Example: Large Scale Load Shifting

ARIZONA PUBLIC SERVICE

In February 2019, Arizona Public Service’s (APS’) announcement to build an additional 850 MW of storage by 2025 marked a meaningful milestone in member company battery storage buildout plans. This is almost three times more than the 311 MW of battery storage that was installed in 2018. The company will add 200 MW of battery storage to existing Maricopa County and Yuma solar power plants by 2021. Also, APS will use 150 MW of storage coupled with solar to meet evening peak demand. Lastly, APS will build an additional 500 MW of solar storage and stand-alone storage by 2025. APS’ plans indicate that storage costs are declining.
Example: Deferred Transmission/Substation, Peak Shaving, VAR Support

Baltimore Gas and Electric—Coldspring Substation

Baltimore Gas and Electric evaluated the construction of a new transmission-supplied distribution substation to offload the Coldspring distribution substation, which tends to be subject to summer overload. The company determined that a 5 MW/20 MWh lithium-ion battery storage system would be a more economical solution. The battery storage project is helping Baltimore Gas and Electric defer construction of a new substation for at least five years, providing peak shaving and VAR injection services. The system is designed to be installed in four phases. The initial 1 MW/1 MWh phase was installed in 2018.
Example: Non-wires Alternative

**DUKE ENERGY—MOUNT STERLING MICROGRID PROJECT**

Mt. Sterling is a remote solar-plus-storage microgrid located in the Great Smoky Mountains. It replaced a 5-mile, 12.47 kilovolt distribution feeder that served one customer—the Mt. Sterling radio tower, which experienced three or more major outages per year and has high operational and maintenance costs due to vegetation management and restoration costs. The microgrid was built as a non-wires alternative, allowing Duke Energy to give back the right-of-way to park services and to remove the distribution feeder, associated equipment, and more than 40 poles. The microgrid enhances reliability, integrates renewables, and reduces operational and maintenance costs.
Example: Mobile Back-up as Needed

Florida Power & Light’s Mobile Uninterruptible Power Supply (UPS) is a mobile lithium-ion battery that is designed to provide emergency back-up power for a short duration during a momentary power outage and/or flicker, which benefits all customers. The ability to mobilize the unit allows the company to position and connect the system wherever it is needed to support the energy grid.
NRI deploys four primary types of grid tied energy storage systems to our client base:

- The 6, 12, 18, 22kWh DES designed for residential and small business use in single phase applications. This is commonly coupled with solar.

- BTM Commercial Three Phase applications for demand reduction, resiliency, or power quality support typically ~125kW/250kWh base design

- FTM Utility Distribution Feeder Sited Systems used for grid support and/or resiliency/islanding. Single or Three Phase designs. 125kW/125kWh to 500kW/1MWh

- Large scale storage applications up to 400MWh. Largest plant under contract, $63M USD in Mexico. Largest plant commissioned, 12MW/26MWh Arkansas.

Pictured: Smallest NRI Lithium Model
Grid-Tied or Grid-Forming Utility Scale Applications

250kWh – 26MWh+

• Generally installed adjacent to substation, at renewable generation site, or in proximity to large customer loads

• Container or Structure housing depending on customer application and permitting

• Multiple modes of operation to allow a single system to capitalize on revenue stacking
Case Study: NRI Fayetteville, Arkansas
12MW / 26 MWh Lithium Peak Demand Reduction (Solar + Storage)

As featured in T&D World Magazine April 2019

- Utility Peak Demand Reduction
- Solar Generation into Grid
Case Study: Fayetteville, Arkansas
12MW / 26.1 MWh Peak Demand Reduction

• OVERVIEW:
  – 2 Project Sites (5.5MW Solar tied solutions per site)
  – 3 - 2MW / 4.35MWh Systems per Site
  – 6 - SC-1000 NRI System Controllers operating in coordinated fleet mode

• GOALS:
  – Increase renewable energy portfolio for City of Fayetteville, AR to 82%
  – Reduce peak electrical demand for Ozark Electric Cooperative by 12MW for 2 continuous hours.
  – Provide NRI’s customer, Today’s Power, a working design to the business model may collect tax credits in addition to planned revenues.
ESCRI Microgrid

30MW/8MWh BESS with Value Stacking

ESCRI South Australia battery project

The first large scale, grid-connected battery to be designed, built and operated in Australia. This sophisticated response to South Australia’s power situation will provide grid stability in multiple ways.

