Planning for energy storage

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Integrated Distribution System Planning
Training for Western States
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Agenda

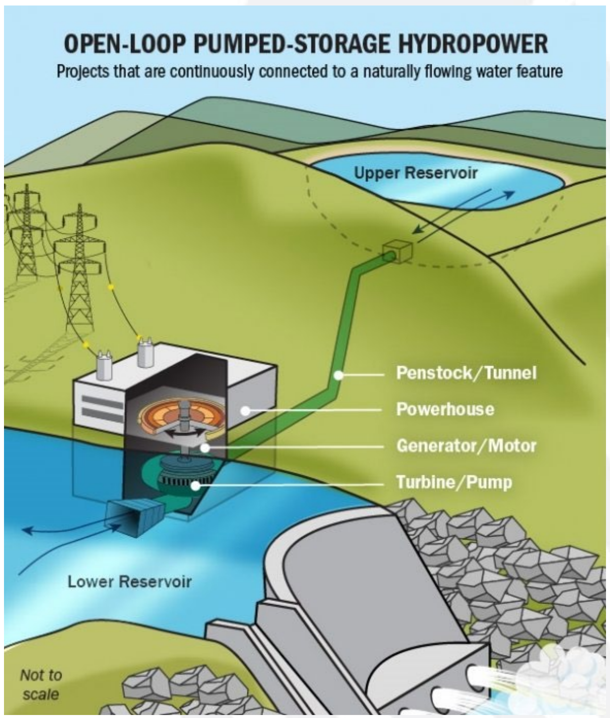
- Technology Overview
- Services and Valuation
- Recent Energy Storage Policy Development in the West
- Storage in Microgrids

Technology Overview

Storage Technologies: Mechanical

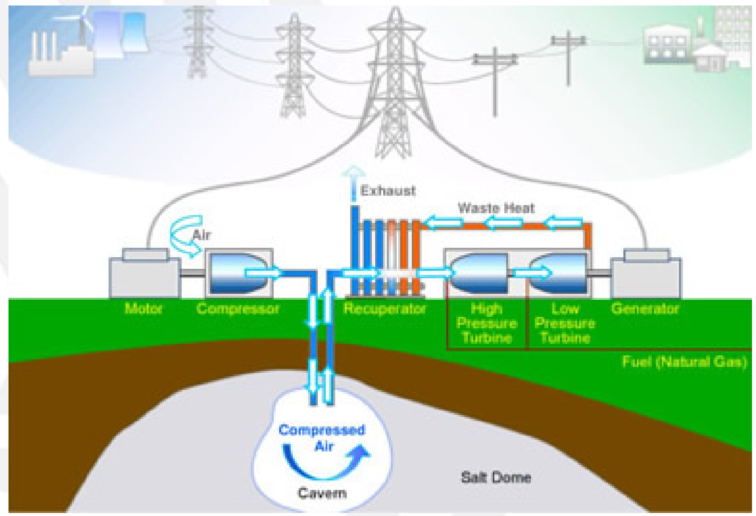
Electricity is stored as potential energy that is later used to generate electricity.

Pumped-Storage Hydro (PSH)



- Long duration (8+ hours)
- Good round-trip efficiency (RTE) – 80%
- Cycle life: 15,000 (40+ years)
- Limited flexibility

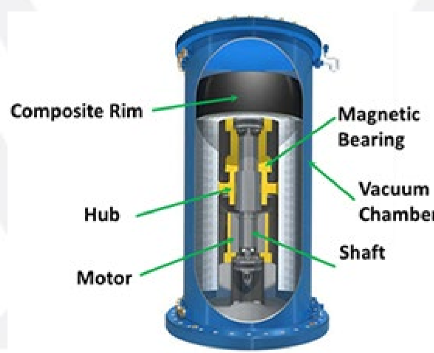
Compressed Air Energy Storage



Ridge Energy Storage & Grid Services LP

- Long duration (8+ hours)
- Low RTE (~50%)
- Cycle life: 10,000 (~25 years)
- Limited flexibility

