UTILITY - SCALE ENERGY STORAGE TO SUPPORT HIGHER PENETRATION OF VARIABLE RENEWABLE ENERGY
Agenda

• Drivers of Storage Growth
  – Market Perspectives
  – Value Propositions
  – Technology Options & Applications

• Battery Energy Storage Systems
  – Components
  – Safety
  – Controls & Performance

• Case Studies

• Commercial Considerations
-Terminology
Battery Fundamentals: Power vs Energy

- Every energy storage system has some unique combination of **Power** and **Energy** capability

**Power (AKA: front end, capacity, inverter, PCS)**
- Measured in kW or kVA
- Represents the instantaneous output limit of the storage system

**Energy (AKA: back end, modules, racks, batteries)**
- Measured in kWh or amp-hours
- Represents the total amount of energy in the storage medium

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Size of the Pipe

Size of the Reservoir

Courtesy Nathan Adams, ABB
Power vs Energy - C Rate

C Rate

Power divided by Energy

- 1 MWh battery will deliver 1 MW for 1 hour (1C)
- 1 MWh battery will deliver 2 MW for 30 min (2C)
- 1 MWh battery will deliver 500 kW for 2 hours (0.5C)
Terminology for describing cost of ES

- Cost of storage technology
  - USD/kWh, example $300 per kWh. Meaningful when there is sufficient energy like one hour or more
  - USD/kW, example $1,500 per kW. Meaningful when there is less energy and more power like 15 minutes or less

- Price of energy delivered by storage
  - USD/kWh, example 0.10 per kWh

- Storage duration: amount of time storage can discharge at its rated power capacity

- Round trip efficiency: AC-AC efficiency

- Lifetime: Years under normal operation

- O&M: variable and fixed
Grid connected ES

Source: Chernyakhovskiy, Principles of Energy Storage, NREL, 2019
USAID workshop
- Value Propositions
Services Provided by Energy Storage

Electric supply
1. Electric energy time-shift
2. Electric supply capacity

Ancillary services
3. Load following
4. Area regulation
5. Electric supply reserve capacity
6. Voltage support

Grid system enhancements
7. Transmission support
8. Transmission congestion relief
9. Transmission & distribution (T&D) upgrade deferral
10. Substation on-site power

End user/utility customer benefits
11. Time-of-use (TOU) energy cost management
12. Demand charge management
13. Electric service reliability
14. Electric service power quality

Renewables integration
15. Renewables energy time-shift
16. Renewables capacity firming
17. Renewables integration

Source: ABB White Paper: Energy Storage: Moving toward Commercialization
How do you know what you want?

Image by NREL, Batteries 101 Series: Use cases and value streams for energy storage
Ancillary Services - apply in Seconds to Minutes timeframe, and include Spinning Reserves, Frequency Regulation, Black Start
Ramping Support - applies in the single to 30 minute timeframe; required to address rapid changes in supply and demand, often from renewable intermittency
Smoothing – used to address intermittency of renewable energy for grid integration, typically 1-4 hours, reducing impact on conventional generators & other equipment
Peaking, or Time Shifting – By supplying extra power during times of high demand, reduces demand on generators and entire system, typically 2-4 hours
Baseload Generation – Supply power over extended period of time to meet baseload demand on system, typically 6 or more hours

Variety of Energy Storage Technologies Based on Application

Managing a Reliable Grid - Multiple Timescales

Figure 13 Overview of Issues in Power System Operations and Control (adapted from Fisher et al. 2012)

Figure 9 Power Rating vs. Discharge Time for Energy Storage Technologies (Source: Akhil et al. 2013)

Pumped Storage Hydropower: Benefits for Grid Reliability and Integration of Variable Renewable Energy, Argonne National Laboratory – Botterud, Levin, and Koritarov

- Technology Options & Applications
Energy Storage Systems

Trends

Islanded Systems

- Greatest potential appears to be battery technologies
- Improving business case for storage especially on islanded systems (e.g., HECO, PREPA, Alaska, Caribbean etc.,) and remote micro grids
  - Abundance of renewables
  - Price volatility of conventional fuels
  - Rapid response ancillary services
- Revenue compensation mechanisms being introduced in markets as a result of FERC Order 755\textsuperscript{†} and 784\textsuperscript{‡}
- Significant advances in modeling are allowing ISOs, utilities and developers to evaluate full potential of ESS

Courtesy Nathan Adams, ABB
Long Duration Energy Storage: Pumped Hydro

Figure 1 Typical Pumped Storage Configuration (Source: Koritarov et al. 2014)

Figure 11 Goldisthal AS PSH plant in Germany (Photo Credit: Vattenfall)
Long-Duration Energy Storage

- Energy storage is an increasingly large problem with renewable energy. Energy Vault wants to solve it by storing extra energy as potential energy in concrete blocks.
- The company recently received a major investment from Japanese holding company SoftBank. $110 million
- That money will allow Energy Vault to build its first full-scale prototypes.