1. Provides fast-acting power response, keeping grid in balance when things go wrong on the system (e.g., generators or transmission lines fail).
2. Reduces constraints on Heywood Interconnector with Victoria (should place downward pressure on SA wholesale power prices).
3. Improves supply reliability by operating as micro-grid with Wattle Point wind farm and rooftop solar when main grid supply is lost.
4. 30MW/8MWh utility scale lithium-ion battery.

Retailer operates battery under agreement with ElectraNet, providing additional market services without compromising security and reliability services.
ESCRI Microgrid

Business Case

Source: ElectraNet – ESCRI-SA Battery Energy Storage Lessons Learned – Energy Networks 2018
## ESCRI Microgrid

### Business Case

#### Benefits

<table>
<thead>
<tr>
<th>Component</th>
<th>Service/benefit</th>
<th>BESS</th>
<th>Comment</th>
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<tr>
<td><strong>Energy</strong></td>
<td>Cap trading</td>
<td>✓</td>
<td>Long term energy: Fast start GTs, gas, PHES, DER, wind, PV, coal, diesels, transmission</td>
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<td></td>
<td>Energy time shifting</td>
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<tr>
<td></td>
<td>Energy security</td>
<td>✓</td>
<td></td>
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<tr>
<td><strong>Network reliability/support</strong></td>
<td>USE reduction</td>
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<td></td>
<td>Capital deferral</td>
<td>✓</td>
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<tr>
<td></td>
<td>Voltage &amp; reactive control</td>
<td>✓</td>
<td></td>
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<tr>
<td><strong>Frequency control</strong></td>
<td>Short term spinning reserve</td>
<td>✓</td>
<td></td>
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<tr>
<td></td>
<td>FACS</td>
<td>✓</td>
<td>Aggregated DER</td>
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<tr>
<td></td>
<td>Fast frequency response</td>
<td>✓</td>
<td>SPS, UFLS</td>
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<tr>
<td><strong>Safety</strong></td>
<td>Fault level</td>
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<td>Synchronous condensors</td>
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<tr>
<td></td>
<td>Black start</td>
<td>✓</td>
<td></td>
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</tbody>
</table>

#### Business model

- **Commercial arrangements** - Competitive market services at arm's length
- **Funding and Commercial**
  - ARENA grant part funding
- **ElectraNet owns BESS & provides regulated services**
- **Operating Principles**
  - Availability Guarantee
  - AGL leases BESS from ElectraNet and is BESS operator
- **Assets and Operation**
- **Services provided to customers and NEM participants**
  - Regulated services
  - Reduced unserved energy
  - Fast frequency response
- **Competitive market services**
  - FCAS, Market caps

**Benefits**

- **Payments**
Combining Gas & Batteries @ Peaker Plant

- Utility Owned & Operated
- Transmission co-located with natural gas plant
- Li-ion battery & natural gas plant
- Battery size: 10 MW/4.3 MWh
- Duration: 26 minutes
- Services: Quick start, spinning reserve (primary); reliability, renewable smoothing (secondary)
- Operation Start: March 2017

In 2017, partnering with General Electric and Wellhead Power Solutions, Southern California Edison (SCE) launched the world’s first 50 MW LM6000 aeroderivative Hybrid Electric Gas Turbine (Hybrid EGT), coupled with a 10 MW/4.3 MWh lithium-ion battery at its two peaker plants. The battery enables instantaneous response capability while the upgraded gas turbine is ramping up. Using its immediate response ability allows the battery and EGT hybrid system to fill the gaps in renewable generation.

Source: Leading the Way – US Electric Company Investment and Innovation in Energy Storage; Edison Electric Institute
Distribution Deferral, non-utility, Reliability

- Third-party owned; developed under 10-year contracts with performance agreements
- Storage located at Distribution level of system
- Lithium nickel-manganese-cobalt
- Battery Size: 10 MW/25 MWh
- Duration: 15 minutes
- Services: Renewable integration, frequency regulation, voltage control, distribution deferral
- Operation Start: 2017

Lithium Nickel Manganese Cobalt Battery

The project consists of a 10 MW lithium nickel-manganese-cobalt battery connected to Tuscon Electric Power’s (TEP) local distribution system. Its goal is to improve service reliability for customers by maintaining the required balance between energy demand and supply in case of a drop in the voltage frequency of the regional energy grid. The facility was completed in 2017 by NextEra Energy Resources, based in Juno Beach, Florida.

The system can also help prevent power outages during periods of high energy demand by supporting stable voltage on TEP’s energy delivery system. In the event of an outage, the systems could provide about 5 MW of power for up to an hour. TEP uses energy storage during system disturbances in lieu of more expensive generating resources to ensure uninterrupted electric supply. Energy storage also allows the company to defer costly investments in other system infrastructure.