Flywheels



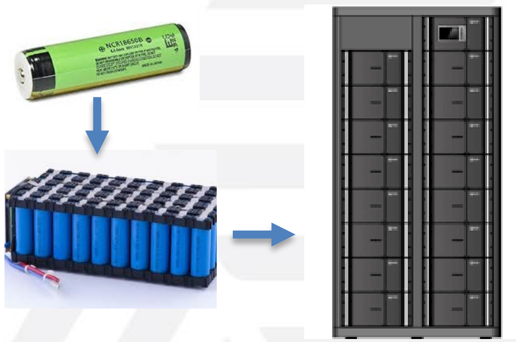
Source: Beacon Power, LLC

- Short duration (~15 min)
- Very good RTE (~85%)
- Cycle life: 200,000 (~20 years)
- Highly flexible

Storage Technologies: Electrochemical

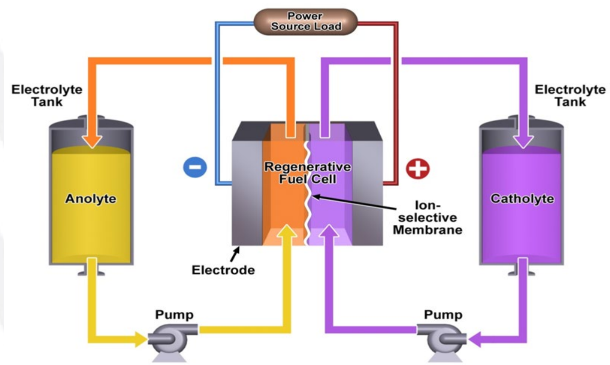
Electricity is stored in chemical bonds and later released.

Lithium-ion Batteries



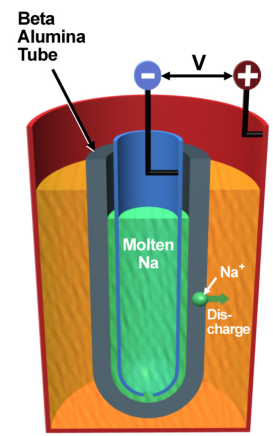
- Short to mid-range duration (0.5 - 4 hours)
- Very good round-trip efficiency (RTE) – 86%
- Cycle life: 3,500 (7-10 years)
- Highly flexible
- Developed supply chain
- Safety concerns
- Recycling challenges

Flow Batteries



- Moderate durations (4-8 hours)
- Moderate round-trip efficiency (RTE) – 70%
- Cycle life: 10,000 (15-20 years)
- Highly flexible
- Improved safety
- Highly recyclable
- Mechanical challenges

Sodium Batteries

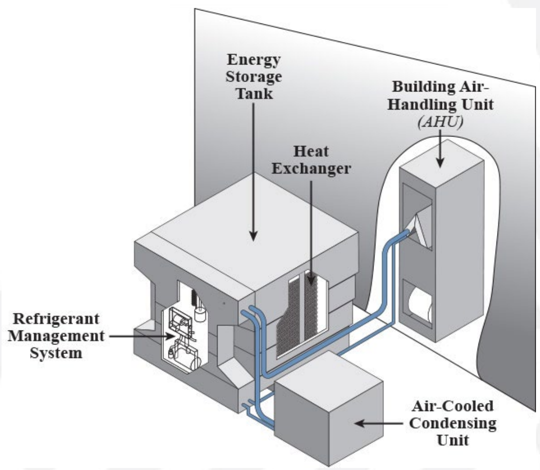


- Moderate durations (4-6 hours)
- Good round-trip efficiency (RTE) – 75%
- Cycle life: 4,000 (10-13 years)
- Highly flexible
- High-temperature ops

Storage Technologies: Thermal

Electricity is stored by heating/cooling air or another medium for energy management or electricity production.