See energyvault.com
450 kW Electric Boiler – using Excess Wind to Heat Hospital

KEA Intensium® Max - key features
- Intensium® Max+ 20M Li-ion container
- 950 kWh
- 2MW maximum capability
- ABB 1.2 MW Power Conversion System (PCS)
- Control system reacts quickly to sudden changes in generation
- Cold temperature package

KEA microgrid - key facts
- Serves a remote off-grid community of 3,700 people
- Winter temperatures can fall to -50°C
- Combines diesel generators, wind turbines and energy storage
- 3 MW peak load
- 19 wind turbines – total 2.9 MW
- 6 diesel generators – total 11 MW
- 500 kW solar planned for the future

Saft ESS solution - key benefits
- Increased utilization of wind power reduces diesel generator run time – cutting fuel consumption by 250,000 gallons in 2015 and saving $900,000
- Avoids curtailment of wind turbines
- Ensures grid stability
- Smooths ramp rates
- Offers future potential for full ‘diesel-off’ operation
Thermal Storage in Alaska: Wind-to-Heat

- Dedicated 3-phase, 480V service for dispatched load
- 120 kW, multistage boiler (tied-in before oil-fired boilers)
- Wind-to-Heat Programmable Logic Controller (PLC)
- Wind-to-Heat relay control panel (powers boiler stages)
- Telemetry communication (radios) for remote control & Monitoring
- Programmable Controller for oil-fired boilers
- Up-sized heat exchangers as needed

Outcomes:
- Displaced diesel & energy cost savings for water system
- Decreased oil boiler maintenance from reduced firing
- Limited O&M for secondary load equipment in water plant
- Additional revenue for electric utility

The Royal Swedish Academy of Sciences awarded the Nobel Prize in Chemistry this morning.

Mechanical engineer John B. Goodenough, chemist Akira Yoshino, and chemist and materials scientist Stanley Whittingham will share the prize for their work developing the lithium-ion battery.

Together, their work has paved a way for technical innovations in how we power everything from smartphones to electric vehicles.
Lithium-ion Battery Prices, 2013-2018

Source: 2019 Utility Energy Storage Market Snapshot, Smart Electric Power Alliance

https://sepapower.org/resource/2019-utility-energy-storage-market-snapshot/
• Battery Energy Storage Systems
  - Components
Hierarchy of the battery solution

- Cell
- Modules
- Battery Container
- Rack
Cell Types

Three Main Cell Types

Cylindrical (18650)

Pouch

Prismatic
Modules

- Modules vary by
  - Size
  - Energy
  - Voltage
  - C rate capability
Racks

- Modules stacked and connected in series
- Voltage range is determined by the number of modules in series

Battery Rack Voltage Range Must Match the Inverter Voltage Range
Battery Container

- Extensive integration work required
  - Cooling
  - Fire suppression
  - Protection
  - Envelope
  - Wiring
  - Lighting

Courtesy Nathan Adams, ABB
Power converter – These are sized according to the applications. For higher power requirements, several units can be connected in parallel to provide dynamic control of active and reactive power flow in both directions.

Control system – Allows manual and automatic operation of all system components. Communication protocols support remote control and monitoring and accept load and weather forecasts.

Protection equipment – Includes AC/DC circuit breakers, protective relays, current & voltage sensors, built-in temperature monitoring devices, etc.

Switchgear – For safe and reliable grid connection and operation of the system.

Transformers – May include either liquid-filled and/or dry-type transformers that meet ANSI, IEC, and other local standards.

Batteries – Depending on the application, utilities can select from a variety of technologies such as lithium-ion (Li-ion), sodium-sulfur (NaS), nickel-cadmium (NiCd), lead-acid, or flow batteries.

Power Conversion

Where the Rubber Meets the Road

- Inverter: Device that converts DC to AC and vice versa
- AKA: converter, PCS

**Critical considerations**

1) Voltage vs current source

2) Quadrant Capability (real and reactive power range)

3) Environmental capability
- Safety
Fire Suppression

- **Fire Suppression Options**
- Lithium-ion subject to “thermal runaway"
- Dry Agent: extinguishes flame
- Hydrogen Sensor: Detects hydrogen leakage from modules
- Dry Pipe Sprinkler: Removes heat
- Burst plate: prevents pressure explosion
## Safety Concerns with Lithium-ion in Korea

### Figure 13: Korea battery fires by type

- **Total 23 fires**
  - During fully-charged standby: 3
  - During charging or discharging: 14
  - During installation: 6