Source: Leading the Way – US Electric Company Investment and Innovation in Energy Storage; Edison Electric Institute
MULTI-STAGE ENERGY STORAGE SYSTEM
COMBINED BATTERY & FLYWHEEL STORAGE PLATFORM FOR RENEWABLES INTEGRATION

Alaska’s Railbelt System

Courtesy Rob Roys, ABB
The Chugach System

- 531.2 megawatts of installed generation
- 434 miles of transmission line
- 42 substations
- 896 miles of overhead distribution lines
- 823 miles of underground distribution lines
- 83,855 service locations
- 68,215 cooperative members
Infrastructure Changes in Alaska

• New combined cycle power plants
  – Chugach/AML&P Southcentral Power Project in 2013 (200 MW)
  – Anchorage Municipal Light & Power Plant 2A in 2017 (127 MW)
  – Homer Electric’s Nikiski Combined Cycle Plant in 2014 (added 40 MW)
• New wind generation
  – Fire Island Wind in 2012 (17.6 MW)
• Future solar power
  – Chugach’s Community Solar in 2018 (500 kWh)
  – Homer Electric solar project (750 kWh)
• Enhanced hydro energy
  – Stetson Creek Diversion Project at Cooper Lake in 2015
  – Battle Creek Diversion Project at Bradley Lake
Light Grid

5.1 sec

60.0 Hz

59.4 Hz
Renewables Penetration in the Railbelt

- Natural Gas: 63%
- HAGO: 13%
- Coal: 6%
- Wind: 2%
- Water: 10%
- Steam: 5%
- Naptha: 1%
Project Background & Purpose

- Determine applicability to renewables

- Investigating synergies between FESS and BESS platforms

- Experience to justify larger scale installation
Project Capabilities

– **Wind smoothing** (ramp rate control)

– **Frequency** regulation
  - System frequency support
  - Droop response (aka “synthetic inertia”)

– Area Control Error (**ACE**) regulation
Equipment Concept

- CHUGACH SYSTEM CONTROL
- INVERTER
- FLYWHEEL
- BATTERY ENERGY STORAGE SYSTEM
- CONTROLLER
- BATTERIES
- BATTERY MANAGEMENT SYSTEM
- CHUGACH GRID
The Equipment: Flywheel

- Manufacturer: Piller
- Rotational Speed:
  - 1,800 to 3,400 RPM
- Flywheel Rotating Mass: 2.9 T
- Power rating: 1MW
- Energy rating: 16.5 MJ
- 30’ Module
The Equipment: Batteries

- Manufacturer: Samsung SDI
- “Power” rated batteries
  - 2 MW at 4C rating (5 min only)
  - 1.25 MW at 2C rating (continuous)
- Battery Specs
  - Nickel Cobalt Manganese (NCM) & Lithium Magnesium Oxide (LMO)
  - ~248.2 Wh per cell
- Rack Design
  - 11 ea. 192S1P racks (517 kWh)
  - 11 racks, 192 cells/rack
The Equipment: Inverters

- Manufacturer: ABB
  - PCS 100
  - ~100 kVA each
  - Stacked to reach target power rating

- Flywheel Application
  - 440 VAC to 800 VDC to 415 VAC

- Battery Application
  - Variable DC to 800 VDC to 375 VAC
## Project Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Start</th>
<th>Finish</th>
<th>Duration</th>
<th>2016</th>
<th>2017</th>
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<tbody>
<tr>
<td>1</td>
<td>Studies &amp; Planning</td>
<td>1/1/2013</td>
<td>7/1/2016</td>
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<td>FESS &amp; Battery PCS Fabrication</td>
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<td>BESS Contact with Samsung</td>
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<td>4</td>
<td>On Site Construction</td>
<td>4/14/2017</td>
<td>6/30/2017</td>
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<tr>
<td>5</td>
<td>Commissioning</td>
<td>6/30/2017</td>
<td>7/25/2017</td>
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<tr>
<td>6</td>
<td>One Year Test Period</td>
<td>7/25/2017</td>
<td>7/25/2018</td>
<td>52.4w</td>
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</tbody>
</table>
Present Applications

• Transmission
  – Shift renewable generation output
    – Voltage support
• Peaker Replacement
  – Replace peaking gas turbine generation
    – Spinning reserve & non-spinning reserve
• Frequency Regulation
  – Fast power injection & absorption
• Distribution Substation
  – Flexible peaking capacity
  – Stability & power quality
• Distribution Feeder
  – Stability & power quality

• Smooth renewable generation
• Area Control Error support

Lazard’s Levelized Cost of Storage Version 2.0, December 2016
MSESS Control Logic
Observations To Date

• Does the flywheel respond more quickly to frequency than the batteries and therefore reduce battery cycling?