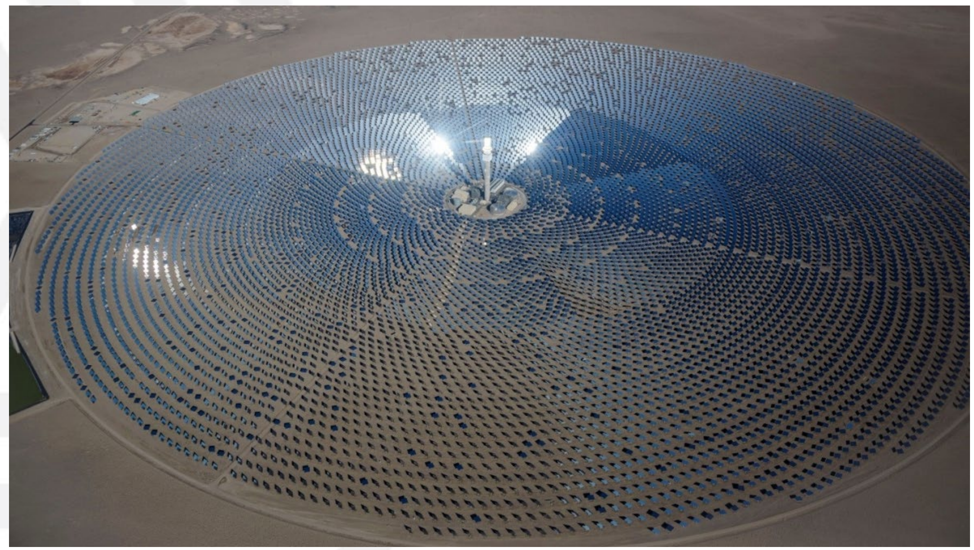
Ice thermal storage



Ice Energy, Inc.

- Moves energy through time, but does not inject electricity into the grid
- Moderate duration (4-6 hours)
- Can shift up to 95% of HVAC loads to off-peak

Concentrating Solar

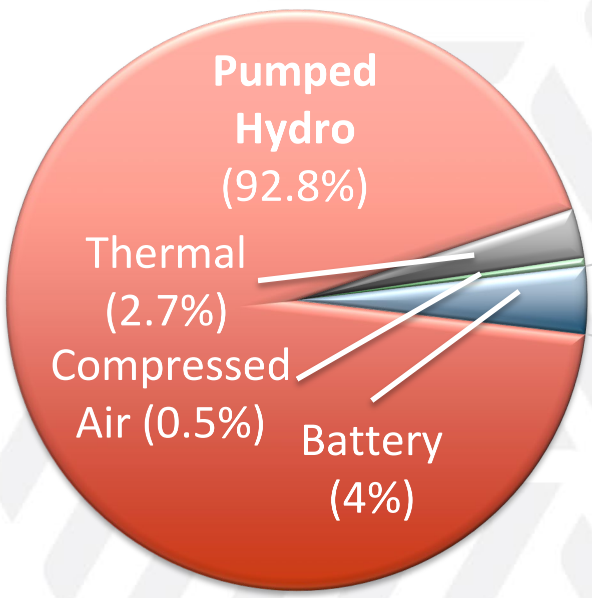


U.S. DOE

- Longer duration (6-12 hours)
- Very good RTE – 86% (Hameer and Van Niekerk 2016)
- Moderate life (20-30 years)
- Moderately flexible (turbine generator)

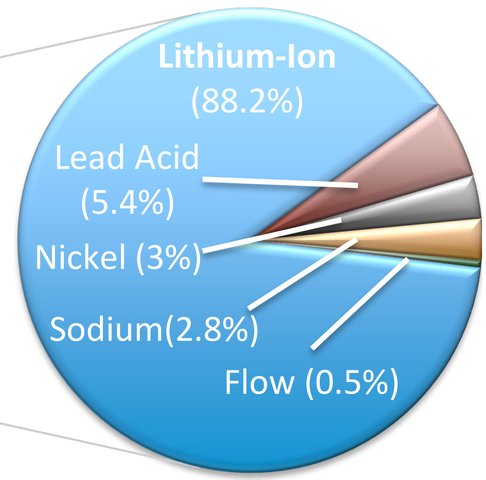
Current Installed Capacity – U.S.

