Kate Howling

Energy Storage Review and Solar Pairing

Energy Storage: **Agenda**

- Introduction
- Market Trends
- Technology Overview
- Risks and Challenges

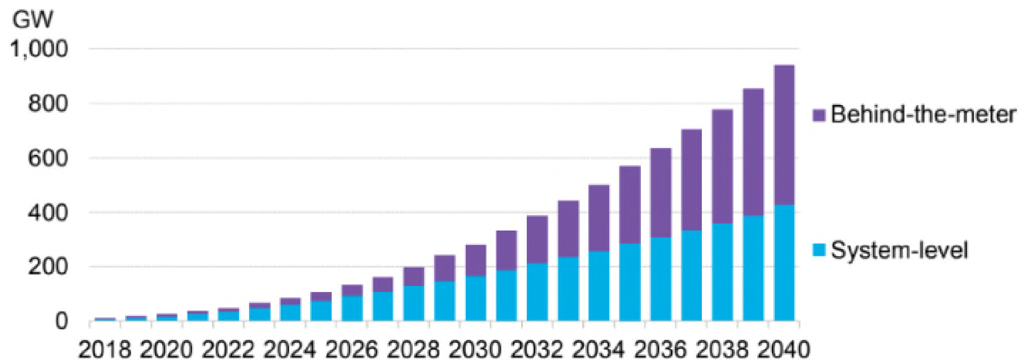
Introduction

Energy Storage: **Intro**

Energy storage is a rapidly growing market:

- $150B industry in US by 2023
- Wood Mackenzie projects a 13 fold increase in global energy storage industry between 2018 and 2024
  - 2018: 12GWh
  - 2024: 158GWh

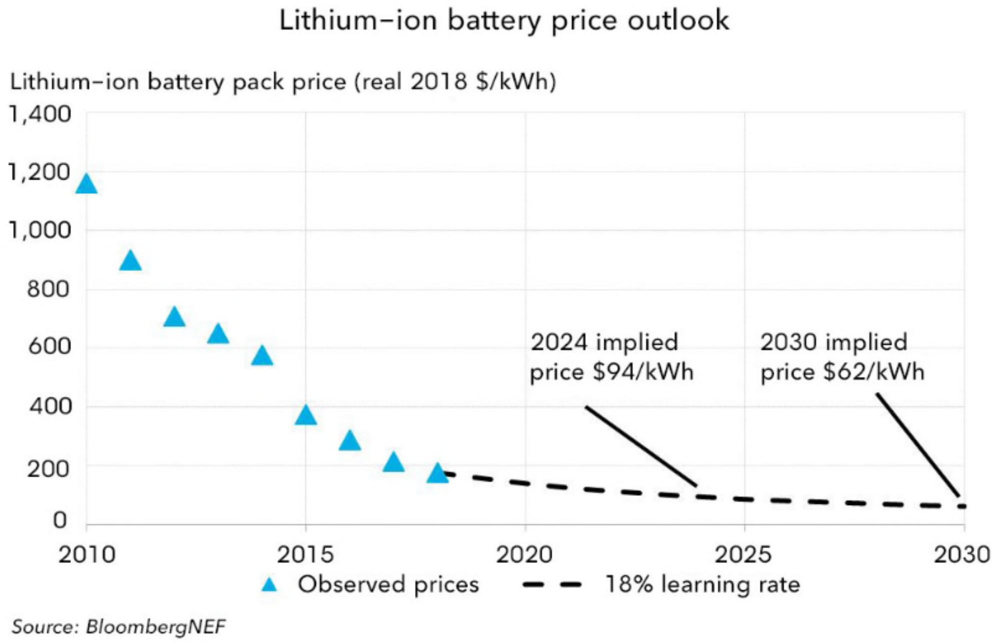
Figure 4: Cumulative storage deployments: system-level services versus behind-the-meter