### Figure 14: Percentage of cumulative capacity affected by fires (as of June 2019)

- **Total 5GWh**
  - Affected by fire: 4%
  - Unaffected: 96%

### Main factors of fires

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defective battery protection system</td>
<td>The fuse (i.e., battery protection system) was not able to properly interrupt the current when electrical surges were caused by ground faults or short circuits. This allowed the failures to cascade to the bus bar, which resulted in fires.</td>
</tr>
<tr>
<td>Faulty operation management</td>
<td>A majority of projects damaged by fire were installed in the mountains or coastal areas. High humidity levels and large temperature swings in these environments resulted in condensation, which then formed residue within the battery system. This caused the electrical insulation inside the battery modules to degrade, resulting in short circuits and subsequent fires.</td>
</tr>
<tr>
<td>Careless installation</td>
<td>It was determined that human errors during system installations can cause fires. Examples include faulty wiring or mechanical damage to the batteries.</td>
</tr>
<tr>
<td>Faulty system integration</td>
<td>The integrated protection and management systems were found to be defective. The energy, power and battery management systems were made by different manufacturers were not properly integrated. This interrupted the system from sharing crucial information and detecting system abnormalities.</td>
</tr>
</tbody>
</table>

Source: Korea Ministry of Trade, Industry and Energy

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Source: 2H 2019 Energy Storage Market Outlook, Bloomberg NEF
## Improved Safety Standards in Korea

<table>
<thead>
<tr>
<th>Safety measures</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturing process</td>
<td>• Heightened safety standards will be applied to the manufacturing process of battery cells and PCS (power conversion system) under KC* safety certification</td>
</tr>
<tr>
<td>System design and installation</td>
<td>• Capacity of storage systems installed in people-occupied buildings must be under 600kWh</td>
</tr>
<tr>
<td></td>
<td>• Storage system must be equipped with protection systems for short circuit, over-voltage, and over-current</td>
</tr>
<tr>
<td></td>
<td>• Storage system must be equipped with emergency shut-down system</td>
</tr>
<tr>
<td></td>
<td>• Storage systems must be equipped with fire extinguishing equipment</td>
</tr>
<tr>
<td>Operation</td>
<td>• Storage system must not be overcharged</td>
</tr>
<tr>
<td></td>
<td>• System must be operated within the temperature and humidity range recommended by the battery manufacturer</td>
</tr>
<tr>
<td>Maintenance</td>
<td>• Government-mandated safety check-up cycle will be shortened to 1-2 years from current 4 years</td>
</tr>
</tbody>
</table>

*Source: Korea Ministry of Trade, Industry and Energy  Note: *A mandatory certification scheme that verifies safety as well as electromagnetic compatibility and radio frequency requirements of all electrical and electronic products entering South Korea.*
Recent Fire in Arizona, USA

- Arizona Public Service (Utility) & Fluence (Battery mfg) – Both very experienced
- Voltage drop across module followed by increase in temperature
- Still under investigation
- Gases exploded - not batteries
- One person died
- Re-evaluating construction, fire suppression, codes, notification/protection of first responders
- Future growth hinges on successful mitigation

Source: https://www.greentechmedia.com/articles/read/arizona-battery-explosion-conventional-wisdom-safety
- Controls & Performance
Asking the Right Questions…

Categorizing Energy Storage Projects

- Where is the storage located within the power system?
  - Transmission Level
  - Distribution Level
  - Behind-the-Meter
- Who is it serving?
  - ISO/RTO
  - Utility
  - Customer
- What size is the storage system?
  - Grid-scale
  - Commercial-scale
  - Residential-scale
- Is it providing direct income, or avoided costs/losses?

Types of Energy Storage

- Bulk Storage
  - large capacity
  - low cost
  - long lead time
  - hard to site
- Compressed Air
- Distributed Storage
  - short lead time
  - easy to site
  - many use cases
  - higher cost
- Flywheels
- Batteries (Flow, Lead Acid, Li-ion)

Source: Energy Storage 101, Joyce McLaren, National Renewable Energy Laboratory, March 2017
Deployments by Utility-Scale ES Technologies

Source: 2H 2019 Energy Storage Market Outlook _ BloombergNEF.pdf
Battery Metrics & Matching Performance with Needs

Know your Battery Terminology

- Charge/Discharge Cycle - # of cycles impacts battery lifetime
- Depth of discharge (DoD) - % of total capacity that is utilized in a discharge cycle
  - shallow cycle vs. deep cycle
  - deep cycling shortens lifetime
- End of Life (EOL) - current standard: 80% of original capacity
- Round trip efficiency (RTE) - Ratio (%) of total energy output (discharge) divided by input (charge)
- State of Charge (SoC) - battery’s current capacity as % of maximum capacity

Using a battery for multiple purposes

- Every battery system can be employed for multiple uses.
  - Some uses may require it to discharge a few hours per year (infrequent outages) or a few minutes each hour (grid services).
- Discharging the battery for one purpose may prohibit its use for another purpose, until it is recharged.
  - Uses must be prioritized
- Battery cycling (charging and discharging) produces wear and tear and shortens the lifetime of the battery.
  - Does the value obtained from cycling the battery outweigh the cost of battery degradation?

