Leading the Way
U.S. Electric Company Investment and Innovation in Energy Storage
Leading the Way
U.S. ELECTRIC COMPANY INVESTMENT
AND INNOVATION IN ENERGY STORAGE

Table of Contents

iii INTRODUCTION

iv REFERENCE TABLE
Electric Company Storage Projects
by Use Case and Business Model

CASE STUDIES
(In alphabetical order by holding company)

AES Corporation
1 Laurel Mountain, West Virginia
2 Warrior Run Advancion Energy Storage System

Alliant Energy Corporation
3 Solar Demonstration Project

Ameren Corporation
4 Ameren Illinois: Cybersecurity Microgrid, Champaign
5 Ameren Missouri: Taum Sauk Pumped Hydroelectric Energy Center

American Electric Power
6 Churubusco, IN; Balls Gap, WV; Bulffton, OH NaS Battery Energy Storage Systems
7 Presidio Battery Energy Storage

Avista Corporation
9 Turner Energy Storage

Berkshire Hathaway Energy
8 NV Energy: Villa Trieste Energy Storage Project

CMS Energy
10 Consumers Energy: Ludington Pumped Storage

Duke Energy
11 Bad Creek Pumped Hydro Storage
12 Marshall Steam Station Energy Storage Project
13 Mount Sterling Energy Storage Project
14 Rankin Substation

Edison International
Southern California Edison
15 Catalina Island Storage
16 Hybrid Electric Gas Turbine and Storage Battery
17 Tehachapi Wind Energy Storage Project

Entergy Corporation
18 Entergy Louisiana: 500 kW Battery Storage

Exelon Corporation
19 Exelon: Clinton County Battery Energy Storage System
20 Baltimore Gas and Electric: Coldspring Substation
21 ComEd: Bronzeville Community Microgrid with Solar and Storage
22 Delmarva Power & Light: Solar & Storage Microgrid at Chesapeake College, MD

Green Mountain Power
23 Stafford Hill Solar Plus Storage Microgrid
24 Tesla Powerwall Partnership

Hawaiian Electric Industries, Inc.
25 Hawaiian Electric Company: Campbell Industrial Park Battery Energy Storage
26 Hawaii Electric Light Company: Hawaii Battery Energy Storage
27 Maui Electric Company: Molokai Battery Energy Storage
Leading the Way
U.S. ELECTRIC COMPANY INVESTMENT
AND INNOVATION IN ENERGY STORAGE

National Grid
28  Distributed Energy Storage Systems Demonstration
29  Nantucket Battery Energy Storage System
30  New York Non-Wires Alternative Storage

NextEra Energy
Florida Power & Light
31  Babcock Ranch Energy Storage
32  Citrus Energy Storage
33  Community Energy Storage (CES)
34  Florida Bay Energy Storage
35  Mobile Uninterruptible Power Supply (UPS)
36  Southwest Storage

NextEra
37  Lee DeKalb Energy Storage
38  Pima Energy Storage
39  Pinal Central Energy Storage

Oncor
40  Solar, Battery, Microturbine Microgrid

PG&E Corporation
Pacific Gas and Electric Company
41  Browns Valley Battery
42  Vaca-Dixon Battery
43  Yerba Buena Battery

PNM Resources
49  PNM: Prosperity Energy Storage Project

Portland General Electric
50  Battelle Memorial Institute
    SmartGrid Demonstration

Public Service Enterprise Group
51  Public Service Electric & Gas Company:
    Yards Creek Pumped Storage

San Diego Gas & Electric
52  Borrego Springs Microgrid Demonstration Project
53  Escondido Substation Storage

Southern Company
55  Alabama Power: Smart Neighborhood Microgrid
56  Georgia Power: Wallace Dam Pumped Storage
57  Southern Company: Cedartown Battery Energy Storage Project

UNS Energy Corporation
Tucson Electric Power
58  Lithium Nickel-Manganese-Cobalt Battery
59  Lithium Titanate Oxide Battery

Xcel Energy
60  MinnWind Storage Project
61  Peña Station Solar Plus Storage
62  Stapleton Battery Storage Project
Introduction

Electric companies increasingly are using energy storage to support and manage all parts of the energy grid. Energy storage technologies offer benefits throughout the energy grid. The various types of storage technologies—pumped hydro, batteries, thermal, compressed air, and flywheel—can increase flexibility, reliability, resilience and support generation, transmission and distribution operations, and can be deployed on customers’ property.

Electric companies recognize these benefits and are already the largest users and operators of energy storage, representing more than 90 percent of approximately 24 gigawatts (GW) of currently operational projects. Historically, electric companies built, owned, and operated pumped hydro storage facilities. Increasingly, as new technologies become technically and economically viable, electric companies are building and investing in these new types of energy storage, such as batteries, flywheels, and various forms of thermal storage. Electric companies are responsible for building or procuring almost 70 percent of the batteries deployed between 2013 and 2017 and more than 90 percent of the flywheels, thermal, and pumped hydro energy storage technologies.

Although not comprehensive, the case studies included in this booklet illustrate the dynamism of EEI member companies in driving the energy storage market throughout the United States. The case studies illustrate that energy companies are fully involved in implementing energy storage of various technology types, and are using it to provide a range of services to the energy grid and customers, through a variety of technology ownership and operation business models and partnerships.
# Electric Company Storage Projects by Use Case and Business Model

<table>
<thead>
<tr>
<th>Energy Storage Technology</th>
<th>Energy Storage Location</th>
<th>Business Model</th>
<th>Energy Grid Services</th>
<th>Customer Services</th>
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<tbody>
<tr>
<td>Table shows primary and secondary use cases associated with documented storage projects</td>
<td></td>
<td>Operator</td>
<td>Frequency Regulation</td>
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</tbody>
</table>

**AES Corporation**

AES: Laurel Mountain, WV
- Battery
- Transmission
- Third-party
- Third-party
- Frequency Regulation: x
- Reserve Capacity: x
- Grid Asset Optimization: 
- Spinning Reserve: 
- Spinning Reserve: 
- Transmission & Distribution: x
- Energy Arbitrage: 
- Integration: 
- Variable Resources: 
- Voltage Support: 
- Load Shifting: 
- Black Start: x
- Power Quality: 
- Harmonics: 
- Inertia Response: 
- Load Shifting: 
- Load Shifting: 
- Microgrid Support: 

AES: Warrior Run Advancion Energy Storage System
- Battery
- Transmission
- Third-party
- Third-party
- Frequency Regulation: x
- Reserve Capacity: x
- Grid Asset Optimization: 
- Spinning Reserve: 
- Spinning Reserve: 
- Transmission & Distribution: x
- Energy Arbitrage: 
- Integration: 
- Variable Resources: 
- Voltage Support: 
- Load Shifting: 
- Black Start: x
- Power Quality: 
- Harmonics: 
- Inertia Response: 
- Load Shifting: 
- Load Shifting: 
- Microgrid Support: 

**Alliant Energy Corporation**

Alliant Energy: Solar Demonstration Project
- Battery
- Customer-sited
- Electric Company
- Electric Company
- Frequency Regulation: x
- Reserve Capacity: x
- Grid Asset Optimization: 
- Spinning Reserve: 
- Spinning Reserve: 
- Transmission & Distribution: x
- Energy Arbitrage: 
- Integration: 
- Variable Resources: 
- Voltage Support: 
- Load Shifting: 
- Black Start: x
- Power Quality: 
- Harmonics: 
- Inertia Response: 
- Load Shifting: 
- Load Shifting: 
- Microgrid Support: 

**Ameren Corporation**

Ameren Illinois: Cybersecurity Microgrid, Champaign
- Battery
- Customer-sited
- Electric Company
- Electric Company
- Frequency Regulation: x
- Reserve Capacity: x
- Grid Asset Optimization: 
- Spinning Reserve: 
- Spinning Reserve: 
- Transmission & Distribution: x
- Energy Arbitrage: 
- Integration: 
- Variable Resources: 
- Voltage Support: 
- Load Shifting: 
- Black Start: x
- Power Quality: 
- Harmonics: 
- Inertia Response: 
- Load Shifting: 
- Load Shifting: 
- Microgrid Support: 

Ameren Missouri: Taum Sauk Pumped Hydroelectric Energy Center
- Pumped Hydro
- Transmission
- Electric Company
- Electric Company
- Frequency Regulation: x
- Reserve Capacity: x
- Grid Asset Optimization: 
- Spinning Reserve: 
- Spinning Reserve: 
- Transmission & Distribution: x
- Energy Arbitrage: 
- Integration: 
- Variable Resources: 
- Voltage Support: 
- Load Shifting: 
- Black Start: x
- Power Quality: 
- Harmonics: 
- Inertia Response: 
- Load Shifting: 
- Load Shifting: 
- Microgrid Support: 

**American Electric Power**

American Electric Power: Churubusco, IN; Balls Gap, WV; Bluffton, OH NaS Battery Energy Storage Systems
- Battery
- Distribution
- Electric Company
- Electric Company
- Frequency Regulation: x
- Reserve Capacity: x
- Grid Asset Optimization: 
- Spinning Reserve: 
- Spinning Reserve: 
- Transmission & Distribution: x
- Energy Arbitrage: 
- Integration: 
- Variable Resources: 
- Voltage Support: 
- Load Shifting: 
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## U.S. Electric Company Investment and Innovation in Energy Storage

