Advanced Energy 101

Energy Storage Presentation

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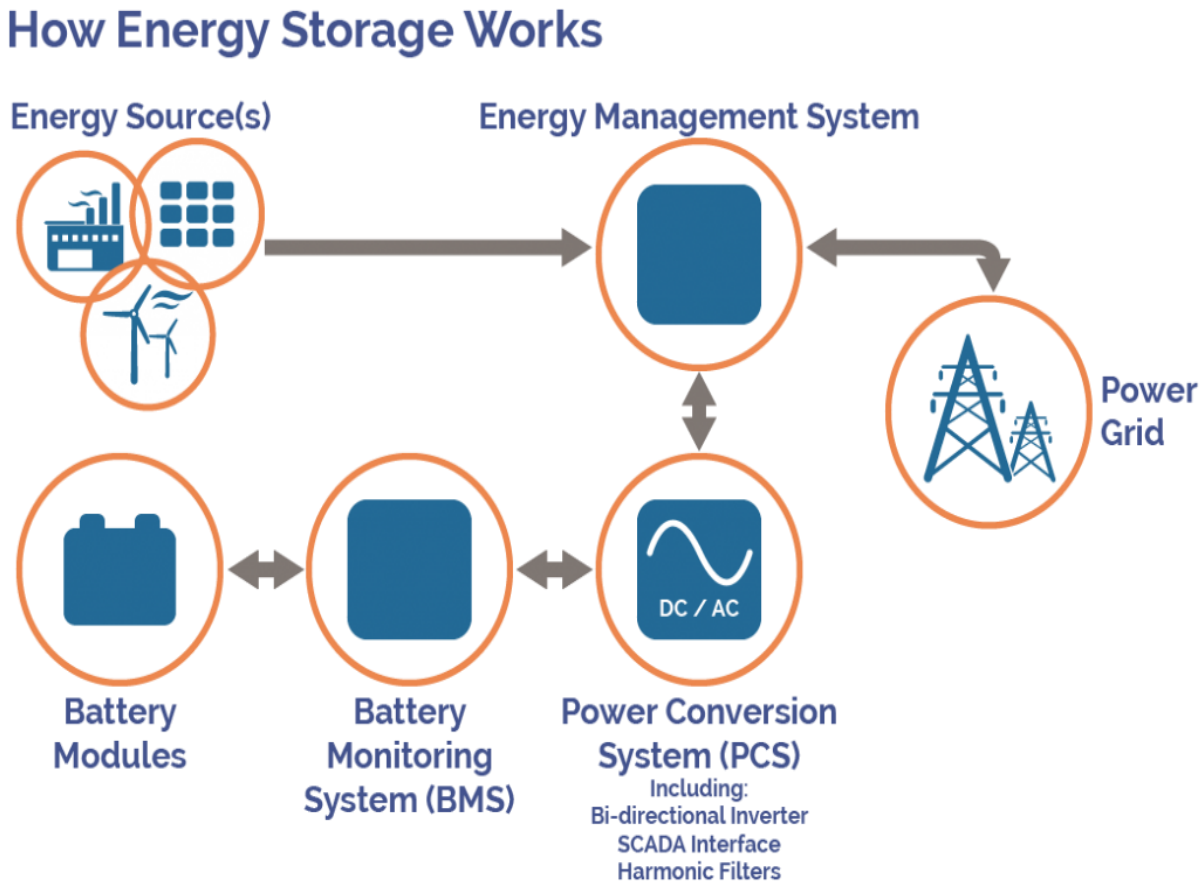
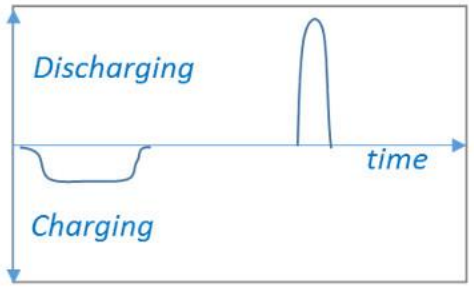
Energy Storage Overview

- Capture of energy produced at one time for use at a later time.
- Energy is stored (charged) when generation exceeds demand.
- Energy is released (discharged) when demand exceeds generation.
- Usefulness exacerbated by growing amount of intermittent resources like solar and wind.