Source: Energy Storage 101, Joyce McLaren, National Renewable Energy Laboratory, March 2017
## Comparison of Energy Storage Technologies

<table>
<thead>
<tr>
<th></th>
<th>Max Power Rating (MW)</th>
<th>Discharge time</th>
<th>Max cycles or lifetime</th>
<th>Energy density (watt-hour per liter)</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumped hydro</td>
<td>3,000</td>
<td>4h – 16h</td>
<td>30 – 60 years</td>
<td>0.2 – 2</td>
<td>70 – 85%</td>
</tr>
<tr>
<td>Compressed air</td>
<td>1,000</td>
<td>2h – 30h</td>
<td>20 – 40 years</td>
<td>2 – 6</td>
<td>40 – 70%</td>
</tr>
<tr>
<td>Molten salt (thermal)</td>
<td>150</td>
<td>hours</td>
<td>30 years</td>
<td>70 – 210</td>
<td>80 – 90%</td>
</tr>
<tr>
<td>Li-ion battery</td>
<td>100</td>
<td>1 min – 8h</td>
<td>1,000 – 10,000</td>
<td>200 – 400</td>
<td>85 – 95%</td>
</tr>
<tr>
<td>Lead-acid battery</td>
<td>100</td>
<td>1 min – 8h</td>
<td>6 – 40 years</td>
<td>50 – 80</td>
<td>80 – 90%</td>
</tr>
<tr>
<td>Flow battery</td>
<td>100</td>
<td>hours</td>
<td>12,000 – 14,000</td>
<td>20 – 70</td>
<td>60 – 85%</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>100</td>
<td>mins – week</td>
<td>5 – 30 years</td>
<td>600 (at 200bar)</td>
<td>25 – 45%</td>
</tr>
<tr>
<td>Flywheel</td>
<td>20</td>
<td>secs – mins</td>
<td>20,000 – 100,000</td>
<td>20 – 80</td>
<td>70 – 95%</td>
</tr>
</tbody>
</table>

Flexibility & Control Required to Manage Grid, VRE

- **Primary Control:**
  - Resides on inverter firmware
  - Required for low latency applications like transient response

- **Secondary Control:**
  - Interfaced PLC or DCS
  - Slower response time (50ms-500ms)
  - Reads measured conditions and issues setpoints
    - Examples include:
      - Peak shaving
      - Renewable smoothing
      - Automated Generator Control
      - Frequency/voltage support

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9/16/2019

Courtesy Nathan Adams, ABB
Control Objective Informs Storage Dimensions

- **Stabilizing**: Frequency regulation
- **Spinning Reserve**: Voltage
- **Standalone**: Island mode
- **Shaving**: Peak lopping
- **Smoothing**: Capacity firming
- **Shifting**: Load leveling
- **STATCOM**: Power quality

**Power** vs. **Time (Energy)**

- **ms** vs. **hrs**

9/16/2019
Deployment of ES by Application

Source: 2H 2019 Energy Storage Market Outlook _ BloombergNEF.pdf
Aggregate Solar PV Output

Solar Plant Profile (~15 MW)
BESS System Performance

24 Hour Operation Window

Graph showing solar PV power and BESS PCS output over a 24-hour period from 30 May 2019 to 31 May 2019. The graphs display original PV output and smoothed PV output.
BESS System Performance

30 Minute Operation Window

- Solar PV Power (kW)
- BESS PCS Output (kW)

- Original PV Output
- Smoothed PV Output

Date: 9/16/2019
BESS System Performance

30 Minute Operation Window

- Solar PV Power (kW)
- BESS PCS Output (kW)

- Original PV Output
- Smoothed PV Output
Energy Storage is Only Part of the Solution

NEW YORK Reforming Energy Vision (REV)

FIGURE 4. BQDM SOLUTION PORTFOLIOS

The Brooklyn Queens Demand Management Program used a portfolio of a variety of DER to provide significant needed load relief and avoid $1.2 billion in grid upgrades.

Image courtesy of SEIA

Source: SEIA

Source: The Role of Distributed Energy Resources in Today’s Grid Transition, GridWorks/GridLab
- Examples & Case Studies for BESS Applications
- Back up slides