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<td>Distribution</td>
<td>Electric Company</td>
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<tr>
<td>Avista Corporation</td>
<td>Battery</td>
<td>Transmission</td>
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</tr>
<tr>
<td>Berkshire Hathaway Energy</td>
<td>Battery</td>
<td>Customer-sited</td>
<td>Electric Company</td>
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</tr>
<tr>
<td>CMS Energy</td>
<td>Pumped Hydro</td>
<td>Transmission</td>
<td>Electric Company</td>
<td>Electric Company</td>
</tr>
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<td>Consumers Energy: Ludington Pumped Storage</td>
<td>Pumped Hydro</td>
<td>Transmission</td>
<td>Electric Company</td>
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</tr>
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<td>Duke Energy</td>
<td>Pumped Hydro</td>
<td>Transmission</td>
<td>Electric Company</td>
<td>Electric Company</td>
</tr>
<tr>
<td>Duke Energy: Marshall Steam Station Energy Storage Project</td>
<td>Battery</td>
<td>Distribution</td>
<td>Electric Company</td>
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</tr>
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<td>Duke Energy: Mount Sterling Energy Storage Project</td>
<td>Battery</td>
<td>Distribution</td>
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<td>Duke Energy: Rankin Substation</td>
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</table>

### Edison International
- **Southern California Edison: Catalina Island Storage**
  - Battery
  - Distribution
  - Electric Company
  - Electric Company
  - X X X X X X X X X X

- **Southern California Edison: Hybrid Electric Gas Turbine and Storage Battery**
  - Battery
  - Transmission
  - Electric Company
  - Electric Company
  - X X X X X X X

- **Southern California Edison: Tehachapi Wind Energy Storage Project**
  - Battery
  - Transmission
  - Electric Company
  - Electric Company
  - X X X X X X X

### Entergy Corporation
- **Entergy Louisiana: 500 kW Battery Storage**
  - Battery
  - Distribution
  - Electric Company
  - Electric Company
  - X X X

### Exelon Corporation
- **Exelon: Clinton County Battery Energy Storage System**
  - Battery
  - Transmission
  - Electric Company
  - Electric Company
  - X

- **Baltimore Gas and Electric: Coldspring Substation**
  - Battery
  - Distribution
  - Electric Company
  - Electric Company
  - X X X

- **ComEd: Bronzeville Community Microgrid with Solar and Storage**
  - Battery
  - Distribution
  - Electric Company
  - Electric Company
  - X X X
### Table: U.S. Electric Company Investment and Innovation in Energy Storage

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<td>Customer-sited</td>
<td>Third-party</td>
<td>Frequency Regulation</td>
<td>x</td>
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<td>Delmarva Power: Solar &amp; Storage Microgrid at Chesapeake College, MD</td>
<td>Battery</td>
<td>Customer-sited</td>
<td>Reserve Capacity</td>
<td>x</td>
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<tr>
<td>Green Mountain Power: Tesla Powerwall Partnership</td>
<td>Battery</td>
<td>Customercited</td>
<td>Grid Asset Optimization</td>
<td>x</td>
</tr>
<tr>
<td></td>
<td>Battery</td>
<td>Distribution location but treated as behind-the-meter by ISO</td>
<td>Transmission &amp; Distribution</td>
<td>x</td>
</tr>
<tr>
<td>Green Mountain Power: Stafford Hill Solar Plus Storage Microgrid</td>
<td>Battery</td>
<td>Electric Company</td>
<td>Upgrading Deferral</td>
<td>x</td>
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<tr>
<td>Hawaiian Electric Industries, Inc.</td>
<td>Battery</td>
<td>Distribution</td>
<td>Energy Arbitrage</td>
<td>x</td>
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<tr>
<td>Hawaiian Electric Company: Campbell Industrial Park Battery Energy Storage</td>
<td>Battery</td>
<td>Electric Company</td>
<td>Integration</td>
<td>x</td>
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<tr>
<td>Hawaii Electric Light Company: Hawaii Battery Energy Storage</td>
<td>Battery</td>
<td>Transmission</td>
<td>Variable Resources</td>
<td>x</td>
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<tr>
<td>Maui Electric Company: Molokai Battery Energy Storage</td>
<td>Battery</td>
<td>Distribution</td>
<td>Voltage Support</td>
<td>x</td>
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<td>Energy Storage Technology</td>
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<tr>
<td><strong>National Grid</strong></td>
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<tr>
<td>National Grid: Distributed Energy Storage Systems Demonstration</td>
<td>Battery</td>
<td>Distribution &amp; Customer-sited</td>
<td>Electric Company &amp; Third-party</td>
<td>Third-party (electric company to take ownership in 2018–2019)</td>
</tr>
<tr>
<td>National Grid: Nantucket Battery Energy Storage System</td>
<td>Battery</td>
<td>Distribution</td>
<td>Electric Company</td>
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<td>National Grid: New York Non-Wires Alternative Storage</td>
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<td><strong>NextEra Energy</strong></td>
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<td>Florida Power &amp; Light: Babcock Ranch Energy Storage</td>
<td>Battery</td>
<td>Solar/Transmission</td>
<td>Electric Company</td>
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<td>Florida Power &amp; Light: Citrus Energy Storage</td>
<td>Battery</td>
<td>Solar/Transmission</td>
<td>Electric Company</td>
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<td>Florida Power &amp; Light: Community Energy Storage (CES)</td>
<td>Battery</td>
<td>Distribution</td>
<td>Electric Company</td>
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<tr>
<td>Florida Power &amp; Light: Florida Bay Energy Storage</td>
<td>Battery</td>
<td>Distribution</td>
<td>Electric Company</td>
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<td>Florida Power &amp; Light: Mobile Uninterruptible Power Supply (UPS)</td>
<td>Battery</td>
<td>Mobile (customer-sited)</td>
<td>Electric Company</td>
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# Leading the Way

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<td>NextEra: Lee DeKalb Energy Storage</td>
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<td>Third-party</td>
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<td>NextEra: Pinal Central Energy Storage</td>
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<td>Transmission</td>
<td>Electric Company</td>
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<td>Pacific Gas and Electric Company: Vaca-Dixon Battery</td>
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<td>Pacific Gas and Electric Company: Yerba Buena Battery</td>
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<td>Harmonics</td>
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<td>Microgrid Support</td>
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</tbody>
</table>

Table shows primary and secondary use cases associated with documented storage projects

Pinnacle West Capital Corporation

Arizona Public Service: Solar Partner Program Phase II—Energy Storage
- Battery Distribution Electric Company Electric Company × × ×

Arizona Public Service: Punkin Center Battery Storage System
- Battery Distribution Electric Company Electric Company × × ×

Arizona Public Service: Residential Battery Storage Program
- Battery (2 Programs) Customer-sited Electric Company Electric Company × × ×

Arizona Public Service: Solana Parabolic Trough Solar Concentrating Plant
- Thermal Transmission Third-party (APS buys 100% of power) Third-party ×

Arizona Public Service: Thermal Storage Programs
- Grid-Interactive Water Heaters and Smart Thermostats Customer-sited Electric Company (with customer override) × × ×

PNM Resources

PNM: Prosperity Energy Storage Project
- Battery Distribution Electric Company Electric Company × × ×
### Energy Storage Technology and Location

| Table shows primary and secondary use cases associated with documented storage projects |

### Business Model

- Operator
- Owner

### Energy Grid Services

- Frequency Regulation
- Reserve Capacity
- Grid Asset Optimization
- Spinning Reserve
- Transmission & Distribution
- Energy Arbitrage
- Integration
- Variable Resources
- Voltage Support
- Load Shifting
- Black Start, Power Quality, Harmonics, Inertia Response
- Microgrid Support

### Customer Services

- Emergency Backup

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Portland General Electric: Battelle Memorial Institute SmartGrid Demonstration</td>
<td>Battery, Distribution</td>
<td>Electric Company</td>
<td>Operator</td>
<td>Owner</td>
</tr>
<tr>
<td>Public Service Enterprise Group: Yards Creek Pumped Storage</td>
<td>Pumped Hydro, Transmission</td>
<td>Electric Company</td>
<td>Owner</td>
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</tr>
<tr>
<td>San Diego Gas &amp; Electric: Borrego Springs Microgrid Demonstration Project</td>
<td>Battery, Customer-sited</td>
<td>Electric Company</td>
<td>Owner</td>
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<tr>
<td>San Diego Gas &amp; Electric: Escondido Substation Storage</td>
<td>Battery, Distribution</td>
<td>Electric Company</td>
<td>Owner</td>
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</tr>
<tr>
<td>Southern Company: Alabama Power: Smart Neighborhood Microgrid</td>
<td>Battery, Customer-sited</td>
<td>Electric Company</td>
<td>Owner</td>
<td></td>
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</tbody>
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**Portland General Electric**

