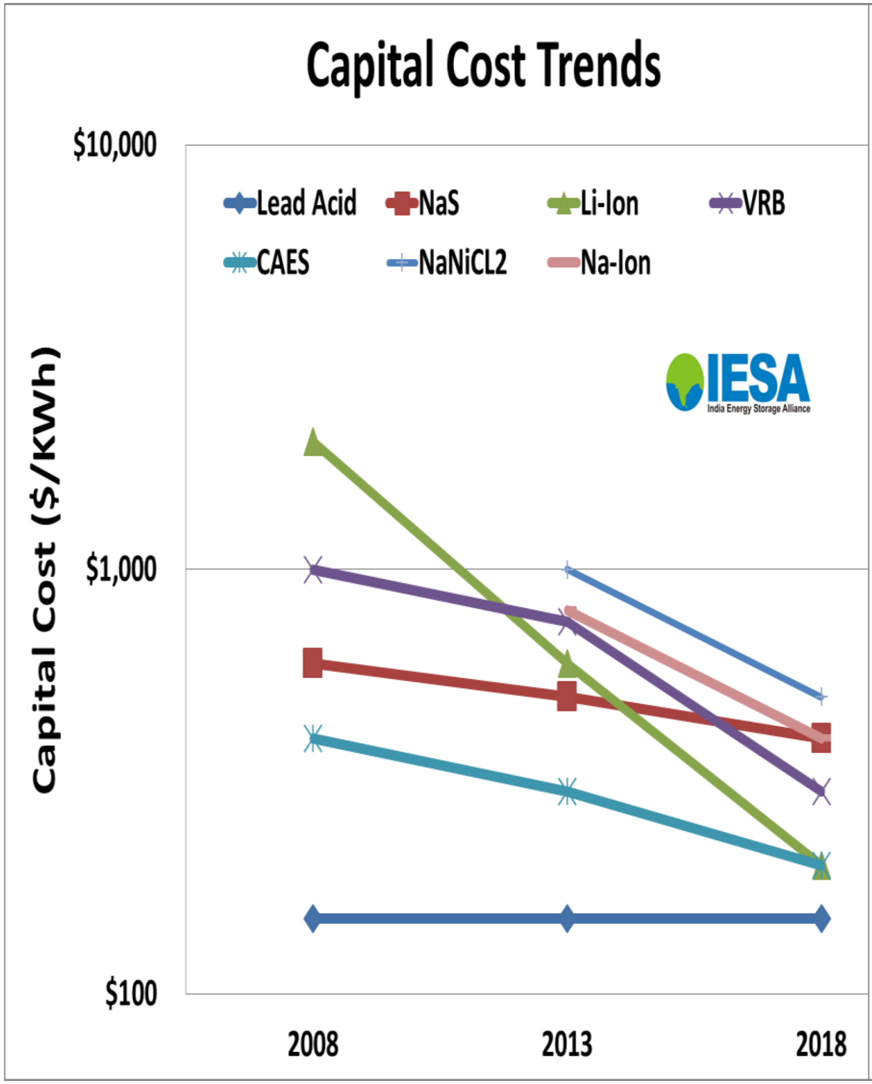


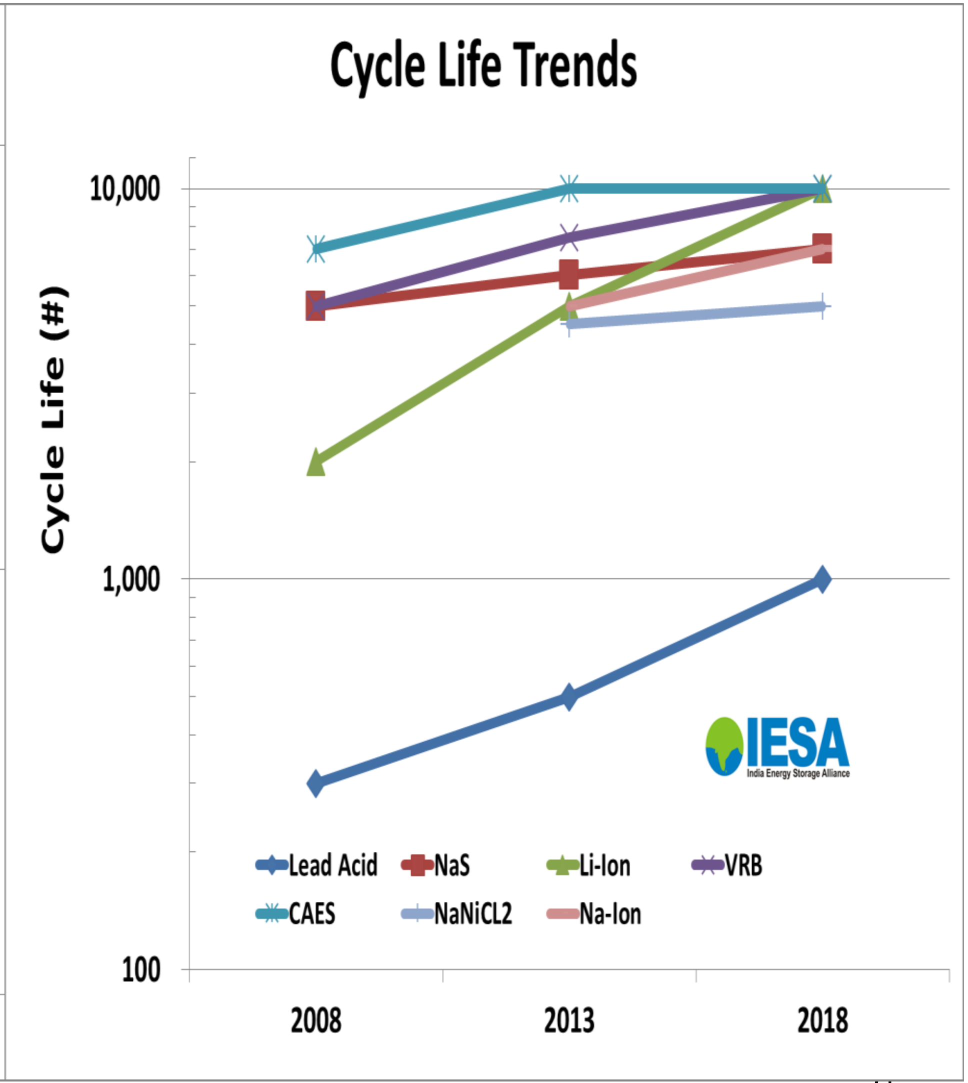
PERFORMANCE ENHANCEMENT

- Flow batteries boast of an exceptional cycle lifetime but have a much lower roundtrip energy efficiency as compared to lithium ion batteries.
- Lead acid batteries have high efficiency and low cost but their cycle lifetime is very low compared to other technologies

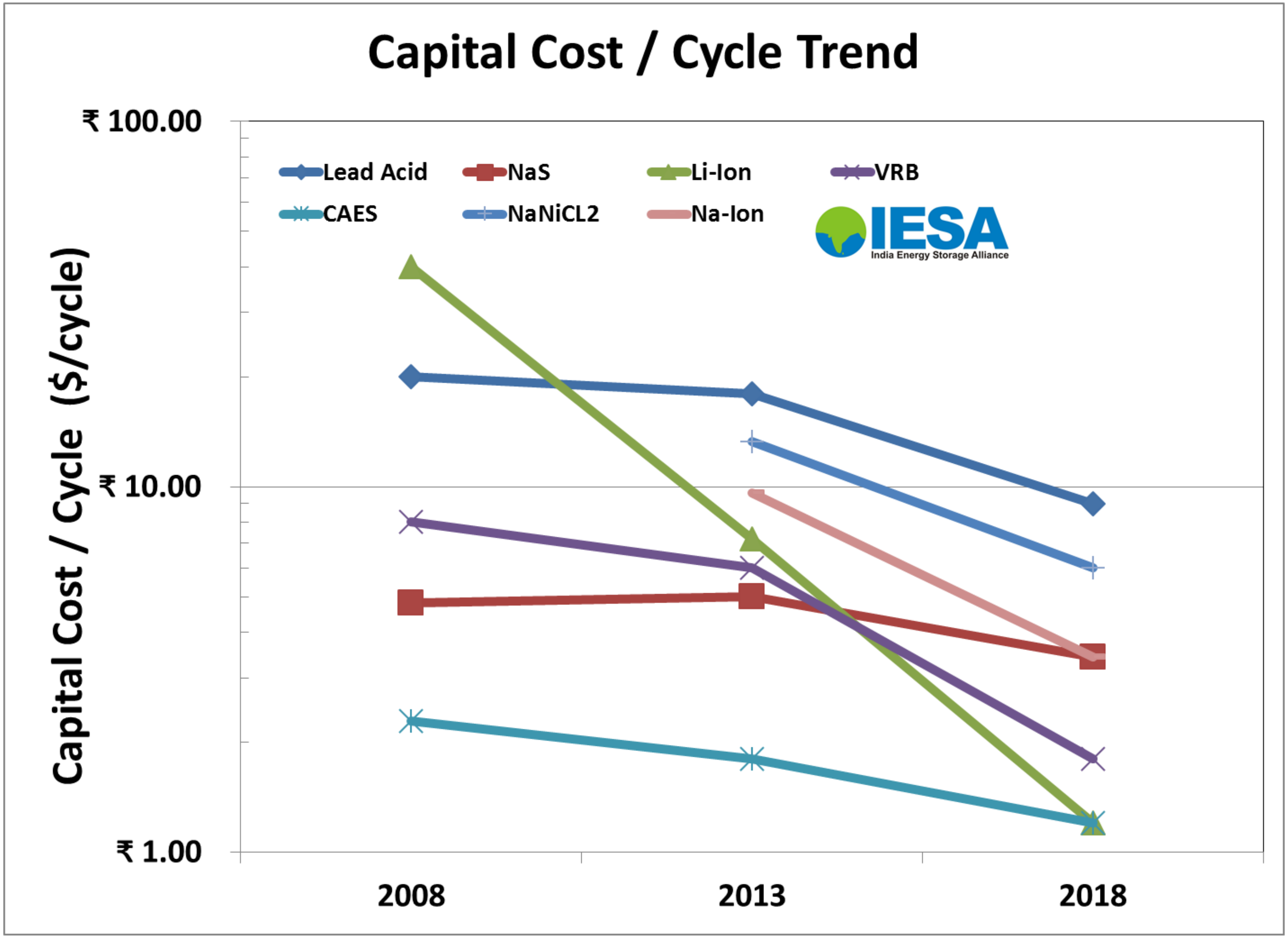
INNOVATIVE materials and cell design improvements which can enhance the specific properties of respective energy storage technologies will play a crucial role in making the technologies attractive for rapid commercialization.

Key Trends in Energy Storage





Cost reduction in per Cycle Capital Costs



Conclusion

- Energy storage technologies are evolving rapidly
- Market rules / policy restructuring is key for opening up the market around the globe
- Different regions will have different drivers for adoption of storage technologies
  - Developed countries are focusing on ancillary services, grid resiliency and solar storage for peak demand management
  - Developing countries can benefit from diesel usage reduction, microgrids for energy access, renewable integration & ancillary services for grid reliability etc.
- As technology performance improves and costs reduce, more and more applications will be available for storage technologies
- A global collaboration for adopting best policies and business models can help accelerate adoption

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