Source: Bloomberg NEF

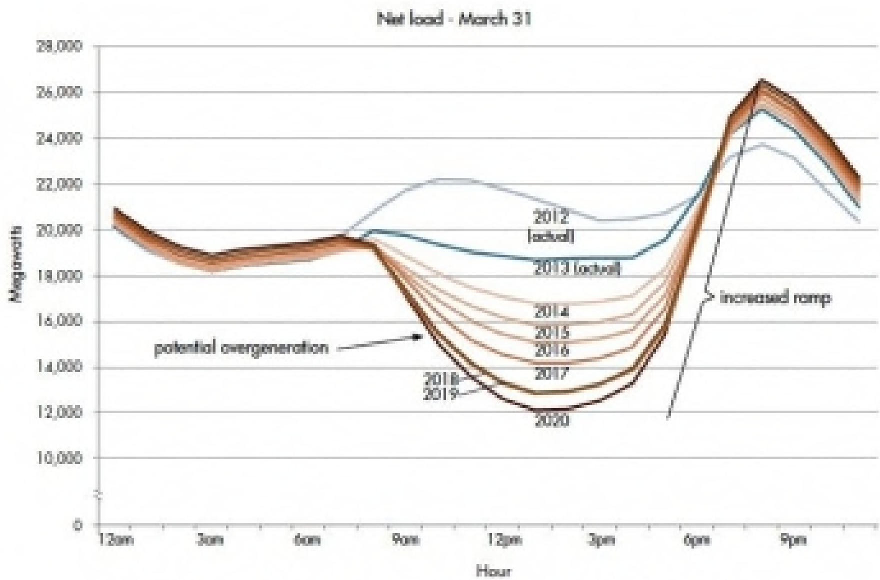
Energy Storage: **Intro**

This growth is largely driven by rapid price decline



Energy Storage: **Intro**

Markets have also opened up that are advantageous for storage



California Independent System Operator

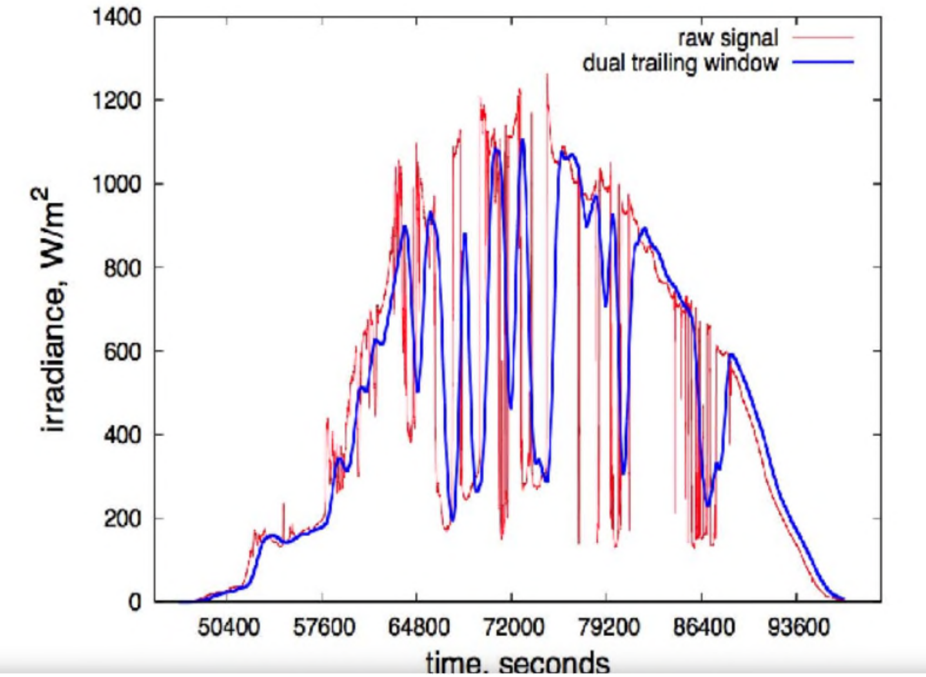
Source: CAISO

Market Trends and Solar Pairing

Energy Storage: **Market Trends**

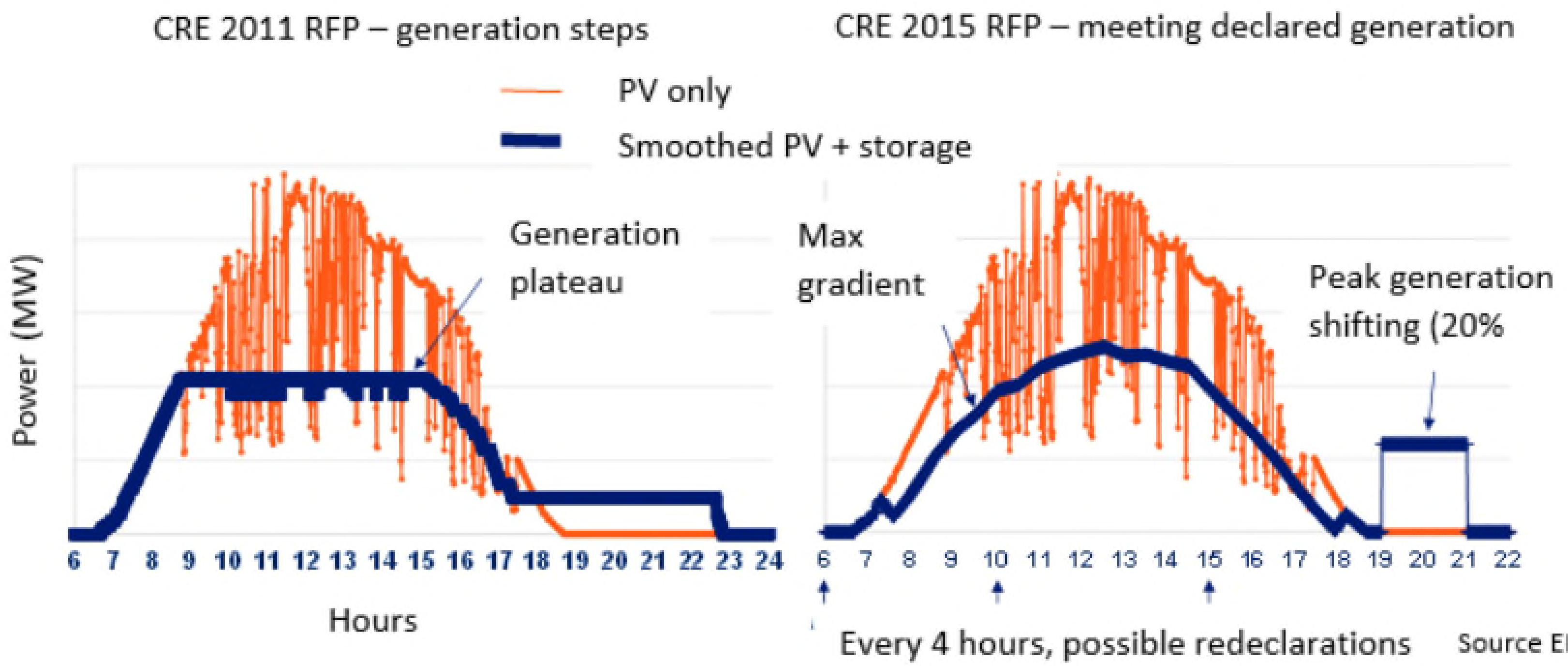
With more renewable penetration, storage becomes a key to solving intermittency issues:

- Renewable smoothing
- Energy shifting
- Ramp rate control
- Day-ahead and hour-ahead bidding