Total Energy Storage Capacity



Pumped Hydro	22.6 GW
Battery	0.9 GW
Thermal	0.7 GW
Compressed Air	0.1 GW
Total	**24.3 GW**

Total Battery Capacity



Lithium-Ion	792 MW
Lead Acid	49 MW
Nickel	40 MW
Sodium	26 MW
Flow	4 MW
Flywheel	58 MW
Capacitor	2 MW

Sources:
DOE Global Energy Storage Database (https://www.sandia.gov/ess-ssl/global-energy-storage-database-home/);
EIA Form 860 Data (https://www.eia.gov/electricity/data/eia860/)

Storage Technologies: Additional Information

Table 4.3. Summary of Compiled Findings by Technology Type – BESS[a]

Parameter	Sodium Sulfur	Li-Ion	Lead Acid	Sodium Metal Halide	Zinc-Hybrid Cathode	Redox Flow
Capital Cost – Energy Capacity ($/kWh)	661 (465)	271 (189)	260 (220)	700 (482)	265 (192)	555 (393)
Power Conversion System ($/kW)	350 (211)	288 (211)	350 (211)	350 (211)	350 (211)	350 (211)
Balance of Plant ($/kW)	100 (95)	100 (95)	100 (95)	100 (95)	100 (95)	100 (95)
Construction and Commission Cost ($/kWh)	133 (127)	101 (96)	176 (167)	115 (110)	173 (164)	190 (180)
Total Project Cost ($/kW)	3,626 (2,674)	1,876 (1,446)	2,194 (1,854)	3,710 (2,674)	2,202 (1,730)	3,430 (2,598)
Total Project Cost ($/kWh)	907 (669)	469 (362)	549 (464)	928 (669)	551 (433)	858 (650)
O&M Fixed ($/kW-yr)	10 (8)	10 (8)	10 (8)	10 (8)	10 (8)	10 (8)
O&M Variable Cents/kWh	0.03	0.03	0.03	0.03	0.03	0.03
System Round-Trip Efficiency (RTE)	0.75	0.86	0.72	0.83	0.72	0.675 (0.7)
Annual RTE Degradation Factor	0.34%	0.50%	5.40%	0.35%	1.50%	0.40%
Response Time (limited by PCS)	1 sec	1 sec	1 sec	1 sec	1 sec	1 sec
Cycles at 80% Depth of Discharge	4,000	3,500	900	3,500	3,500	10,000
Life (Years)	13.5	10	2.6 (3)	12.5	10	15
MRL	9 (10)	9 (10)	9 (10)	7 (9)	6 (8)	8 (9)
TRL	8 (9)	8 (9)	8 (9)	6 (8)	5 (7)	7 (8)

(a) An E/P ratio of 4 hours was used for battery technologies when calculating total costs.
MRL = manufacturing readiness level; O&M = operations and maintenance; TRL = technology readiness level.

Mongird et al, *Energy Storage Technology and Cost Characterization Report*. http://energystorage.pnnl.gov/pdf/PNNL-28866.pdf.