- Battery
- Distribution
- Electric Company

**Public Service Enterprise Group**

- Pumped Hydro
- Transmission
- Electric Company

**San Diego Gas & Electric**

- Battery
- Customer-sited
- Electric Company

**Southern Company**

- Battery
- Customer-sited
- Electric Company
### Leading the Way

**U.S. Electric Company Investment and Innovation in Energy Storage**

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</tr>
</tbody>
</table>

| Georgia Power: Wallace Dam Pumped Storage | Pumped Hydro | Transmission | Electric Company | Electric Company | x | x |
| Southern Company: Cedartown Battery Energy Storage Project | Battery | Transmission | Electric Company | Electric Company | x |  | x | x |
| UNS Energy Corporation | | | | |
| Tucson Electric Power: Lithium Nickel-Manganese-Cobalt Battery | Battery | Distribution | Third-party | Third-party | x |  | x | x | x |
| Tucson Electric Power: Lithium Titanate Oxide Battery | Battery | Distribution | Third-party | Third-party | x |  | x | x | x |
| Xcel Energy | | | | |
| Xcel Energy: MinnWind Storage Project | Battery | Transmission | Electric Company | Electric Company | x |  | x | |
| Xcel Energy: Peña Station Solar Plus Storage | Battery | Distribution | Third-party | Electric Company | x |  | x | x | x |
| Xcel Energy: Stapleton Battery Storage Project | Battery | Distribution & Customer-sited | Electric Company | Electric Company | x |  | x | x | x |
Laurel Mountain, West Virginia

The AES Laurel Mountain storage system was one of the largest of lithium-ion battery clusters in the United States at the time of construction and uses A123 Systems’ advanced lithium-ion battery technology. The project helps support the delivery of wind energy to the PJM Interconnection, the largest power market in the world. In addition, the battery provides flexible operating reserve capacity and ramping, services that play a critical role in maintaining reliability of the energy grid. In addition, it provides frequency regulation to PJM, adding a revenue stream and operating capability not available at most wind farms.

HMT Inc. provides high voltage maintenance and technical services to the project. Other participants include A123 Systems, Stantec, Parker, Casteel, Power Engineers, Sargent & Lundy.
Warrior Run Advancion Energy Storage System

At 10 MW, the Warrior Run Advancion Energy Storage System is the largest battery system in Maryland, capable of absorbing and releasing a 5 MW charge. The Advancion 4 platform storage management system integrates the hardware and software. The control system measures and records some 80,000 separate data points. Having visibility into the operational granularity allows AES to stack services, including frequency regulation to the PJM market, reserves, renewable ramping, energy delivery, and voltage control to increase the battery system’s economic viability.

Additionally, the storage units allow for the project to manage any extreme changes that might affect wind output which, when combined with an algorithm designed to collect telemetry data and issue proper responses, results in renewable energy generation with greater ramp rate control for stability of the energy grid.

Implementing partners include battery provider LG Chem and Parker Hannifin.
Alliant Energy’s lithium-ion battery, connected to ground-level and building-mounted solar panels, supports the company’s broader collaborative demonstration effort, in partnership with the Electric Power Research Institute (EPRI), to install more than three dozen unique renewable energy features such as electric vehicle charging stations. The project will result in lower electric bills in its Madison headquarters by storing energy during low-cost times and discharging it during peak periods.

Phase I of the project includes several ground-level and building-mounted solar panels, solar parking canopies covering nearly 50 parking spaces, 13 electric vehicle charging stations, solar café tables, and a battery energy storage system to support the various solar activities.

The purpose of the project is to research solar technology. While the data is being collected, solar generation and energy storage are being used for electric bill management and energy time shift.
Cybersecurity Microgrid, Champaign

The 250 kW 500 kWh energy storage battery provided by LG Chem and S&C Electric is part of a complex distributed energy resource mix that also includes wind, solar, and natural gas which are integrated to make up a microgrid at Ameren’s Technology Applications Center (TAC), adjacent to the University of Illinois in Champaign. The microgrid is one of the most technologically advanced electric company-scale microgrids in North America. The project exemplifies the first time an electric company is serving paying customer loads on an electric company distribution feeder in North America. The energy generated by the microgrid can be delivered directly to local customers, routed to the central energy grid, or stored in the microgrid’s battery.

The use of energy storage batteries allows the microgrid to take advantage of renewable energy generation by charging when it is available via the wind turbines and the solar array, and allowing the battery to serve as generation when needed, lessening the need for natural gas. The battery also operates as a voltage source during islanding conditions of the TAC and microgrid loads. This feature enables the wind turbine and solar array to operate while separated from the energy grid, and this allows the company to test the operational parameters of the individual distributed energy resources.

The Ameren microgrid is the only known large-scale microgrid in the nation capable of seamlessly transitioning the power source for an entire distribution circuit from the microgrid to the energy grid and vice versa.

This microgrid marks the first installation by a U.S. energy company of a military-grade cybersecure microgrid controller. The GridMaster, manufactured by S&C Electric subsidiary IPERC, is the only microgrid controller that has obtained an Authority to Operate (ATO) from the Department of Defense.
The Taum Sauk Energy Center, among the largest pumped hydro projects when it was built in 1963, is notable in that it is a pure pump-back operation—there is no natural primary flow (via a river) available for generation, unlike at most other pumped storage sites. The two originally installed reversible pump turbine units were each capable of generating 175 megawatts of power, but were upgraded in 1999 and are now capable of generating 225 MW each.

This storage system is driven by point-to-point water flow, where water from a reservoir on top of Proffit Mountain flows into a lower reservoir on the East Fork of the Black River. The downhill flow of the water spins turbines that generate electricity. The water is then pumped back to the top reservoir, where it is stored until needed.

Its storage component helps meet peak power demand during the day through an energy time shift. While the primary use of the project is electric energy time shift, it also provides additional electric supply capacity.
Churubusco, Balls Gap, and Bluffton NaS Battery Energy Storage Systems

American Electric Power (AEP) pioneered NaS battery use, installing its first demonstration unit in Gahanna, Ohio in 2002 after testing at its Columbus, Ohio Dolan Technology Center. This was followed by installation of a 1.2 MW stationary NaS battery near Charleston, West Virginia in 2006. In 2008, Churubusco was part of a 2 MW trifecta of installations that went up in Balls Gap, West Virginia, as well as in Bluffton, Ohio. The batteries at Churubusco provide AEP with greater flexibility in managing the energy grid.

More specifically, the battery systems provide load leveling, defer capital upgrades, alleviate transformer load during summer peaks, and offer seven hours of emergency backup power to several hundred customers during electricity outages. AEP uses an in-house SCADA system and custom software that creates a feedback loop to control all its batteries. The NaS battery systems also have the potential to be used for electric energy time shift and spinning reserve capacity, though these are not the primary purposes of the battery.

AEP partnered with NGK Insulators, and S&C Electric, among others, to implement this project.
**Presidio Battery Energy Storage System**

The Electric Transmission Texas joint venture battery storage project provides backup power to the transmission grid vulnerable to the Texas plains’ electric storm outages in the Mexico-border town of Presidio, Texas. The $25 million battery improves the reliability of Presidio’s energy grid by smoothing voltage fluctuations and momentary outages. From project launch in 2010 until 2012 when the $45 million, 60-mile, 69-kilovolt (kV) transmission line from Marfa, Texas, to Presidio was finished and replaced the line built in 1948, the battery helped defer capital costs and allowed for maintenance on the new transmission line without loss of electric power.

An S&C Electric Company Smart Grid Storage Management System (SGSMS) controls the battery. The SGSMS is a fast-response, automatic power converter and controller that provides the ability to store energy in a variety of battery storage technologies and to control the discharge of that power into the energy grid.

The battery can supply up to eight hours of electricity for a total of 4 MW. It can also eliminate the outages of up to several hours that result from transferring electricity sourcing from the Texas grid to Mexico’s neighboring Comisión Federal de Electricidad (CFE) in emergencies.

**COMPANY**
- American Electric Power (AEP)

**LOCATION**
- Presidio, Texas

**PROJECT OVERVIEW**
- **Business Model:** Electric company owned and operated
- **Energy Storage Location:** Distribution
- **Technology:** Sodium-sulfur battery (NaS), NGK Japan
- **Battery Size:** 4 MW/32 MWh
- **Duration:** 08:00 (HH:MM)
- **Services:** Transmission capital cost deferral, reliability/resiliency improvements—voltage fluctuations, momentary outages
- **Operation Start:** 2010
At its inception in 2015, Avista’s vanadium redox flow battery was the largest of its kind in North America and Europe. It was installed as part of a Washington Clean Energy Fund Award coordinated through Washington State’s Department of Commerce. The battery is used for multiple purposes, including frequency regulation and voltage control.

The system provides manufacturer Schweitzer Engineering Laboratories (SEL), an Avista customer, with an uninterruptable power supply, black start, and 4-cycle ride-through (to avoid a potential short-circuit).

Avista studied the characteristics of the battery during its deployment and operation, including maximum output levels depending on State of Charge. Avista also implemented a Phase II to the project that switched anti-islanding invertors to neutral point switched inverters that allowed for automatic islanding and seamless transfer to a microgrid.