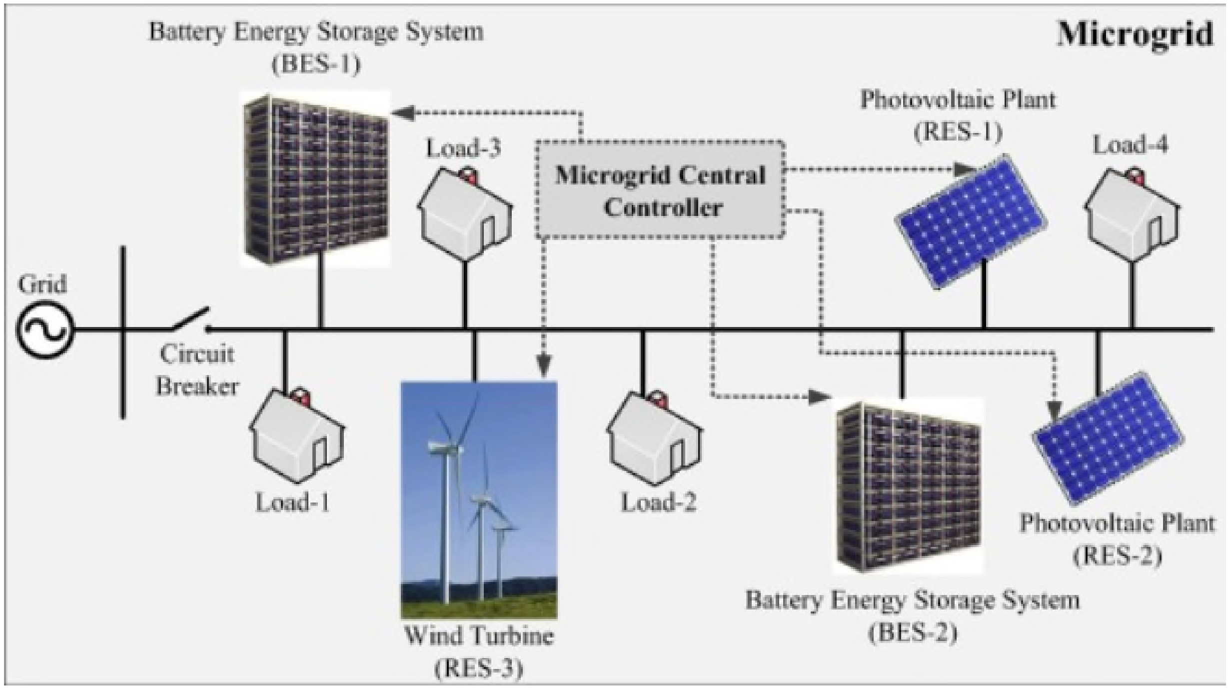
Source: IEEE PES Paper: Analysis of battery storage utilization for load shifting and peak smoothing on a distribution feeder in New Mexico, 2012

Energy Storage: **Solar Pairing**



Source EDF 2017

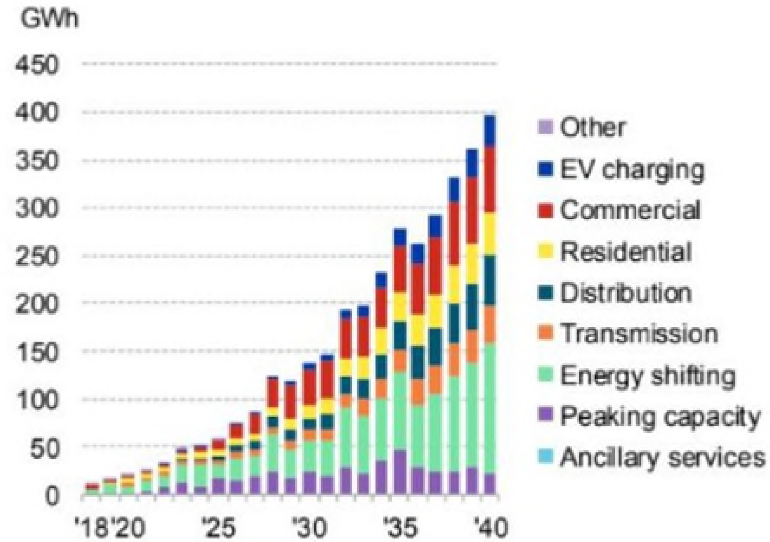
Energy Storage: **Microgrid**



Energy Storage: **Value Stacking**

"Value stacking" combines all of these applications

Figure 6: Annual storage deployments by application based on energy capacity



Source: Bloomberg NEF

Energy Storage: **Regulatory Drivers**

Regulatory drivers are encouraging or requiring storage to be deployed

- FERC order 841
- AZ: Moratorium on gas peakers
- AZ: goal of 3,000MW of storage by 2030
- MA: goal of 1,000MWh of storage by 2025
- NY: goal of 1,500MW of storage by 2025
- CA: requirement of 1,825MW of storage by 2024
- OR: requirement of 5MWh by 2020
- NJ: goal of 2,000MW by 2030

Technology

Energy Storage: **Technology**

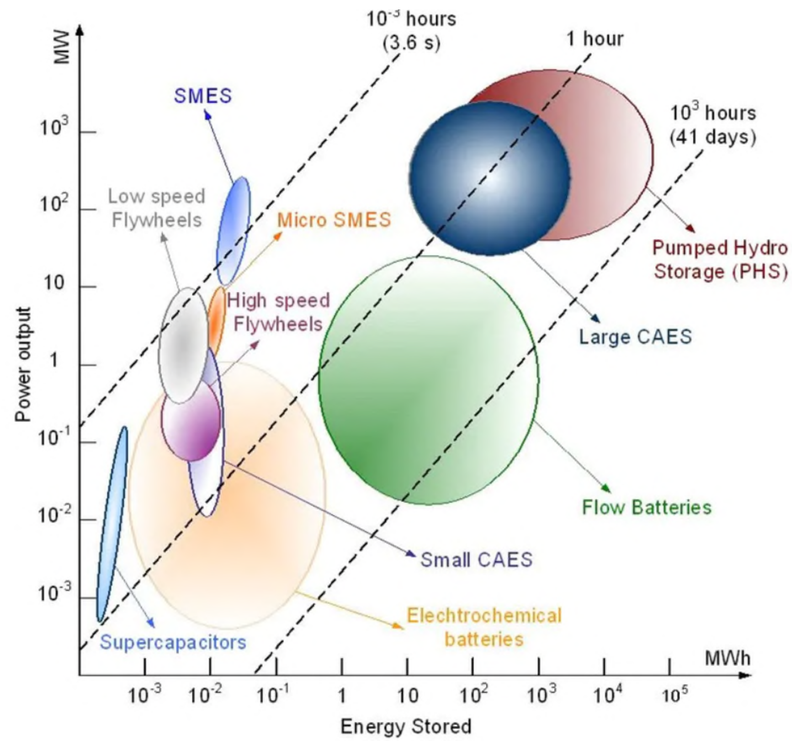
Key Terms:

- Energy
- Power
- State of Charge (SOC)
- Point of Interconnect (POI)

Energy Storage: **Technology**

Many types of batteries that achieve different **power and energy balance**:

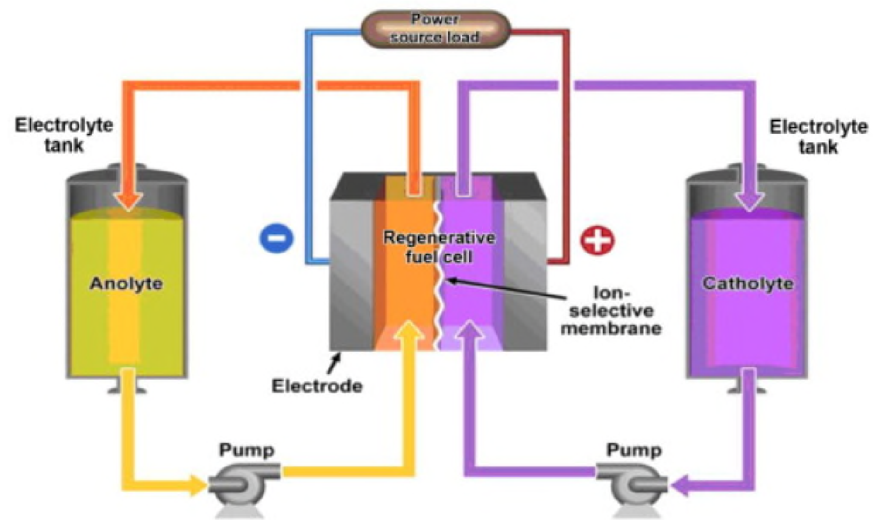
- Mechanical
    - CAES
    - Fly wheels
- Electrochemical
    - Lithium Ion
    - Lead Acid
    - Flow
- Thermal



Source: Ibrahim, H.; Ilinca, A.; Perron, J. Energy storage systems—Characteristics and comparison, 2008

Energy Storage: **Flow Batteries (Vanadium Redox, Iron Redox, etc)**

"Deconstructed" aqueous battery where electrolyte is pumped across electrodes to facilitate redox reaction creating electricity. Flow batteries represented just 7% of battery deployments in 2017



Pros:

- Scalable
- Virtually no degradation

Cons:

- Low energy density
- High capital cost

Energy Storage: **Zinc Bromine**

Zinc bromide electrolyte plates onto the anode to form zinc bromine. Can be aqueous (flow) or non aqueous (packed in a cell)

Pros:

- Scalable
- Virtually no degradation

Cons:

- Needs to be cycled to prevent damage
- Low energy density
- High capital cost

Energy Storage: **Lithium Ion**

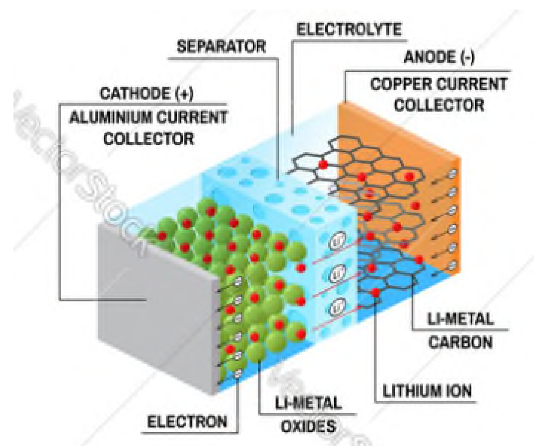
Lithium ions flow through electrolyte to anode and cathode to produce electricity. There are many types of lithium ion batteries.

Pros:

- Flexible design
- Common in market; increasing demand
- High energy density

Cons:

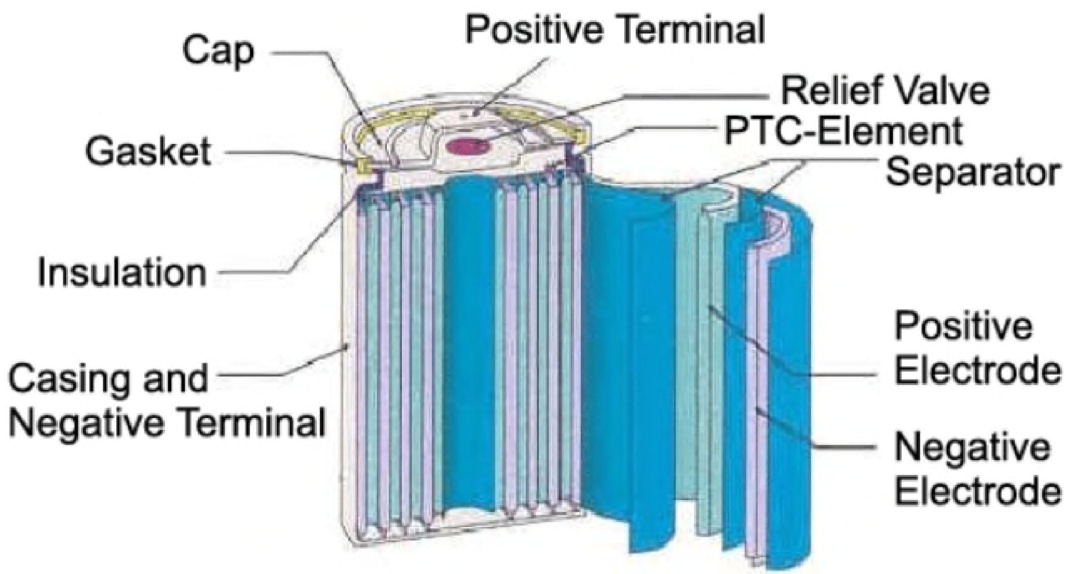
- Degradation
- Limited operating range



Energy Storage: **Lithium Ion Batteries**

Cell components:

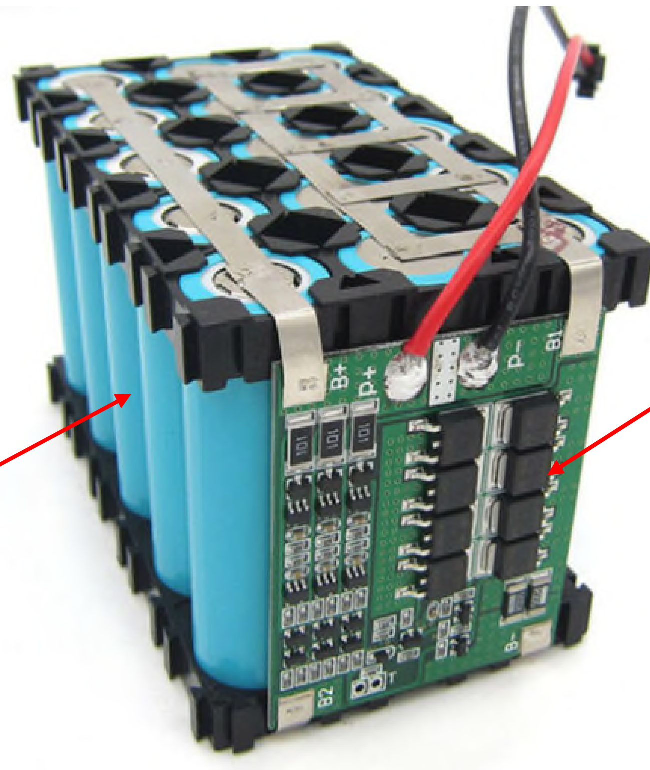
- Anode (Negative)
- Cathode (Positive)
- Electrolyte
- Separator
- Venting
- Housing



Energy Storage: **Lithium Ion Batteries**

Batteries consist of 3 major components:

- Cells
- Controls
- Modules



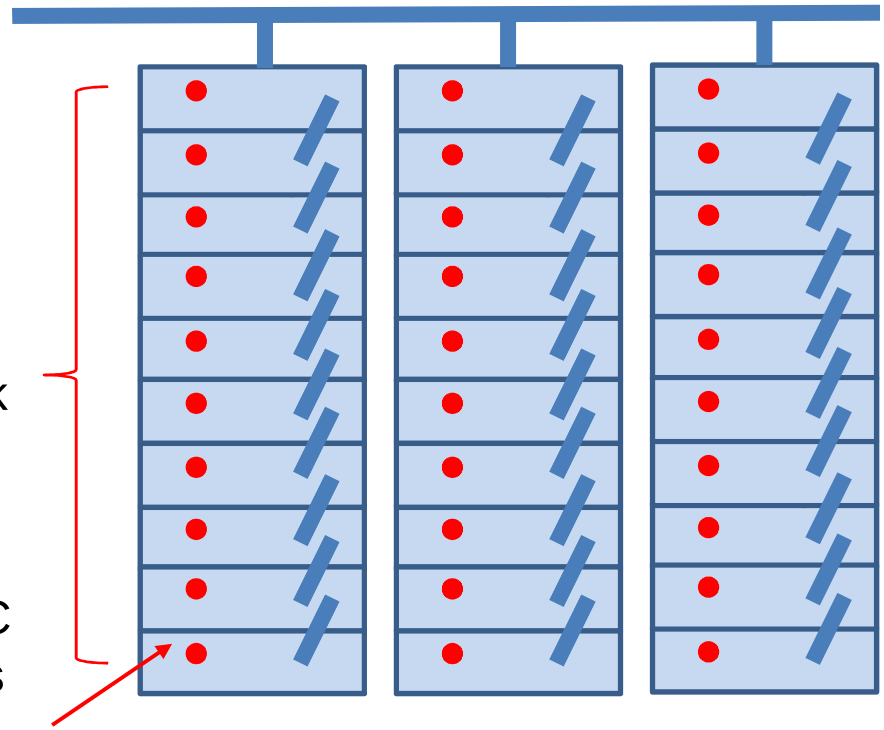
Individual cells are wired in series to form a module

Battery management system, “BMS”

Energy Storage: **Lithium Ion Batteries**

Modules are packaged together to form racks, which are wired in parallel to build systems.

DC bus to Inverter:
900-1200VDC



~10 trays in series per rack

(32) ~3.5VDC cells in series per tray

Energy Storage: **Battery Controls**

BMS: Battery Management System

- Maintains operating and warranty limits on each rack
    - Temperate, voltage, SOC range
    - Charge and discharge limits
- Provides data aggregation for battery