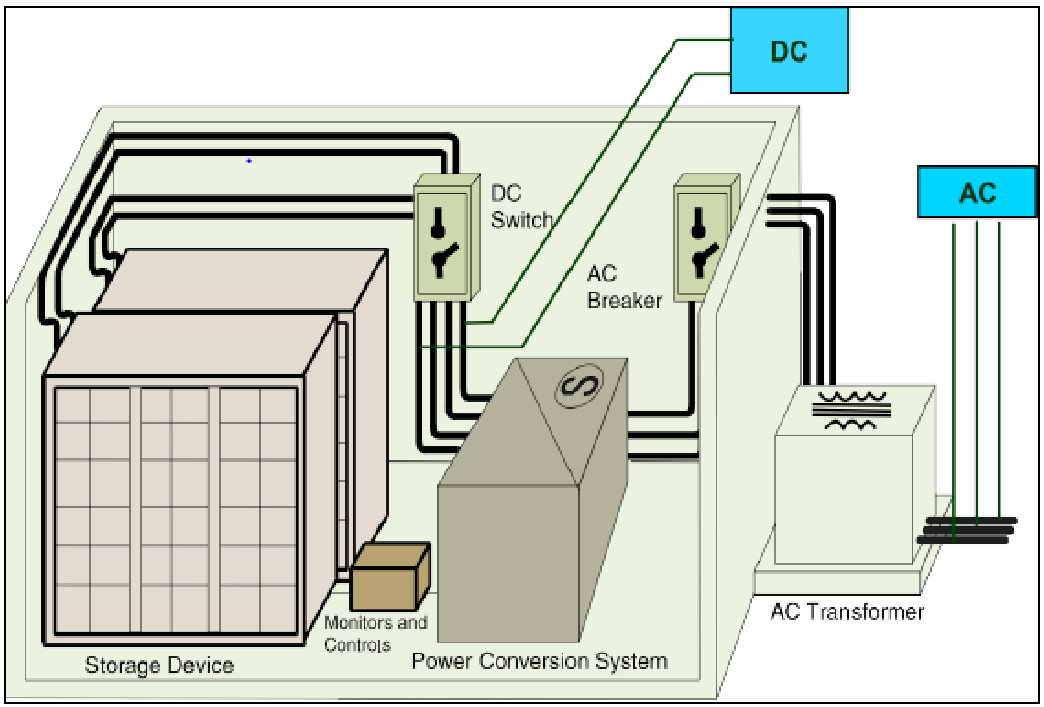
Interconnection and Control Infrastructure

Battery storage prices are generally given based on the battery itself, but interconnecting the device to the grid and allowing for control and interoperability requires additional infrastructure (and cost).

Example 4-hour lithium-ion project

Balance of Plant (controls, switches, HVAC, etc.):
$100/kW
($25/kWh)

Battery Capacity:
$271/kWh
($1,084/kW)



DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA

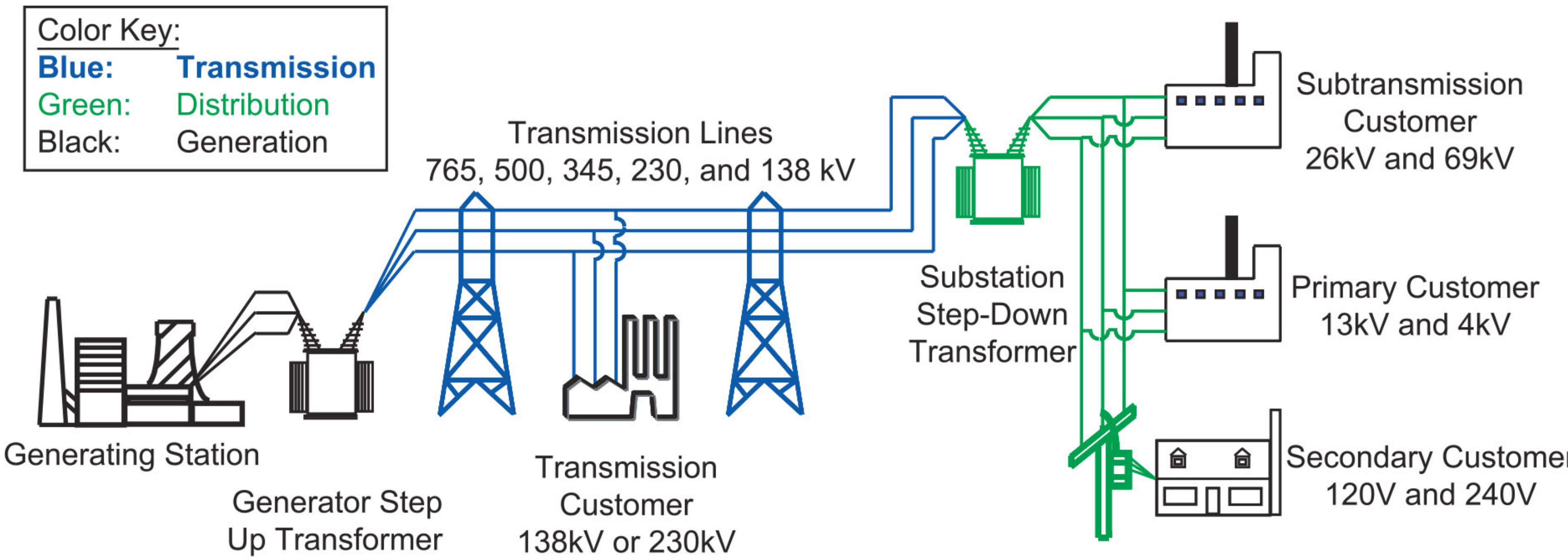
Construction & Commissioning:
$101/kW
($25/kWh)