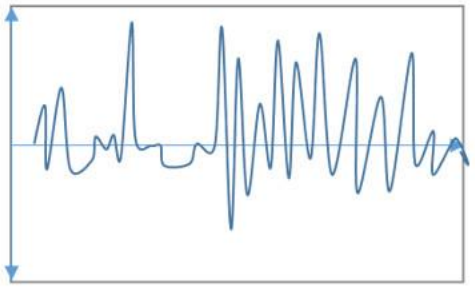


Energy Storage Applications/Value Streams

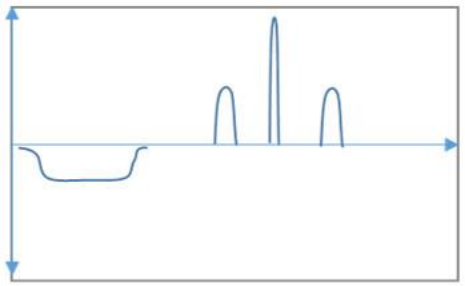
- Energy Arbitrage
- Frequency Regulation
- Volt/Var Support
- Peak Shaving/Demand Response
- Renewable Smoothing/Shifting
- Islanding During Outages



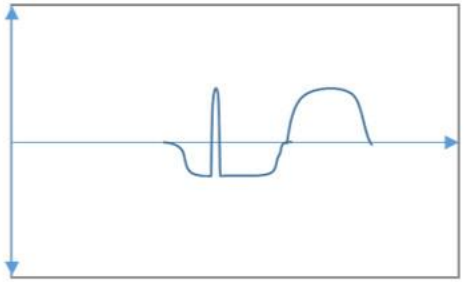
Energy Arbitrage



Frequency/Voltage Support



Peak Shaving / Demand Response



Renewables Smoothing & Shifting

Energy Storage Business Models

Centralized Utility or Merchant Owned
- Economic Benefits to Utility
- Little to No Resiliency Benefits

Distributed Utility Owned
- Economic Benefits to Utility
- Resiliency Benefits to Customer

Distributed Customer Owned
- Economic Benefits to Utility and Customer
- Resiliency Benefits to Customer

Energy Storage Technologies

Technology Type	Subtechnology Type
Electro-chemical	Electro-chemical capacitor, lithium-ion battery, flow battery, vanadium redox flow battery, lead-acid battery, metal air battery, sodium-ion battery
Electro-mechanical	Compressed air storage, flywheel
Chemical	Hydrogen storage, liquid air energy storage
Pumped hydro storage	Closed-loop pumped hydroelectricity storage,open-loop pumped hydroelectricity storage
Thermal storage	Chilled water thermal storage, concrete thermal storage, heat thermal storage, ice thermal storage, molten salt thermal storage

Source: US DOE, 2017.

Electro-Chemical Energy Storage

Li-Ion and Flow batteries currently are the two most commercially viable technologies for grid BESS.

Technology	Typical Duration	Size	Service Life	AC Round trip efficiency	Cycle Life	Advantages	Disadvantages
Lithium-Ion	0-6 hour	Up to 100 MW+	10-15 years*	85%	Annual degradation	Efficient power Energy dense Flexible	Flammable** Cycle life limited
Flow	2-8 hour	Up to 100 MW+	20 years	65-75%	Theoretically unlimited and can be discharged 100%	High cycle life/service life No degradation Not flammable	Reduced efficiency

* Warrantees are around 7 years with 1-2 year workmanship warranties

** Note: flammability is dependent on specific chemistry used to develop battery. When considering any type of battery, including li-ion, it is important to discuss flammability issues with the vendor.

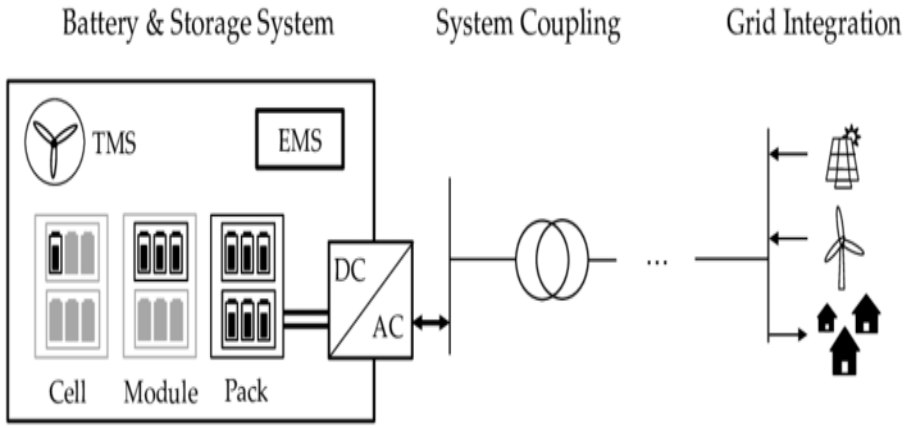
Source: Lazard

Lithium-Ion Battery Energy Storage Systems (BESS)

Lithium-Ion has enjoyed the Lion's share of deployment primarily due to:

- Higher Round-Trip Efficiency
- Modular Characteristics
- Flexibility in Siting
- Ample Supply Chain Availability
- Falling Cell and System Costs
- Favorable Performance Metrics

BESS System Design



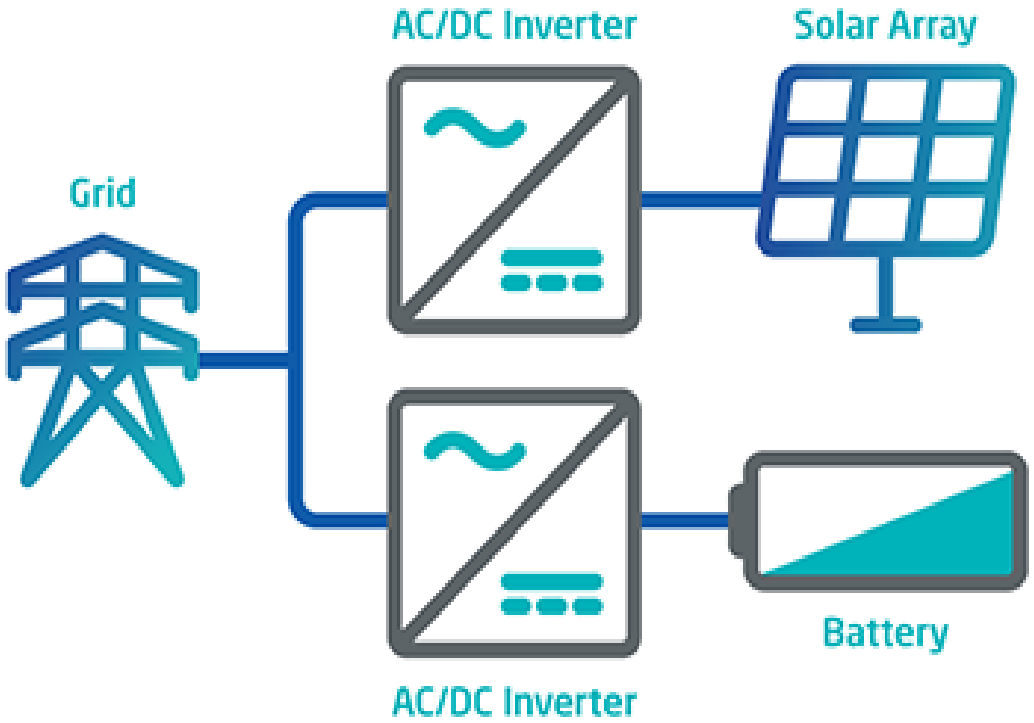
	Battery & Storage System	System Coupling	Grid Integration
Technical	• Battery System (Cell, Module, Pack) • Thermal Management (TMS) • Energy Management (EMS)	• Power Electronics (AC/DC) & Transformer • Environmental Conditions	• Application Specific Profile • Local Connection / Grid Level of Integration
Economic	• Investment (Batt., Periphery, Casing) • Degradation and Efficiency • Sizing & Operation Control	• Power Electronics Invest • Conversion Efficiency • Placement of System	• Profit / Savings via Application • Stakeholder Involvement • Regulatory Framework

Solar + Storage

- Solar + Storage pairs a battery with a new or existing solar system to increase its value.

- This makes solar dispatchable by allowing the sytem to operate at night or during cloudy days.

Solar + Storage – AC Coupled



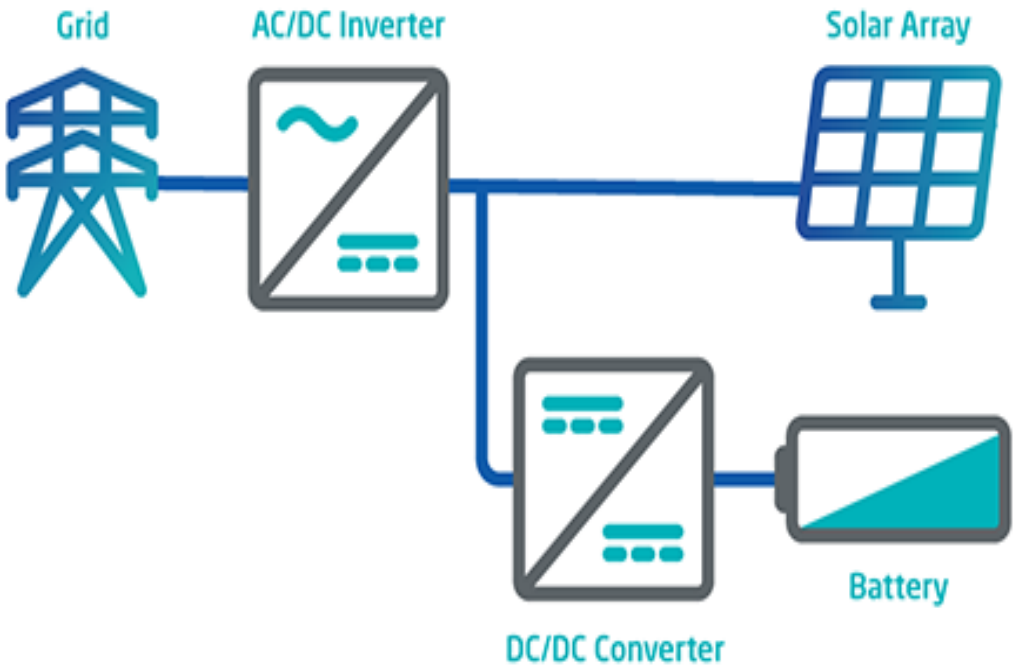
Pros:

Flexibility in location.

Ease in retrofitting existing solar generating assets.

Reduced HVAC and fire suppression requirements.

Solar + Storage – DC Coupled



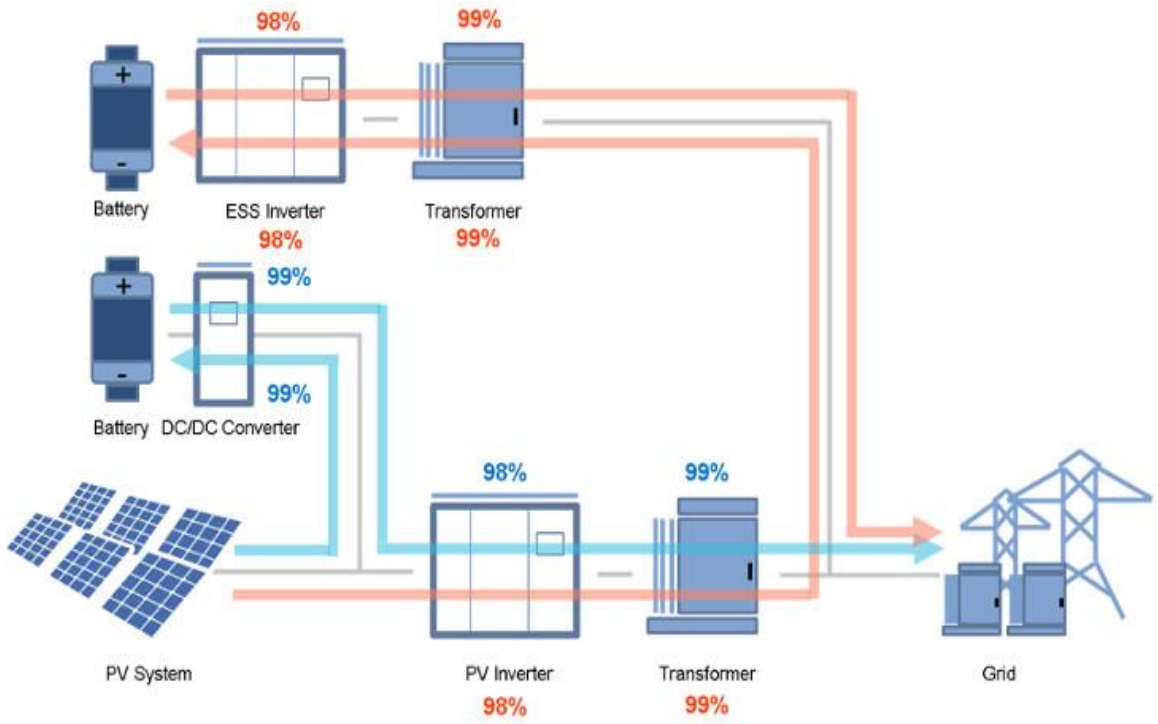
Pros:

Single bi-directional inverter.

Higher round-trip efficiency.

Ability to capture excess clipped PV.

AC-Coupled and DC-Coupled Efficiency Comparison



	DC Coupled	AC Coupled
DC/DC CHG	99%	N/A
DC/DC DCHG	99%	N/A
PV INV DCHG	98%	98%
ESS INV CHG	N/A	98%
ESS INV DCHG	N/A	98%
XFMR CHG	N/A	99%
XFMR DCHG	99%	99%
TOTAL:	**95.1%**	**92.2%**

AC-Coupled and DC-Coupled Value Comparison

	DC-COUPLED	AC-COUPLED
CAPACITY FIRMING	✓	✓
ENERGY TIME SHIFTING	✓	✓
CLIPPING RECAPTURE	✓	
CURTAILMENT RECAPTURE	✓	
LOW VOLTAGE HARVEST	✓	
RAMP RATE CONTROL	✓	✓

Thank You !