• Does the system control downward wind ramp rate?

• How well does the system respond to frequency disturbances?
Battery Life Preservation

• Initial results are positive

• Flywheel cycling mitigates impacts battery cycling

• Battery SOH testing in mid-2018
Cycling Response

- Battery Power Meter Output
- Flywheel Power Meter Output
- Flywheel Frequency Support Power Setpoint
- Frequency

Date: 9/16/2019
Wind Ramp Rate Control

- Based on active power measurement at the Fire Island Wind project

- Attempts to regulate wind to a rate ($\pm$ 2.5 MW/min)

- Logic is contained in the Dispatch Controller from ABB
Wind Response
Area Control Error (ACE) Regulation

- ACE signal is smoothed to prevent reaction to momentary spikes
- Flywheel and battery are dispatched separately
- Adjustable deadband
Recharge

- Returns the battery and flywheel to the programmed state of charge
- Battery is currently set at 80% SOC
- Flywheel is currently set at 50% SOC
- **Acts gradually;** doesn’t counteract the other programmed responses
Future Applications

- **Transmission**
  - Shift renewable generation output
  - Voltage support
- **Peaker Replacement**
  - Replace peaking gas turbine generation
  - Spinning reserve & non-spinning reserve
- **Frequency Regulation**
  - Fast power injection & absorption
- **Distribution Substation**
  - Flexible peaking capacity
  - Stability & power quality
- **Distribution Feeder**
  - Stability & power quality

*Lazard’s Levelized Cost of Storage Version 2.0, December 2016*
Main Lessons Learned

• Currently no direct evidence of long battery life with high cycling

• Be clear about the purpose of the system in order to define success

• Storage is not yet a solution for wind energy shifting (Don’t yet have enough…)
Is it the answer?

• Energy storage works
  – Lithium-ion batteries
  – Flywheels
  – Controls to integrate them

• It works for Chugach
  – Smoothing, not firming renewables

• Future advances are in development
  – Energy shifting is the Holy Grail
Lessons Learned

• Charge & discharge rates (the “C” rate) needs to be clearly specified in order to ensure proper chemistry selection and expected battery response

• FM has specific expectations on firewall ratings for Lithium Ion batteries but was not interested in inspecting modules with a single loss less than $1M

• Modular design will negate high civil construction costs

• In-ground style of flywheel may lead to significant foundation design issues and high construction costs
Lessons Learned

• Modular design leads to HVAC requirements and higher operation and maintenance costs

• Be prepared for training of the O&E team – an energy storage platform does not act the same way as a typical generating facility
Frequency Support Current Settings

- **Battery (PS1) Frequency Support**
  - Deadband: 0.15 Hz
  - Gain: 6,000 %

- **Battery (PS1) Inertia Support**
  - Deadband: 1 Hz/sec
  - Gain: 0 kW/Hz/sec

- **Flywheel (PS2) Frequency Support**
  - Deadband: 0.05 Hz
  - Gain: 4,000 %

- **Flywheel (PS2) Inertia Support**
  - Deadband: 0.2 Hz/sec
  - Gain: 0 kW/Hz/sec
- Commercial Considerations

- Energy storage project stages and lead times
- Battery Sizing
- Performance Guarantees and degradation
- Augmentation/replacement
## Typical Energy Storage Project Timing/Planning

<table>
<thead>
<tr>
<th>Stage</th>
<th>Lead Times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial use case determination, modeling, sizing</td>
<td>1-6 months</td>
</tr>
<tr>
<td>Site Location/Permitting</td>
<td>1-6 months</td>
</tr>
<tr>
<td>Supply of Equipment</td>
<td>4-6 months (small product)</td>
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<tr>
<td></td>
<td>6-8 months (large project)</td>
</tr>
<tr>
<td>Site construction</td>
<td>4-6 months</td>
</tr>
<tr>
<td>Transportation/Delivery Point</td>
<td>3-6 weeks</td>
</tr>
<tr>
<td>Commissioning/Site Acceptance Testing</td>
<td>1 week (small product)</td>
</tr>
<tr>
<td></td>
<td>4-6 weeks (large project)</td>
</tr>
</tbody>
</table>
Battery Sizing

This is where it gets complicated

• **Customer Need:**
  - 1MW of storage for 1 hour

• **Vendor Proposal:**
  - 1MW Inverter
  - Ten 100kWh battery racks
## Battery Sizing