Inverter Controls

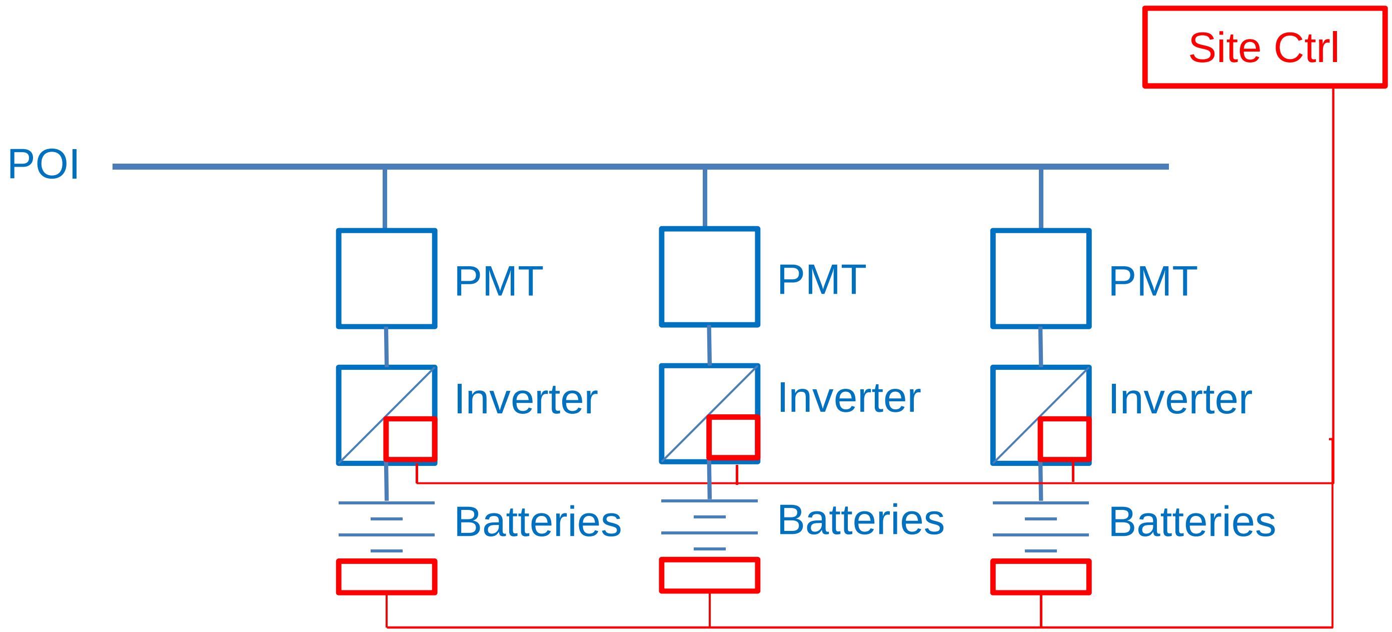
- Monitors performance and enforces operational health
- Coordinates with BMS warnings and faults
- Provides data aggregation for inverter

Site Controller

- Sits above the BMS's, inverters
- Dispatch and monitoring

Energy Storage: **Battery Controls**

BMS: Battery Management System



Risks and Challenges

Energy Storage: **Risks and Challenges**

1. Supply chain constraints
2. SOC balancing and degradation
3. Reactive power capabilities
4. Short circuit contribution

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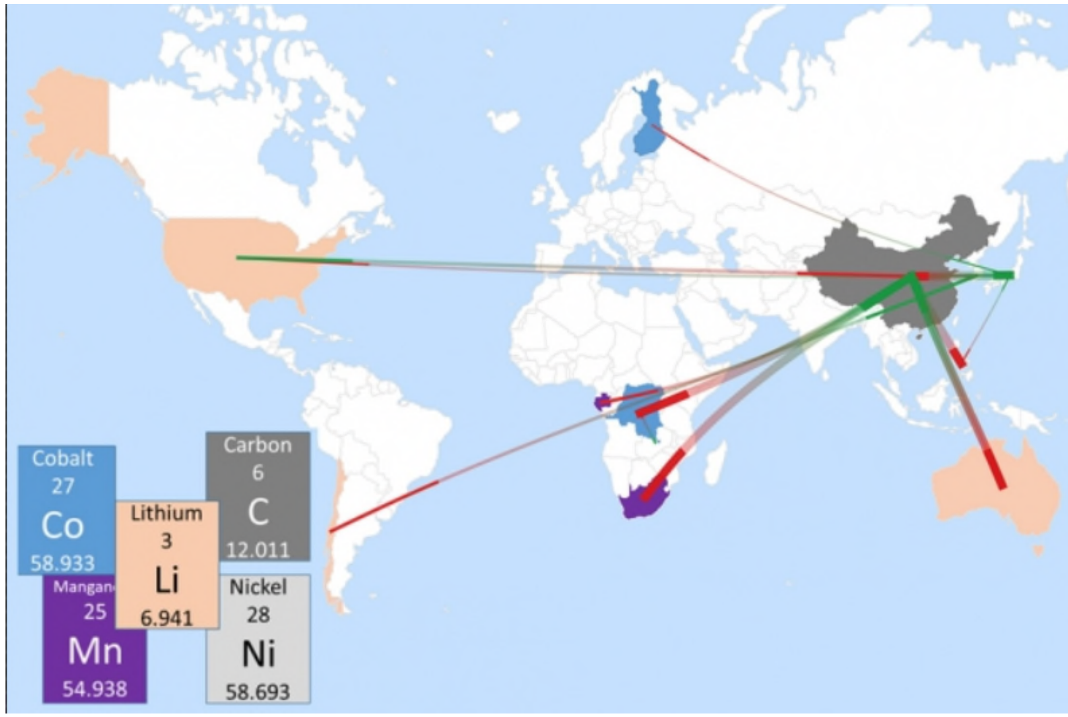