Avista received retail cost recovery of 60 percent, or $4.8 million of the $8 million project in 2016. The remainder was funded by the Washington State Clean Energy Fund, proposed by Governor Jay Inslee and approved by the Legislature in 2013, making the project financially viable.

Avista is in the process of planning and designing for a Clean Energy Fund 2 project in downtown Spokane, WA that will include two solar installations and two batteries, which will be able to operate in one or two microgrids.
Villa Trieste Energy Storage Project

Using a grant from the U.S. Department of Energy from 2009 to 2015, the University of Nevada Las Vegas partnered with NV Energy and Pulte Homes to develop Villa Trieste—a 185-home LEED Platinum residential community. The homes were equipped with smart meters, demand responsive thermostats, automated intelligent agents, a home display of energy consumption, 2 kW private rooftop solar systems photovoltaics; and energy efficient appliances, windows, and a building envelope.

The residential development reduced peak demand by more than 65 percent. NV Energy aimed to test and integrate new technologies such as private solar with the energy grid, to optimize peak load management and to develop a distributed energy resources roadmap and new customer energy solutions. Testing how private solar and batteries interact with the grid is ongoing, and NV Energy is working to configure the storage systems to support voltage support, frequency regulation, and renewables firming.

COMPANY
- NV Energy

LOCATION
- Las Vegas, Nevada

PROJECT OVERVIEW
- Business Model: Partnership includes electric company, customer, and developer—electric company owned and operated
- Energy Storage Location: Customer-sited
- Technology: Lithium-ion battery paired with private solar
- Battery Size: Sunverge (7.78 kWh); Tesla Powerwall 1 (6.4 kWh)
- Duration: On-Going
- Services: Dispatch optimization, peak load management, operating reserve
- Operation Start: 2013
Ludington Pumped Storage

Built in 1973 for $327 million (1973 dollars), the Ludington Pumped Storage Plant sits on a 1,000-acre site along the Lake Michigan shoreline. Jointly owned by Consumers Energy, and DTE Energy and operated by Consumers Energy, Ludington is one of the world’s largest energy storage projects and can provide power at a moment’s notice. The system runs by moving water from a 27-billion-gallon reservoir through a set of six turbines that drive electric generators. Those same turbines double as giant water pumps to fill the reservoir with water from Lake Michigan. At night, when electric demand is low, Ludington’s reversible turbines pump water 363 feet uphill from Lake Michigan.

The plant can generate up to 1,872 MW—roughly enough electricity to serve a community of 1.4 million residential customers. The output is more than double the capacity of any single generation unit on Consumers Energy’s system. Ludington’s relatively simple technology enables the plant to respond within three minutes to the daily, weekly, and seasonal highs and lows of Michigan’s energy demand. The plant also saves customers money by enabling Consumers Energy to avoid the expensive spot market when customer demand exceeds the capacity of the company’s baseload plants.

In 2013, a six-year, $800 million upgrade project commenced with participation by Toshiba. The upgrade will extend the plant’s life by at least 40 years, as well as uprate the generating capacity from 1,872 MW to 2,172 MW upon completion in 2020.
Bad Creek Pumped Hydro Storage

The Bad Creek Hydroelectric Station is a 1,065 MW pumped storage facility located in Oconee County, eight miles north of Salem, SC. The pumped storage facility is attached to the four-turbine dam—the largest hydroelectric station on the Duke Energy system. The Bad Creek facility is named after two upstream creeks, Bad Creek and West Bad Creek, which together created the Bad Creek Reservoir. The pumped hydro storage system works in conjunction with the dam. Water stored in a reservoir above the dam is released into underground power tunnels. The water rushes down the tunnels, driving huge turbines that are located beneath the base of the dam. The spinning turbines are connected to large generators, which produce electricity. The water then flows through draft tubes into a lower lake, where the pumped-storage system returns the water to the upper reservoir. The system is water-efficient as it reuses the water continuously.

The water is used to generate electricity when demand is high. When demand low, operators can refill the upper reservoir using the pumped system. When the upper reservoir is full, it constitutes stored energy, just like energy stored in a battery. Water is pumped back to the upper reservoir at night and on weekends.
Marshall Steam Station Energy Storage Project

The Exergonix lithium polymer battery system, part of Duke Energy’s Smart Grid Demonstration, helps manage energy generated from an adjacent 1 MW photovoltaic solar system. Specifically, the battery system provides peak shaving for a nearby distribution substation and simultaneously provides capacity firming, energy time shift, and voltage control. This battery project aims to quantify the efficiency of storing electricity for short and long periods of time.
Mount Sterling Energy Storage Project

Mt. Sterling is a remote microgrid located in the Great Smoky Mountains. Its 5 mile 12.47 kV distribution feeder serves one customer—the Mt. Sterling radio tower. The customer experiences three or more major outages per year and has high operational and maintenance costs due to vegetation management and restoration costs. The project allows Duke Energy to give back the right-of-way to park services and remove the distribution feeder, associated equipment, and over 40 poles.
Rankin Substation

The Rankin Substation battery storage project demonstrates a first-of-its-kind Hybrid Energy Storage System (HESS) that provides multiple services in a low-cost configuration. The installation combines Maxwell Technologies’ ultracapacitors, which can respond rapidly with high power density, and Aquion Energy’s Aqueous Hybrid Ion (AHI) batteries, which provide low-cost performance and very high energy density.

The combination of the two technologies allows the system to hold greater amounts of electricity and provide near-instantaneous response. The system is primarily used for simultaneous integration of solar energy, as well as other energy grid support functions, such as load following and peak shaving.

COMPANY
- Duke Energy

LOCATION
- Mt. Holly, North Carolina

PROJECT OVERVIEW
- Business Model: Electric company owned and operated
- Energy Storage Location: Distribution
- Technology: Aqueous hybrid ion batteries plus ultracapacitors
- Battery Size: 50 kW/300 kWh
- Duration: 06:00 (HH:MM)
- Services: Renewables integration and ramping
- Operation Start: 2016
Catalina Island Storage

Southern California Edison’s (SCE) Catalina Island sodium sulfur battery project was completed in 2013 to help meet the energy needs of Santa Catalina Island, off the coast of Southern California. The island’s isolated electrical system has daily load variations from approximately 2 MW in the very early morning to approximately 5 MW in the late afternoon. SCE’s existing diesel generating capacity must be constantly cycled to accommodate the varying system load. The battery system was built to help manage swings in load. The battery system provides necessary energy storage capacity during off-peak periods, and energy supply capacity during on-peak periods, allowing for more efficient operation of the diesel generators.
Hybrid Electric Gas Turbine and Storage Battery

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.

COMPANY
- Southern California Edison (SCE)

LOCATION
- Norwalk and Rancho Cucamonga, California

PROJECT OVERVIEW
- Business Model: Electric company owned and operated
- Energy Storage Location: Transmission (co-located with natural gas power plant)
- Technology: Lithium-ion battery paired with natural gas
- Battery Size: 10 MW/4.3 MWh
- Duration: 00:26 (HH:MM)
- Services: Quick start, spinning reserve (primary); reliability, smoothing variability of renewables (secondary)
- Operation Start: March 2017
Tehachapi Wind Energy Storage Project

The Tehachapi Wind Energy Storage Project is an 8 MW, 32 MWh lithium-ion battery storage system housed adjacent to Southern California Edison’s (SCE) Monolith Substation. The project was strategically located in the Tehachapi Wind Resource Area to test the integration of the area’s 4,500 MW of wind capacity.

The $50 million Tehachapi storage project was co-funded by SCE and the U.S. Department of Energy. The project started as a pilot to test multiple operational functions, including integration of large-scale variable wind generation, voltage support and frequency regulation, diminishing congestion, deferring transmission investment, providing an energy time shift, and increasing reserves. Additionally, SCE demonstrated the lithium-ion battery’s ability to provide nearly instantaneous maximum capacity for renewables ramping to minimize the need for traditional back-up generation.

The pilot and testing portion of the project concluded after 24 months in operation, and the facility remains operational.
500 kW Battery Storage

This 500 kW lithium-ion battery storage system is used to help integrate electricity generated from over 4,200 solar panels. The panels can generate enough electricity to power approximately 160 homes. This system is hailed as the city’s first large-scale effort to produce solar power. The attached battery system helps with solar integration through ramping and load shift.
Clinton County Battery Energy Storage System

The 10 MW/4.1 MWh Samsung battery and controls are designed and were installed by Renewable Energy Systems Americas, Inc. (RESS) in 2016. Exelon Renewables purchased the battery, and it is operating under a full-service contract with RESS until Exelon takes ownership in November 2018.

The project interconnects at a 34.5 kV Duke Energy Ohio substation and has been on-line since October 2016, participating in PJM’s merchant frequency regulation. The project has encountered significant operational issues and market signal changes. Operational issues are related to the integration of protection systems and heating deficiencies in the HVAC system. Market signal changes to PJM’s Reg D signal have significantly impacted business case design life assumptions, cutting the life of the equipment in half relative to the original contract of 10 years.
Coldspring Substation

Coldspring Distribution Substation is subject to summer overload. As a solution, Baltimore Gas and Electric evaluated the construction of a new transmission supplied distribution substation to offload Coldspring. However, a 5 MW/20 MWh storage system will allow the electric company to defer construction of the new substation for at least five years. The system is designed to be installed in four phases. The initial 1 MW/1 MWh phase was installed in 2018. The installation timing of phases II to IV can be adjusted based on future load forecasts. The lithium-ion battery storage system is installed inside the substation fence and connected to the substation bus in parallel with a feeder.