Power Conversion:
$288/kW
($72/kWh)

Total all-in cost for a 4-hour li-ion battery: $469/kWh, $1,876/kW

Services and Valuation

Energy Storage Services



Generation Services
- Capacity
- Energy
- Ancillary services
  - Regulation
  - Frequency response
  - Spin/non-spin reserve
  - Etc. …

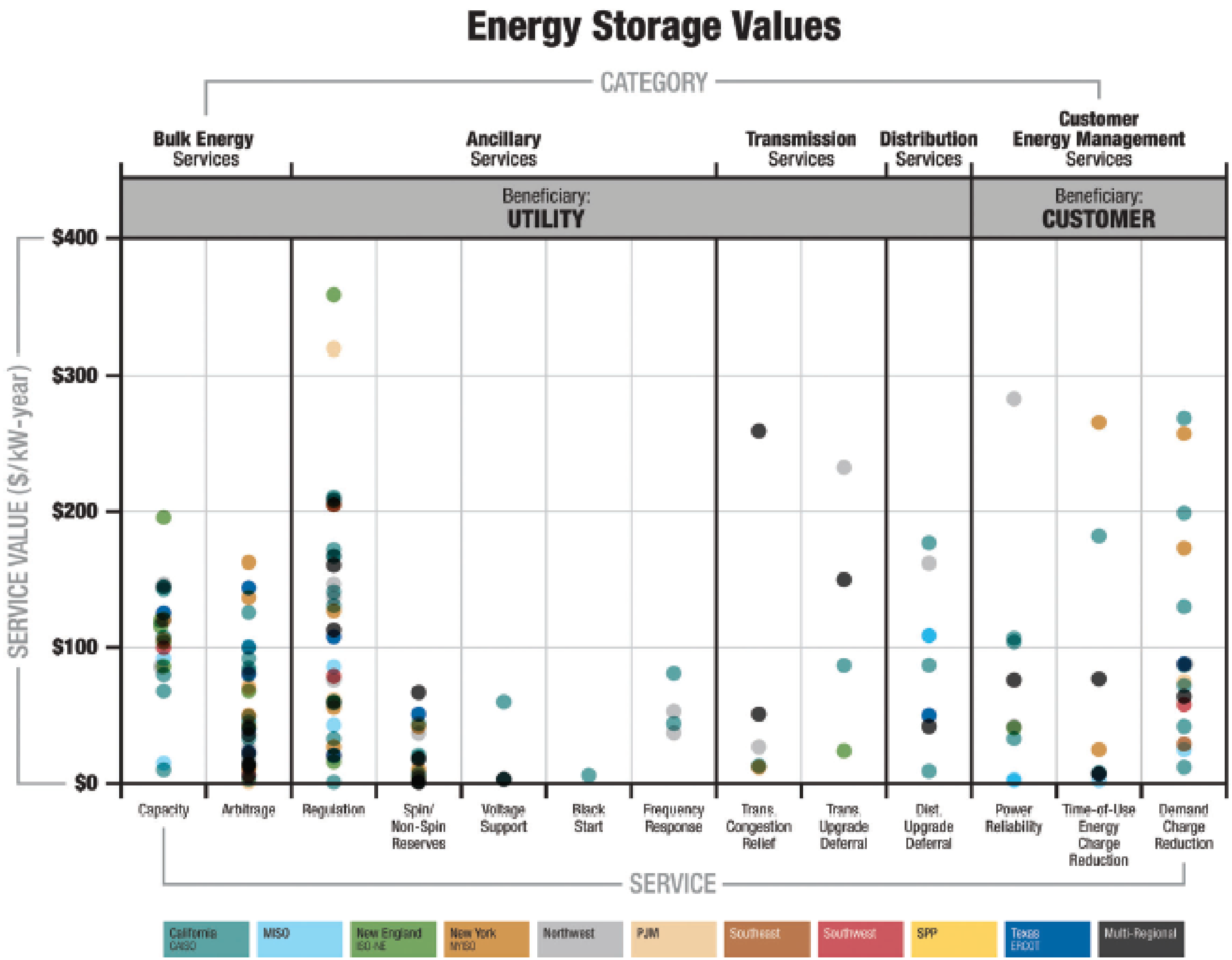
Transmission Services
- Thermal management
- Congestion relief
- Infrastructure deferral