### Useable Energy

<table>
<thead>
<tr>
<th>Item</th>
<th>kWh</th>
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<tbody>
<tr>
<td>Start</td>
<td>1000</td>
</tr>
<tr>
<td>Minimum SOC 10%</td>
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<tr>
<td>Maximum SOC 90%</td>
<td>100</td>
</tr>
<tr>
<td>Net Energy</td>
<td>800</td>
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</table>
### Battery Sizing

#### Efficiency Losses

<table>
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<th>Item</th>
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<tbody>
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<td>Start</td>
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<tr>
<td>Battery losses @ .95</td>
<td>40</td>
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<tr>
<td>Net Energy</td>
<td>760</td>
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<table>
<thead>
<tr>
<th>Item</th>
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<td>Start</td>
<td>760</td>
</tr>
<tr>
<td>DC Line Losses@ .995</td>
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<td>Net Energy</td>
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<table>
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<td>Inverter Losses@ .98</td>
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## Battery Sizing

### Degradation

<table>
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<tr>
<td>Expected Degradation .85</td>
<td>111.2</td>
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<tr>
<td>Net Energy (year 10)</td>
<td>629.9</td>
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</table>
Battery Degradation

Key Considerations

- Energy throughput
- Average depth of discharge
- Average resting SOC
- Average C rate
- Time
- Temperature

Figure C.1—Cycle-life curve for a sample battery system
Performance Guarantee

- Specifics vary by OEM
- Guarantee of the DC energy available over a certain time period
- Based on a specific use case and cycle shape
- Temperature band requirements
- Any violations in use outside of modeled use typically result in warranty void
- 1-3% of battery cost per year
- Often minimum size requirements for consideration
Augmentation/Replacement

Augmentation Concept:
• Add battery racks to existing system periodically to increase capacity after aging

Potential Advantages
• Reduces initial investment in batteries
• Batteries likely to be cheaper later

Potential Dis-advantages
• More up-front engineering required
• Potentially more up front investment in other equipment required
• Out year technology risk
• Likely only feasible on very large projects
Augmentation Challenges

New and Old Batteries Don’t Mix Well

- As a battery module degrades, its internal resistance increases
  - Heat dissipation increases
  - Voltage increases

- New batteries and old batteries will discharge differently based on internal resistance

### Shifting Augmentation Method

<table>
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<tr>
<th>Inverter</th>
<th>Inverter</th>
<th>Inverter</th>
<th>Inverter</th>
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<td>3</td>
<td>4</td>
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<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

All old battery racks combined, new modules separated on their own bank
End of Life

- Most applications now assuming 10-15 year life
- Once modules reach ~70% state of health, most OEMs consider them to be at end of life
- 70% modules still have useful capacity but may be repurposed for other use
- Recycling of lithium ion in early stages with vendors located almost entirely in China
- Cost of recycling varies by supply/demand
- Recently some recyclers were rumored to be paying for recyclable material
Accelerating Growth of BESS in USA

Planned Projects

In March 2019, Florida Power and Light announced the Manatee Energy Storage Center, a 409 MW, 900 MWh storage system that will be powered by an existing solar plant. The project is planned to be operational by late 2021.\(^{21}\)

In February 2019, Portland General Electric Company announced plans to build the Wheatridge Renewable Energy Facility, which will consist of 300 MW of wind and 50 MW of solar, paired with 30 MW, 120 MWh of energy storage. The project is slated to be fully operational in 2021.\(^{22}\)

Pacific Gas and Electric received approval in June 2018 for four energy storage projects to replace three power plants that would otherwise require reliability must-run (RMR) contracts. Totalling 2,270 MWh, one of the projects will be the largest lithium-ion battery installation in the world to-date, and another will be the largest utility-owned non-hydro storage project in the world. The four projects are all scheduled to be operational by the end of 2020.\(^{23}\)

In August 2018, the Colorado Public Utilities Commission approved a plan by Xcel Energy to close two of its coal-powered plants (totaling 660 MW) by 2026. Under its Colorado Energy Plan, Xcel Energy plans to replace some of this coal generation with 1,100 MW of wind, 700 MW of solar and 275 MW of battery storage.\(^{24}\)

In March 2019, the Hawaii Public Utilities Commission approved six large solar-plus-storage projects for HECO. In total, the six projects account for an additional 253 MW of solar and 1 GWh of storage, and will provide energy to power 105,000 homes and reduce fossil fuel consumption by 48 million gallons annually.\(^{26}\)

Source: 2019 Utility Energy Storage Market Snapshot, SEPA