The battery controller monitors the Coldspring Substation load and automatically discharges the battery when the station load exceeds the station rating.

Company

- Baltimore Gas and Electric

Location

- Northern Baltimore City, Maryland

Project Overview

- Business Model: Electric company owned and operated
- Energy Storage Location: Distribution
- Technology: Lithium-ion [nickel-manganese-cobalt (NMC)] battery
- Battery Size: 1 MW/1 MWh end of life design criteria
- Duration: 01:00 (HH:MM)
- Services: Peak shaving, VAR injection
- Operation Start: 2018
Bronzeville Community Microgrid with Solar and Storage

The microgrid, developed by ComEd to demonstrate technical innovation, is funded in part by the U.S. Department of Energy starting in 2014. The microgrid aims to provide information on the use of microgrids and other advanced technologies to enhance the operation of the distribution system and increase the penetration of renewable generation into the distribution grid. The Illinois Commerce Commission approved the microgrid, allowing ComEd to own it (except for generation) and recover the costs through distribution formula rates. The microgrid will be built in two phases; the energy storage and at least 750 kW of solar PV will be installed by the end of 2018, with the entire project completed by the end of 2019. The microgrid project is part of ComEd’s Community of the Future initiative that aims to find new ways of leveraging smart grid technologies and services for community benefit.
Chesapeake College has developed a combined 1.58 MW solar array and battery storage to provide continuous operations of two campus buildings—the Caroline Student Center and the Todd Performing Arts Center. The microgrid is capable of islanding and can provide electricity to refrigerators storing emergency supplies of medicine as well as to a 900-seat theatre designated as an emergency shelter. The solar array has the ability to charge a 1 MW battery during an energy grid outage in order to provide sustained power to the aforementioned campus buildings. During normal operation, both the battery and PV system will feed into Delmarva Power’s (DPL) regional grid, and will help keep electricity supply steady during peaks. The battery can provide grid support in PJM’s Distributed Energy Resource integration pilot. The pilot aims to show that each of the technologies can work in an integrated system with increasing amounts of solar power.

At first, it was perceived that there was no additional local grid capacity to accommodate a solar PV array at Chesapeake College. However, by using smart inverters, DPL engineers enabled the microgrid to receive control signals from the electric company. The college and DPL agreed to pilot incremental array curtailment for the first five years of operation—DPL can curtail production up to 3 percent in Years 1–3, and up to 1.5 percent in years 4–5. On the energy grid, DPL installed voltage regulation devices and switched capacitors with communications and control capability.

The college incurred no cost in building the microgrid. To help with financing, DPL and AF Mensah received a $250,000 grant from the Maryland Energy Administration to partially fund the battery installation. AF Mensah owns and operates the system, and will eventually provide ancillary services through PJM to finance the battery. The solar panels are financed through a 20-year Power Purchase Agreement (PPA) with no escalator. In 2016, the PV system saved the college $85,000, providing about 45 percent of its electricity supply.
Stafford Hill Solar Plus Storage Microgrid

According to the U.S. Department of Energy, the Stafford Hill Solar Storage Project in Rutland, VT is the first project to establish a microgrid powered solely by solar and battery back-up with no other fuel source on a landfill. Stafford Hill includes 7,700 solar panels that can generate 2 MW of electricity with an additional 3.4 MWh of battery storage to store the solar energy. The solar-plus-storage combination is expected to enable the disconnection of an entire circuit from the energy grid in an emergency and to provide critical power for an emergency shelter.

Green Mountain Power (GMP) constructed Stafford Hill at a former landfill to improve community resilience and safety by generating and storing clean energy to power an emergency shelter at Rutland High School.
Tesla Powerwall Partnership

Green Mountain Power (GMP) was the first electric company to partner with Tesla to offer Powerwall batteries. As of July 2018, about 550 batteries have been installed, another 515 customers have contracted for a Powerwall and more than 620 are in the process but have not signed a contract yet. GMP expects to have 2,000 Powerwall contracts with customers by the end of 2018. Customers pay GMP $15 per month or a one-time payment of $1,500 per battery. The low cost of the program reflects the value of the distributed resource benefit.

For customers, a Powerwall operates like a home generator during outages, seamlessly turning on to keep power flowing. For GMP, the network of batteries offers a powerful resource to knock down peak power demand. Deploying stored energy in GMP’s network of Powerwalls and at two solar storage facilities helped GMP offset about $500,000 in costs during a recent heatwave. July 5th was the ISO-NE peak. GMP uses the Powerwall network to take on monthly peaks, too. The combined storage capacity of the batteries reduces the need for traditional peaking generation and helps provide back-up power to Vermont’s energy grid.
Campbell Industrial Park (CIP) Battery Energy Storage

Between 2012 and 2016, Hawaiian Electric Companies—Hawaiian Electric, Maui Electric, and Hawaii Electric Light—installed three Battery Energy Storage Systems (BESS) in partnership with the Hawaii Natural Energy Institute (HNEI) at the University of Hawaii, funded by grants from the Office of Naval Research. These projects are part of broader energy storage research to understand how storage can mitigate energy grid operational issues caused by high penetration of variable renewable energy and allow more renewable energy to be integrated across the five islands served by the Hawaiian Electric Companies.

Hawaiian Electric installed the 1 MW/250 kWh BESS at Hawaiian Electric’s CIP Generating Station to evaluate the BESS’s ability to perform power smoothing and voltage support on a distribution circuit with high PV penetration. Hawaiian Electric is also using the battery to test frequency support on the Hawaiian Electric grid and to demonstrate daily energy shifting.
Hawi Battery Energy Storage

Between 2012 and 2016, Hawaiian Electric Companies—Hawaiian Electric, Maui Electric, and Hawaii Electric Light—installed three Battery Energy Storage Systems (BESS) in partnership with the Hawaii Natural Energy Institute (HNEI) at the University of Hawaii, funded by grants from the Office of Naval Research. These projects are part of broader energy storage research to understand how storage can mitigate energy grid operational issues caused by high penetration of variable renewable energy and allow more renewable energy to be integrated across the five islands served by the Hawaiian Electric Companies.

Hawaii Electric Light installed the 1 MW/250 kWh BESS at the Hawi Wind Farm to evaluate the BESS's ability to perform wind smoothing and provide energy grid frequency support.
Molokai Battery Energy Storage

Between 2012 and 2016, Hawaiian Electric Companies—Hawaiian Electric, Maui Electric, and Hawaii Electric Light—installed three Battery Energy Storage Systems (BESS) in partnership with the Hawaii Natural Energy Institute (HNEI) at the University of Hawaii, funded by grants from the Office of Naval Research. These projects are part of broader energy storage research to understand how storage can mitigate energy grid operational issues caused by high penetration of variable renewable energy and allow more renewable energy to be integrated across the five islands served by the Hawaiian Electric Companies.

Maui Electric installed the 2 MW/397 kWh BESS at the Palaau Power Plant on Molokai to evaluate the BESS’s ability to provide fast frequency response to support Molokai Island’s 4.5 MW grid with over 90 percent renewables during fault occurrences and to prevent cascade load shedding.
Distributed Energy Storage Systems Demonstration

This $6 million-per-battery, dual-site demonstration project funded by the U.S. Department of Energy’s American Recovery and Reinvestment Act, uses long-duration advanced flow batteries, and helps National Grid lower peak energy demand and reduce the costs associated with power interruptions.

One of the systems is being installed next to a 1,000 kW PV array in Shirley, Massachusetts. The second ESS was installed next to a 600 kW wind turbine located on a customer site in Worcester, Massachusetts. Both storage systems will be used to for multiple purposes, primarily helping integrate renewables and shift peak load.
To meet Nantucket’s energy needs over the long term, and to help defer the need for a third submarine cable, National Grid has developed a holistic, integrated plan—called IslandReady—to upgrade the Island’s electricity infrastructure. A significant piece of this plan is a new Battery Energy Storage System (BESS), that when combined with a new, upgraded diesel generator, will supply the Island should one of the two submarine cables currently serving Nantucket experience an outage.

The demand for electricity on Nantucket (particularly during the summer season) has grown significantly in the last 10 years, and it is projected to continue growing for the foreseeable future. Because of this, the back-up system that would help supply the island if one of the two existing submarine supply cables were to experience an outage needs to be upgraded. In addition, National Grid expects that a third submarine cable will be necessary in about a dozen years. The BESS could delay the need for a third cable for up to 15–20 years by supplying electricity to supplement the cables.