Distribution Services
- Voltage support
- Conservation voltage reduction
- DG integration/hosting capacity
- Flow management
- Infrastructure deferral

Customer Services
- TOU rate management
- Demand charge reduction
- Power quality
- Resilience

Image: U.S. Department of Energy, "Grid Modernization Multi-Year Program Plan"

Energy Storage Values



Storage values are locational, subject to:

- Resource mix
- Local infrastructure
- Contingency conditions
- Utility tariffs
- Market structure

Balducci et al, "Assigning Value to Energy Storage Systems at Multiple Points in an Electric Grid."

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A Different Paradigm: Embedded Energy Storage

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Electricity is unique among commodities in that its "supply chain" was developed without a storage component.

- Every other commodity has the ability to store excess quantities built into its supply chain – warehouses, granaries, reservoirs, etc.
- Embedded storage creates a buffer between mismatches in supply and demand, stabilizing prices and protecting customers.

Question: Now that we have the technology to store electricity, should we retrofit the grid with it?

- To date, energy storage has been added "on the margins" to impart flexibility to the grid.
- If storage were embedded infrastructure, similar to a substation or a transformer, it could act as a natural buffer between mismatches in supply and demand and the grid would *be* flexible.

First report available here; watch PNNL's Grid Architecture site for additional reports in the series

Embedded Storage in the Natural Gas System

A simple comparison: Natural gas and electricity

- Simple assumptions: City has average daily demand of 1 million cubic feet (CF) of natural gas, peaking to 1.5 million CF; average electricity demand of 100 MW, peaking to 125 MW

Adapted from Aspen Environmental Group

Result: Embedded storage on the natural gas system means that pipelines upstream of the storage facility can be sized based on average demand, and only downstream pipelines need to be sized based on peak.

- On the electric side, the entire system (generation, transmission, and distribution) serving the city must be designed based on peak demand.

Interesting Idea, Lots of Questions

Theoretically, embedded storage could facilitate more efficient design and use of the electric grid and reduce costs by managing volatility (no daily price swings, reduced need for ancillary services, etc.).