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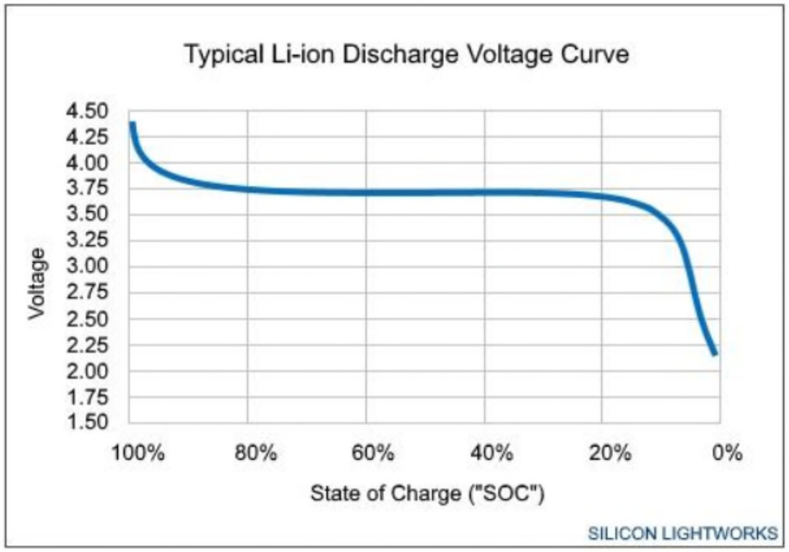

Energy Storage: **Risks and Challenges**

1. Supply chain constraints
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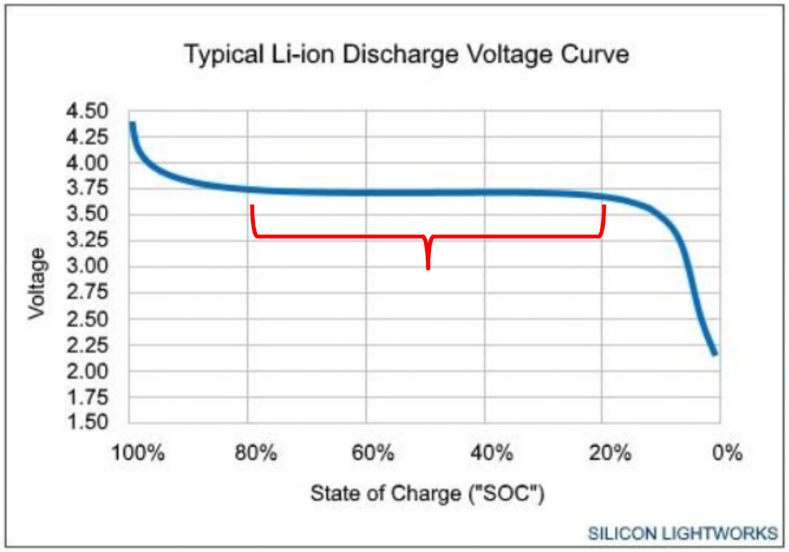
It is difficult to estimate SOC in the flat area of the voltage curve



Energy Storage: **Risks and Challenges**

1. Supply chain constraints
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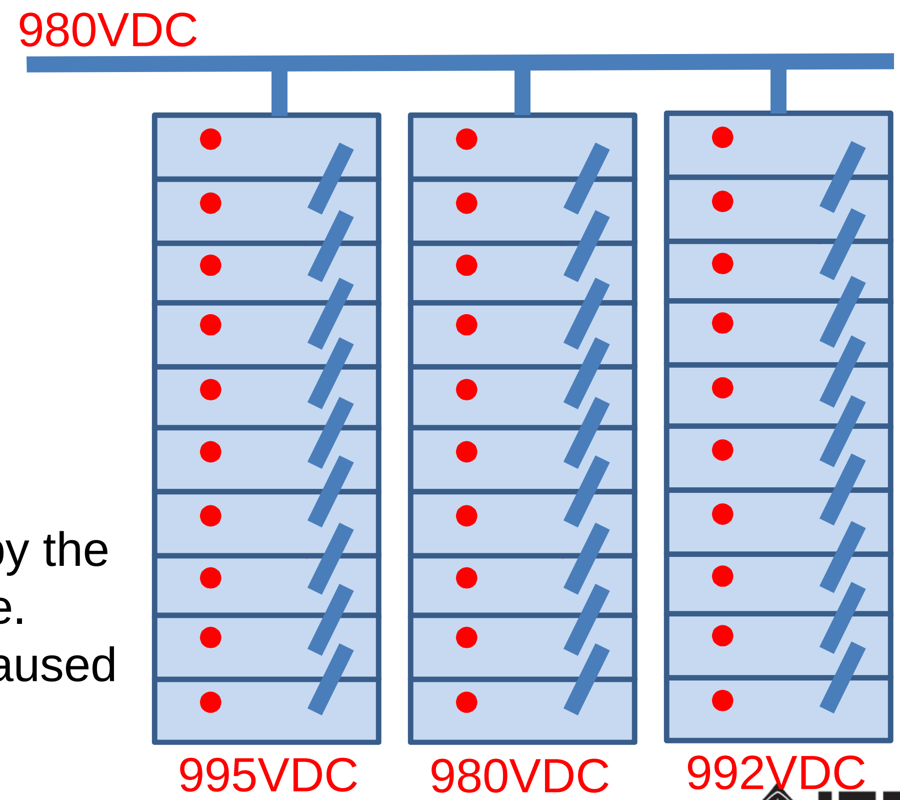
DC bus is limited by the lowest rack voltage. Loss of capacity caused by degradation



Energy Storage: **Risks and Challenges**

1. Supply chain constraints
2. SOC balancing and degradation
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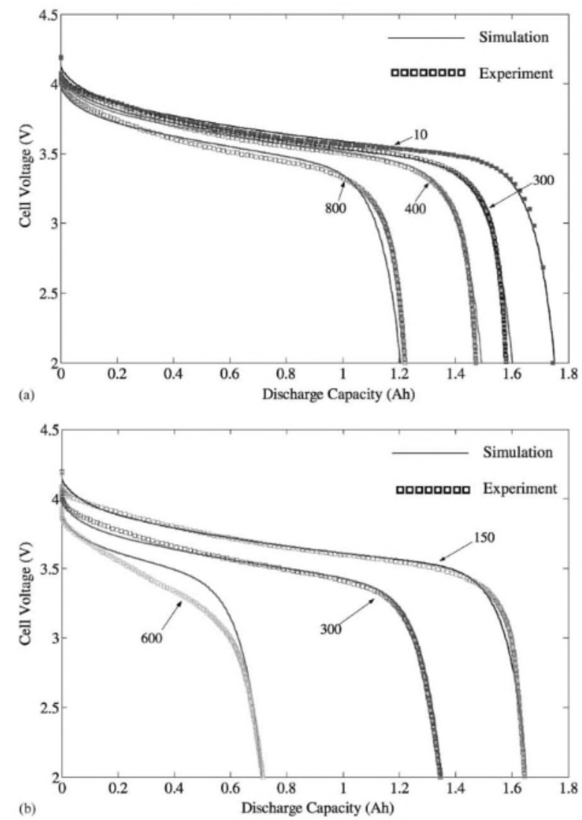
4. Short circuit contribution