The BESS will be installed within the footprint of National Grid’s existing Bunker Road substation site. The proposed design will have a capacity of 48-megawatt hours (MWh).
New York Non-Wires Alternative Storage

In March 2017, National Grid submitted a proposal to install a single, company-owned energy storage asset to its existing New York transmission and distribution system in an effort to prove the technology’s ability to provide benefits as a electric company asset, the business case behind value of those benefits, and learnings in order to improve upon our own process to update the electric company business model and its role in modernizing the energy grid.

Around the same time, the New York Public Service Commission released an order which required all public electric companies in New York to install at least two energy storage systems by the end of 2018. In order to accommodate this order, National Grid expanded this energy storage program and began the site selection process for an additional location for a second energy storage asset. In July 2017, National Grid updated its proposal with the PSC with its two selected locations and their associated business models, focused on the best value for customers and the energy grid.

The two proposed energy storage assets will each be located at substations on existing company property. The primary application of these assets will be to defer traditional “wires” investments around these substations. At Kenmore, the asset will provide local peak load reduction to prevent thermal overload on the area’s sub-T cables. At East Pulaski, the asset will act as a localized energy source in an N-1 contingency event. This adds tools to the company’s historical distribution processes, and may prove valuable in deferring expensive, sometimes invasive upgrades to the infrastructure serving customers.

In addition to the primary applications, the energy storage assets will provide services aimed at reducing peak capacity for customer supply, thereby reducing costs of procuring that capacity, as well as services to the NYISO.
Babcock Ranch Energy Storage

Florida Power & Light Company’s (FPL) 10 MW Babcock Ranch Energy Storage is the largest solar-plus-storage system in the U.S. The battery system’s primary purpose is to dispatch to the energy grid to supplement dips in the plant’s operation with secondary services such as peak shaving and reserve capacity to power FPL customers.

COMPANY
- Florida Power & Light Company (FPL)

LOCATION
- Punta Gorda, Florida

PROJECT OVERVIEW
- Business Model: Electric company owned and operated
- Energy Storage Location: Solar/Transmission
- Technology: Lithium-ion battery paired with solar energy
- Battery Size: 10 MW/40 MWh
- Duration: 04:00 (HH:MM)
- Services: Solar shifting
- Operation Start: 2018
Citrus Energy Storage

Florida Power & Light Company’s (FPL) 4 MW/16 MWh Citrus Energy Storage facility is connected to the FPL Citrus Solar Energy Center—a 74.5-megawatt solar generation plant—which was the first-of-its-kind large-scale application of “DC-coupled” batteries at a solar power plant in the U.S. The battery system’s primary purpose is to provide increased predictability and reliability in the distribution of solar energy to the energy grid for FPL customers.
Community Energy Storage (CES)

Florida Power & Light Company’s Community Energy Storage serves as a backup to 120 V/240 V load on individual customer transformers. As a secondary use, the system serves a peak sharing capacity function.
Florida Bay Energy Storage

Florida Power & Light Company’s (FPL) 1.5 MW Florida Bay Energy Storage is connected to a 45-mile radial. The storage system’s primary use is to provide emergency backup power as well as serves as a peak shave feeder on programmed times. It is the first megawatt scale intentional island on the FPL system.
Florida Power & Light Company’s Mobile Uninterruptible Power Supply (UPS) is designed to provide emergency power for a short duration during a momentary power outage and/or flicker. The ability to mobilize the unit provides a unique opportunity to connect at various locations or events where needed (i.e. Miami Tennis Open).
Southwest Storage

Florida Power & Light Company’s 1.5 MW Southwest Storage is comprised of second life electric vehicle batteries from 210 vehicles (5,250 total modules). The storage facility serves in a peak shaving capacity for the urban landscape within Miami-Dade County.
Lee DeKalb Energy Storage

NextEra Energy Resources 20 MW Frontier Battery Energy Storage facility includes approximately 170,000 cells in nearly 3,000 batteries. The battery system’s primary purpose is to provide frequency regulation to the PJM Interconnection. Implementing partners include LG Chem, ABB, Greensmith, and Blattner Energy.
Pima Energy Storage

NextEra Energy Resources 10 MW/2.5 MWh Pima Battery Energy Storage facility is a distribution connected project providing a variety of services to Tucson Electric Power’s energy grid. The battery system’s primary purpose is to provide automated frequency response services, with secondary services including voltage support, reserve capacity and peak shaving, with the capability for either NextEra or Tucson Electric to dispatch the system as required.

COMPANY
- NextEra Energy Resources

LOCATION
- Tucson, Arizona

PROJECT OVERVIEW
- Business Model: Third-party owned and operated in conjunction with electric company
- Energy Storage Location: Distribution
- Technology: Lithium-ion battery
- Battery Size: 10 MW/2.5 MWh
- Duration: 00:15 (HH:MM)
- Services: Frequency Response, distribution voltage support, and short duration reserve capacity
- Operation Start: 2016
Pinal Central Energy Storage

NextEra Energy Resources 10 MW/40 MWh Pinal Central Battery Energy Storage facility is designed to store energy produced by a co-located solar facility, and enable Salt River Project (SRP) to provide clean energy to customers when usage is at its highest and needed most. Solar generation starts to ramp down in the late afternoon when SRP customers are typically using energy at the highest level. With this battery system, the stored energy will be available to customers during that critical time.
Solar, Battery, Microturbine Microgrid

The autonomous microgrid at Oncor’s System Operating Services Facility, built in six months by S&C and Schneider Electric, consists of four interconnected microgrids and nine different distributed generation resources: two solar PV arrays, a microturbine, two energy storage units, and four generators. The microgrid project aims to test Oncor’s ability to operate a microgrid, as well as to showcase how solar, microturbines, and battery storage can integrate renewable energy sources into the energy grid through advanced hardware and software. The system’s peak capacity is 900 kW, although it can be scaled to meet varying needs, dropping to 550 kW as energy is drained during the night.

The two batteries—one from S&C, and the other made by Tesla—enable integration of solar power, allow for voltage control, and release stored energy during an outage. Oncor paid for the microgrid in full.
Between 2012 and 2017, Pacific Gas and Electric Company (PG&E) deployed three large-scale battery energy storage systems onto its energy grid in Northern California. Energy storage plays an increasingly important role in California’s clean energy future, and while it has been a part of PG&E’s energy mix for decades—starting with the Helms Pumped Storage Plant in the 1980’s—PG&E believes that battery energy storage will play an integral role in enhancing overall energy grid reliability, integrating renewable generation sources, and helping customers save energy and money.

This 0.5 MW large-scale BESS is PG&E’s first lithium-ion energy storage facility and features Tesla Powerpack technology. Browns Valley is PG&E’s first energy storage system installed to shave summer peaks (addressing system capacity overloads to defer infrastructure upgrades). Browns Valley also represents the first time a Tesla energy storage system was fully integrated into an electric company Supervisory Control and Data Acquisition (SCADA) system.

Goals for the Browns Valley BESS involved demonstrating energy storage on PG&E’s electric distribution system to address a projected overload condition and reliability concerns; evaluating various energy storage control systems and developing learnings to inform future controls deployment for both electric company and third-party owned energy storage resources; and integrating energy storage functionality with existing Distribution Operations protocols, roles, and responsibilities.
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This 2 MW large-scale sodium sulfur BESS is the first battery storage resource in California to participate in the California electricity markets. Through an Electric Program Investment Charge (EPIC) project involving the BESS, PG&E studied the system's performance and functionality (along with the Yerba Buena Battery) in the electricity markets, and shared results of the project in a comprehensive report, which includes detailed overviews of the market participation process and the unique challenges to operating battery resources in the electricity markets.
Yerba Buena Battery

Between 2012 and 2017, Pacific Gas and Electric Company (PG&E) deployed three large-scale battery energy storage systems onto its energy grid in Northern California. Energy storage plays an increasingly important role in California's clean energy future, and while it has been a part of PG&E's energy mix for decades—starting with the Helms Pumped Storage Plant in the 1980’s—PG&E believes that battery energy storage will play an integral role in enhancing overall energy grid reliability, integrating renewable generation sources, and helping customers save energy and money.

This 4 MW large-scale sodium sulfur BESS supports power quality and reliability for a select customer on a distribution feeder, allows the customer facility to operate autonomously, and can be used to study battery use cases including load shaping and smoothing of variable resources.

The system, funded in part by the California Energy Commission, also provides energy and ancillary services in California Independent System Operator (CAISO) markets. The Yerba Buena BESS is the first battery storage resource to both participate in the market and serve a reliability function supporting PG&E’s distribution system in the event of an energy grid disturbance or outage.

The Yerba Buena battery was also utilized for an Electric Program Investment Charge (EPIC) project involving the coordination of third-party distributed energy resources (DERs)—such as residential and commercial solar—using smart inverters and battery storage controlled through a distributed energy resource management system (DERMS).
Solar Partner Program Phase II—Energy Storage

In 2016, Arizona Public Service Company (APS) installed private rooftop solar on over 1,600 homes as part of its Solar Partner program (SPP). These deployments were the basis for a comprehensive study on the integration of private rooftop solar at the distribution level. Key research topics included the command and control of advanced inverter functions to limit negative impacts to the local power quality and voltage levels.

As part of SPP Phase II, APS installed a battery on each of two different distribution feeders. One battery was located in the middle of the feeder, while the other battery was located near the substation. What followed was a research effort no less significant than that of SPP—Phase I. The same voltage and power factor regulating functions APS studied on solar PV inverters were also studied at the MW-scale with the energy storage inverters. The research then compared and contrasted the relative impacts on the distribution circuit between inverters, energy storage, and traditional voltage regulating equipment. The research also looked into how these various technologies can and should operate together. The results of this research will be released in mid-2018.
Punkin Center Battery Storage System

Arizona Public Service Company (APS) recently procured and installed a battery storage system in rural Punkin Center, AZ because it was the most cost-effective option to address a distribution system constraint. In this case, the traditional solution would have been to upgrade the near 20-mile radial 21 kV feeder that passes through rough terrain. Punkin Center’s rural location, coupled with reduced implementation costs and added technological benefits, created the ideal financial situation for battery installation.

The 8 MWh system, comprised of Fluence’s Advancion batteries, is increasing power system reliability for a community of 600 residents, located about 90 miles northeast of Phoenix. The batteries deliver locally stored power on the 20 to 30 days a year when local and system peaks strain the wires. The goal is to make local load invisible to the system. The site can accommodate increased energy capacity over the next 10+ years to meet additional load growth. The inverters that are installed with the system can regulate voltage and power factor. When not used for local load demand, the battery storage system also provides energy arbitrage—storing energy when it is negatively priced, and dispatching it when it is economically advantageous for APS’s customers.
Residential Battery Storage Program

Arizona Public Service Company (APS) designed, built and owns residential customer sited battery storage for two programs: Solar Innovation Study (10 systems) and Storage Rewards (40 systems). The Solar Innovation Study couples battery storage with private rooftop PV and other energy savings devices to learn how customers choose to use the technologies to maximize their energy savings. The Storage Rewards program is a battery storage only installation where the goal is to provide the customer with backup power and some energy savings plus reserving a portion of the battery at all times for energy grid support. The reserved capacity can be called on by APS for system needs.
Solana Parabolic Trough Solar Concentrating Plant

Abengoa Solar installed a 280 MW parabolic trough solar plant—the world’s largest—enabling six hours of molten salt thermal storage. The plant covers about 3 square miles, and generates enough electricity to supply 70,000 homes in Arizona Public Service Company (APS) territory. APS has a 30-year offtake agreement with Abengoa for the electricity.

The Solana thermal storage plant consists of two molten salt tanks that can store up to 1,000 MWh, and allows energy to be dispatched as needed during cloudy periods and after sunset. The Solana plant is thus able to generate electricity well into the evening to help meet consumer demand.

The plant cost approximately $2 billion to build, with $1.45 billion backed by the Federal Loan Guarantee Program. APS and Abengoa received an extension of the state investment tax credit that enabled it to receive a 30 percent credit, making the plant economically feasible. Over the next 30 years, the plant is forecasted to generate tax revenue of about $300–400 million, and help keep the state’s energy spending within the state.
In addition to the residential chemical batteries deployed in Arizona Public Service Company’s (APS) Storage Rewards program, thermal storage technologies are also being deployed in related programs: smart thermostats via the Cool Rewards program; and grid-interactive water heaters via the Reserve Rewards program. Together the technologies in all Rewards programs will be operated as a coordinated fleet to support load management, demand response, and load shifting to the benefit of both host customers and the energy grid.

APS’s Reserve Rewards program will employ grid-interactive water heaters (80 gallon capacity) in customer homes located on targeted feeders with high solar penetration. These water heaters will help to shift water heating demand into the midday solar production peak to take advantage of excess solar generation. The hot water heaters will be customer owned, with APS providing an up-front rebate for the full purchase price, as well as an annual participation reward for 10 years. APS will control the water heaters to heat water during times when power is at its cheapest, and when excess solar generation is at its highest. Reserve Rewards seeks to deploy 500 kW of load shifting capability through 200 grid-interactive water heaters.

Cool Rewards will allow residential customers to connect their smart thermostats to automatically respond to demand response requests from APS. The program will also encourage customers to use smart thermostat functionality to pre-cool their homes before peak demand hours, offering the potential for significant bill savings. In this application, the thermal mass of customer homes serves as a thermal storage device. Thermostats will be customer owned, and APS will provide an annual participation reward for 10 years. While APS will be able to control the thermostats remotely, customers retain full control to override any demand response requests. The program seeks to recruit 6,000 customer thermostats.
Prosperity Energy Storage Project

PNM Resource’s solar-plus-storage Prosperity project was the first of its kind that was fully integrated into an electric company energy grid using smart grid technology. Approximately 40 percent, or $2.3 million of the total cost of $5.8 million, was funded through Department of Energy’s American Recovery and Reinvestment Act. PNM Resources recovered the remaining 60 percent through a renewable rate review filing in 2009–2010 timeframe.

Two on-site batteries are dispatched through a single inverter. One is an advanced lead acid with ultra-capacitor rated at 500 kW used for smoothing. The second battery is an advanced lead acid rated at 250 kW/1 MWh and is used for arbitrage, renewable firming, peaking shaving.

Sophisticated PV modeling and feeder, combined with dynamic feeder models, made the development of this solar-plus-storage project possible and maximized the results. PNM used an algorithm to dispatch a signal to the batteries to direct them to release stored solar energy, or when they need to charge.

The system achieved a 15 percent reduction of feeder peak load goal, simultaneously shifted peak demand, and smoothed the PV. Depending on the market and system conditions, the shifting function can do reliability-based peak shaving, as well as arbitrage, or renewables firming. Reliability is the top priority of the shifting algorithm, and algorithms automatically re-prioritize the storage applications based on pre-set parameters such as pricing or loading on the circuit.

Project results show that the economic effectiveness needs to constantly be monitored, even though all the battery’s applications are bringing in value in a prioritized sequence.

The project has helped PNM understand optimal conditions for the battery to store energy in the mornings and release it during the afternoon or evening peak (depending on the season). PNM learned that when the energy storage performance was combined with signals from the PV meter using algorithms, the batteries flattened the highs and the lows of the total output. In addition, PNM realized the need to better understand the energy demand of the solar farm of-takers (the local manufacturers) as well as to more accurately forecast weather and cloud cover.

The project is also a teaching laboratory for Northern New Mexico College and the University of New Mexico students, enabling them to learn from integrating technological advances in the real world.
Battelle Memorial Institute Pacific Northwest SmartGrid Demonstration

Portland General Electric’s (PGE) Salem Smart Power Center (SSPC) is an Energy Storage Facility (ESF), originally a pilot component of a larger Battelle’s Pacific Northwest SmartGrid Demonstration, a U.S. Department of Energy battery research effort that ended in 2015. The project has a 5 MW, 1.25 MWh storage resource designed to respond to low-frequency events, aid renewable resource integration, and mitigate peak-price risk.

PGE built the facility as an R&D effort, and developed algorithms and software that have successfully tested PGE’s ability to implement a range of battery applications. This includes using storage as a resource to serve peak demand, provide local voltage control using the kVAR output of the inverters, and smoothing the combined fluctuations of load and solar output on the feeder. Once various use cases were demonstrated and analyzed, it became clear that primary frequency response was the highest and best use case.

The project cost $25 million, with 50 percent funded by the U.S. Department of Energy’s American Recovery and Reinvestment Act, and 25 percent paid for by battery manufacturer Enerdel and smart inverter provider Eaton.
Yards Creek Pumped Storage

The Yards Creek Pumped Storage Facility has been in operation since 1965. The facility is filled when water is conveyed between the hydroelectric plant and the upper reservoir via a large exposed steel pipe. The storage facility provides spinning reserve during on-peak hours and stores energy during off-peak hours.
Borrego Springs Microgrid Demonstration Project

Funded in part by the U.S. Department of Energy and the California Energy Commission as a demonstration project, the San Diego Gas & Electric (SDG&E) microgrid at the Borrego Springs Substation provides services to the energy grid and its customers. The first large-scale microgrid in the U.S. serves as an upgrade of distribution, manages solar generation, and reduces feeder peak load. The project also studied microgrid islanding of an entire substation, and ways to improve system reliability. SDG&E aimed to reduce peak feeder load by at least 15 percent, and succeeded by reducing 100 percent of the load.

The Borrego Substation, with a peak load of over 10 MW, was selected because it provides a unique opportunity to explore microgrid islanding of a substation. The project involves integration of five technologies, including DER, solar and VAR management, feeder automation system technologies (FAST), advanced energy storage, an outage/distribution management system, and price-driven load management. Storage is not directly paired with solar, but the goal is to use both resources on the energy grid. Using R&D funds, the project team conducted a cost/benefit analysis for full-scale deployment.
Escondido Substation Storage

The Escondido Substation storage facility, located in Escondido, California, is the largest lithium-ion battery storage project in North America. Owned by San Diego Gas & Electric (SDG&E) and built in partnership with Fluence, the 30 MW storage facility is comprised of approximately 400,000 batteries installed in 20,000 modules within 24 containers. At capacity, it can provide electricity to 20,000 homes for four hours.