Biggest contributors to degradation:

- Temperature
- High cycling
- SOC range
- Calendar life

P. Ramadass et al. / Journal of Power Sources 123 (2003) 230–240



Energy Storage: **Risks and Challenges**

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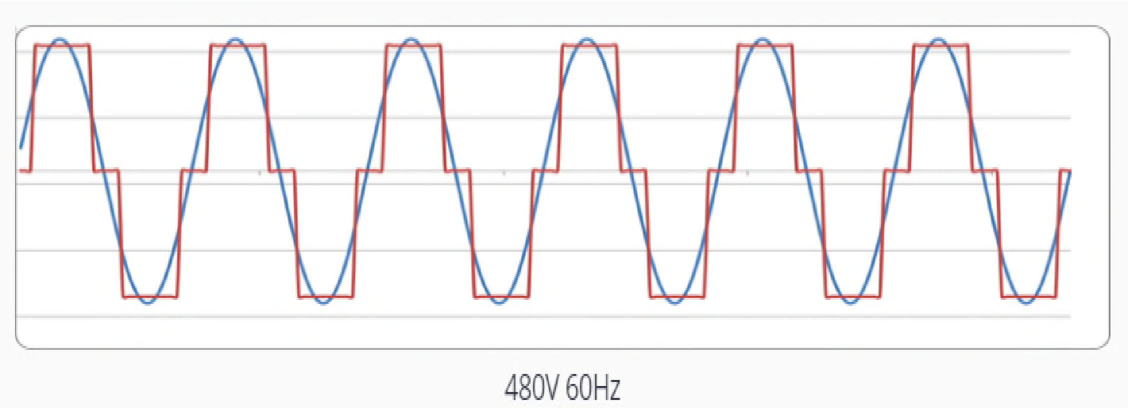
One ancillary benefit of using inverter based generation is the ability to manipulate the power output



Energy Storage: **Risks and Challenges**

1. Supply chain constraints
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This means that batteries can generate or absorb full nameplate Watts and VARs

Energy Storage: **Risks and Challenges**

1. Supply chain constraints
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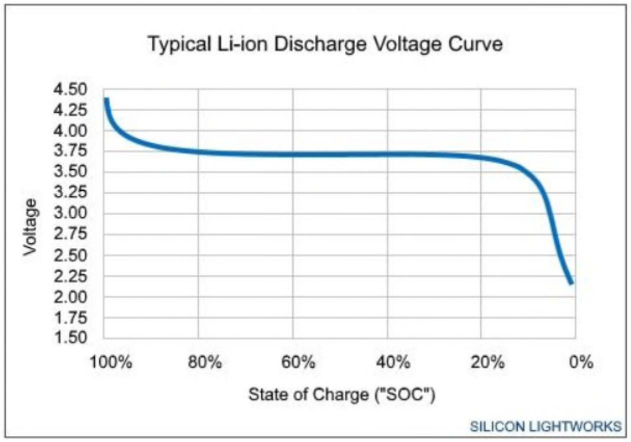
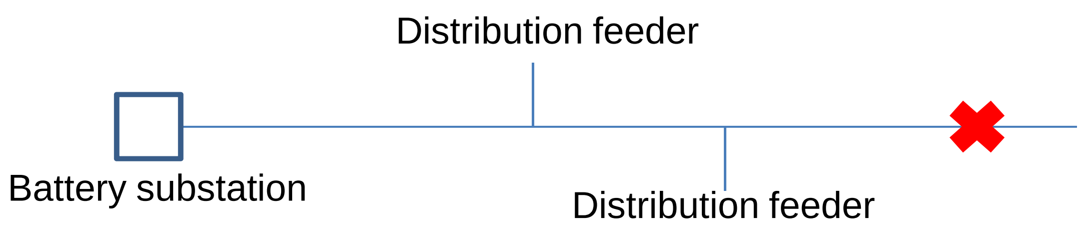
One further limitation to real or reactive power output is the input DC voltage. DC voltage must be high enough to sustain power output.



Energy Storage: **Risks and Challenges**

1. Supply chain constraints
2. SOC balancing and degradation
3. Reactive power capabilities
4. Short circuit contribution

Reciprocating machines provide much more short circuit contribution than inverter-based generators. This can cause issues when inverters are on long distribution or transmission lines, or when they are supporting a whole grid.



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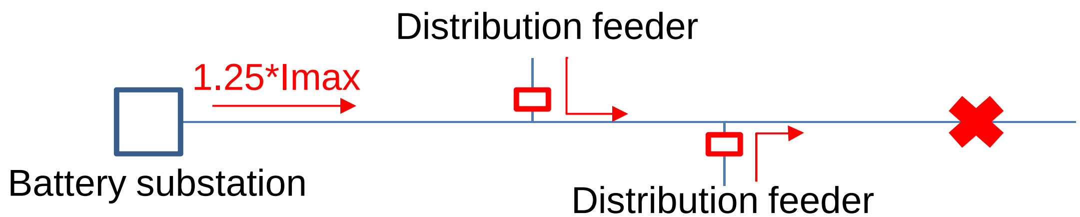

Questions?