The facility has two primary purposes. First, it helps balance the large amount of solar generation entering the Southern California energy grid during peak daylight hours. Second, the facility enables energy time shift, which allows SDG&E to make smart financial decisions about when to supply and to store energy; these decisions directly benefit customers. Time shifting allows the company to charge customers lower rates during traditionally high-cost peak demand. By taking in and storing electricity during the day when it is most abundant (and therefore at lowest cost), SDG&E can release low-cost stored electricity in the early evening when solar generation has dissipated, and demand has picked up because people are returning home from work. Ultimately, this storage facility helps reduce the energy costs paid by customers.

From announcement to operation, this state-of-the-art 30 MW installation was completed in roughly eight months. Notable milestones include:

- **May 26, 2016**: SDG&E released a request for bids on storage projects in response to Governor Brown’s call to accelerate energy storage development to meet supply shortages caused by the gas leak at the Aliso Canyon Natural Gas Facility.
- **July 2016**: SDG&E signed a contract with Fluence to purchase a total of 37.5 MW of lithium-ion battery storage (30 MW at Escondido and 7.5 MW at El Cajon).
August 18, 2016: The CPUC approved both storage projects.

September 15, 2016: Ground breaking on the Escondido facility.

December 2, 2016: The Fluence battery containers arrived on-site in Escondido.

February 24, 2017: The project became fully operational.

Owned by SDG&E, the Escondido battery is rate-based over a 10-year period. Fluence, the initial installer, is responsible for maintaining the batteries’ capacity and performance during this 10-year period, thus removing the perceived risk to customers regarding battery life and performance for this early-adopter project. After 10 years, SDG&E will assume full responsibility for operation and management of the installation.
Smart Neighborhood Microgrid

Alabama Power partnered with Southern Company and Oak Ridge National Laboratory to build the Shannon-Oxmoor Road microgrid, powering the state-of-the-art, 62-home, Smart Neighborhood™ at Reynolds Landing. The neighborhood is grid-tied and equipped with a central microgrid containing 1,200 solar modules (330 kW AC) capable of generating over 600,000 kWh annually, paired with energy storage (300 kW/680 kWh) and backup generation (400 kW NG). The community can seamlessly island and reconnect to the energy grid.

The houses are constructed using energy efficient materials and are fitted with efficient interconnected appliances that feed consumption data into an intelligent home comfort system, including a smart thermostat. Alabama Power will use the information from HVAC, water heaters, and other appliances to study how these homes use energy, and how to supply the homes with electricity in the most efficient way.

Oak Ridge National Laboratory provided a microgrid controller (CSEISMIC) and a home energy management system (VOLTTRON) for the project. CSEISMIC can coordinate the operation of the assets at the microgrid in tandem with the major customer loads, namely HVAC and water heater. This provides Alabama Power a truly unique test facility to learn how customer loads can increase the functionality of distributed generation assets in the real world.
Wallace Dam
Pumped Storage

The Wallace Dam Project is a pumped storage project consisting of the Wallace Dam and Lake Oconee. Lake Sinclair serves as the lower reservoir and is operated by Georgia Power under a separate license. Water for generation at Wallace comes from inflow plus storage in Lake Oconee. The Wallace Dam generates during peak power demand hours, and then pumps some of the water back at night during off-peak and lower-cost power hours.

For normal operations on a day to day basis, Lake Oconee fluctuates between an elevation of 435 feet (ft) plant datum (PD), which is full pond, and an elevation of 433.5 ft. Lake Oconee may start at an elevation 435 ft before the Wallace Dam generation cycle, and end at an elevation of 433.5 ft. During the night-time pumping cycle, Lake Oconee will be pumped up to an elevation of 435 ft. Depending upon power demand, the reservoir may not fluctuate the full amount on a daily basis.
Cedartown Battery Energy Storage Project

The Cedartown Battery Energy Storage Project is a 1 MW lithium-ion system located at a solar PV facility. Southern Company and the Electric Power Research Institute (EPRI) co-operate the battery, use it to assess the ability to enhance the integration of PV solar, and evaluate the impacts of battery storage on energy time shift and voltage support on the energy grid.

EPRI assisted with testing and analysis of data from the project to help Southern Company assess the granularity of the battery system’s ability to absorb and release energy from the solar plant. The batteries were installed and are maintained by LG Chem.
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.
Lithium Titanate Oxide Battery

Tucson Electric Power’s project consists of a 10 MW lithium titanate oxide (LTO) storage facility and an accompanying 2 MW solar photovoltaic plant. Its goal is to improve service reliability and to study how energy storage systems can help integrate solar power and other renewable energy technologies. The facility was completed in 2017 by the Chicago-based E.ON Climate & Renewables.

The systems are used primarily to boost frequency and maintain reliability, and to help keep the required balance between energy demand and supply in case of a drop in the voltage frequency of the regional energy grid. The systems also can 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.
Xcel Energy’s MinnWind storage project is a 1 MW 7.2 MWh sodium sulfur (NaS) battery system consisting of 20 50 kW modules used to demonstrate the capabilities of battery storage. Specifically, the system was intended to test the ability to store wind energy and move it to the energy grid when needed. Funded in part by $1 million grant from Minnesota’s Renewable Development Fund, this is the first U.S.-based pairing of wind energy and a storage battery.

The battery system is connected to a nearby 11 MW wind farm owned by MinWind Energy, LLC.

After two years in operation, Xcel Energy reported that the project was extremely successful. The results showed the battery could shift wind energy from off-peak to on-peak availability; support the transmission system by providing voltage support and frequency regulation, which contributes to system reliability; and additionally, support the regional electricity market by responding to real-time imbalances between generation and load.

The storage is in front of the meter and is electric company owned and operated. Xcel Energy purchased the NaS battery from Japan’s NGK Insulators, Ltd. Xcel Energy contracted with S&C Electric to design and build the power conversion system and to install the distributed energy storage system. GridPoint, Inc. provided the communication and control system for system integration, remote control, and data access. No costs associated with the battery were rate-based.
The Panasonic battery storage microgrid project aimed to show that the value of batteries can be “stacked” to increase the economic viability of storage projects. The project resulted from a public-private partnership between Xcel Energy, Panasonic Enterprise Services, and the City of Denver/Denver International Airport. The project cost was not rate-based, and was funded by Xcel Energy’s Innovative Clean Technology (ICT) demonstration program, approved in 2016 by the Colorado Public Utilities Commission (PUC).

The project consists of a 1.3 MW solar system, a 1 MW/2 MWh battery storage system, islanding switch, and the associated controls equipment. The storage system is located in front of the meter. The battery system is owned by Xcel Energy, but is maintained by Panasonic. Xcel Energy owns the switching and control systems that operate the energy storage system and the microgrid.

The storage system’s primary function is to provide grid services: facilitate the integration of high PV penetration on the feeder, enhance feeder reliability, and act as a demand response and ancillary service resource to address system conditions. Additionally, the system can provide back-up service to the Panasonic facility in the event of a grid outage. Should a grid outage occur, an islanding switch will open, forming a microgrid between the battery system and Panasonic’s facility. The storage system will allow the building’s PV solar system to operate during daylight hours, supplying power to the building and recharging the battery with any excess generation. Thus, the facility could operate in microgrid mode for an extended period.

The system became fully operational in 2017. Through 2019, the system will be run in various configurations to determine which value streams can be “stacked” to extract the most economic value from the system. It will then be operated in the optimized configuration for the remainder of the batteries’ expected life of approximately 10 years.
The Stapleton battery storage demonstration project examines how battery storage can help integrate higher concentrations of PV solar energy into the energy grid and overall electric company’s distribution system. Xcel Energy installed six in-home, behind-the-meter batteries and six larger, front-of-the-meter batteries in Denver’s Stapleton neighborhood, and will help manage solar integration as well as support other areas of the energy grid. The Colorado PUC approved the project in March 2016, funding it from Xcel Energy’s ICT program. No part of the cost associated with the batteries was rate-based.

The batteries are located both in front and behind the meter. While the pilot portion of the project is underway, the in-home batteries, as well as those sited in the neighborhood, are owned and operated by Xcel Energy. Xcel Energy chose the Stapleton area for its high concentrations of rooftop solar installations in the Denver area. Northern Reliability Inc. provided the six front-of-the-meter batteries, installed in the right-of-ways or in easements in Stapleton’s North Central Park and Eastbridge neighborhoods. Xcel installed two sets of 18 kW batteries, two sets of 36 kW batteries, and two sets of 54 kW batteries. Sunverge supplied 6 kW in-home batteries. Xcel Energy is in the process of testing them. Once the pilot is complete, customers will own the in-home batteries for the life of the battery—approximately eight additional years.

Since its approval by the Colorado PUC in 2009, a limited number of projects that promise lower greenhouse gas emissions and other environmental benefits have been funded through the Xcel Energy’s ICT program. The ICT provides Xcel Energy with the ability to test new technologies and evaluate their cost, reliability, and environmental performance on a small demonstration scale before determining whether to deploy them more widely for customers. Past ICT projects include the Colorado Integrated Solar Project in Palisade, Colorado, and the community energy storage project at SolarTAC in Aurora, Colorado.
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