Several regulatory barriers exist:

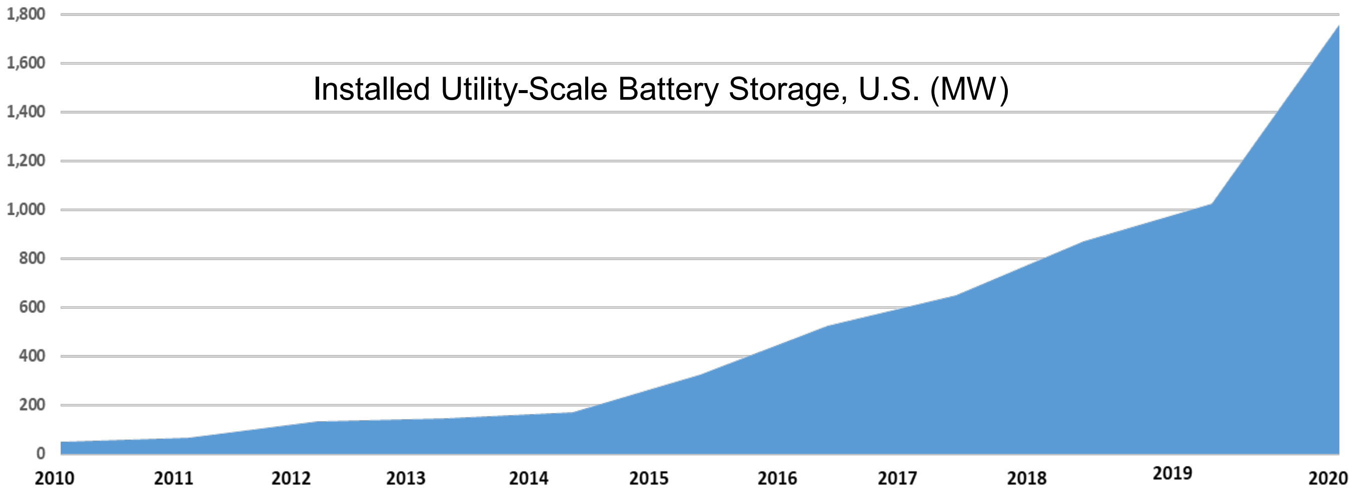
- Lack of underlying standards (not contemplated in reliability standards; no resilience standards)
- Inclusion in planning processes (regional transmission planning processes are generally slow to integrate new technologies)
- Ownership models (security and control issues complicate third-party ownership)
- Compensation structure (current market structures not designed to value this kind of service; lack of standards means it’s difficult to make a case for it as a regulated asset)
- Metrics (how do you measure a buffer?)

Valuing this type of asset is something we’re just starting to think about:

- How would you quantify its impacts on the grid and compensate them?
- Valuation will be the focus of a forthcoming paper.

Recent Energy Storage Policy Development in the West

State Policymaking Is Accelerating and Diversifying



2010
- CA: Target legislation

2011
- FERC: Order 755

2012

2013
- CA: 1,325 MW Target
- WA: $14m demo fund
- HI: MPIR mechanism

2014

2015
- OR: 10 MWh target
- NY: REV demo project
- HI: Inter-connection changes

2016
- CA: SGIP storage focus
- CA: 500 MW target increase
- AZ: $4m aggregation pilot
- UT: Demo project

2017
- MA: 200 MW target
- MA: $20m demo fund
- NV: Target legislation, incentives, storage as a right
- NY: Target legislation
- WA: Policy statement
- NM: IRP rule
- AZ: $2m BTM pilot
- MD: Tax credit
- VT: Study, demo fund

2018
- FERC: Order 841
- MA: 1,000 MWh target, planning requirements
- NJ: 2,000 MW target
- NY: 1,500 MW incremental target
- CA: Planning requirements
- CO: Storage as a right
- VA: Planning requirements, demo projects

2019
- OR: Solar + storage rebates
- MA: Storage in public retrofits requirements
- NY: Resilience incentives
- CO: Storage in dist. plans
- MD: Ownership pilot program
- SC: Storage in net metering
- NH: Property tax exemptions
- MN: Storage in IRPs; storage study; pilots
- DE: Storage in cooperatives
- MT: Storage in net metering
- NC: End of life management
- ME: Storage study; non-wires coordinator
- MO: Storage in IRPs

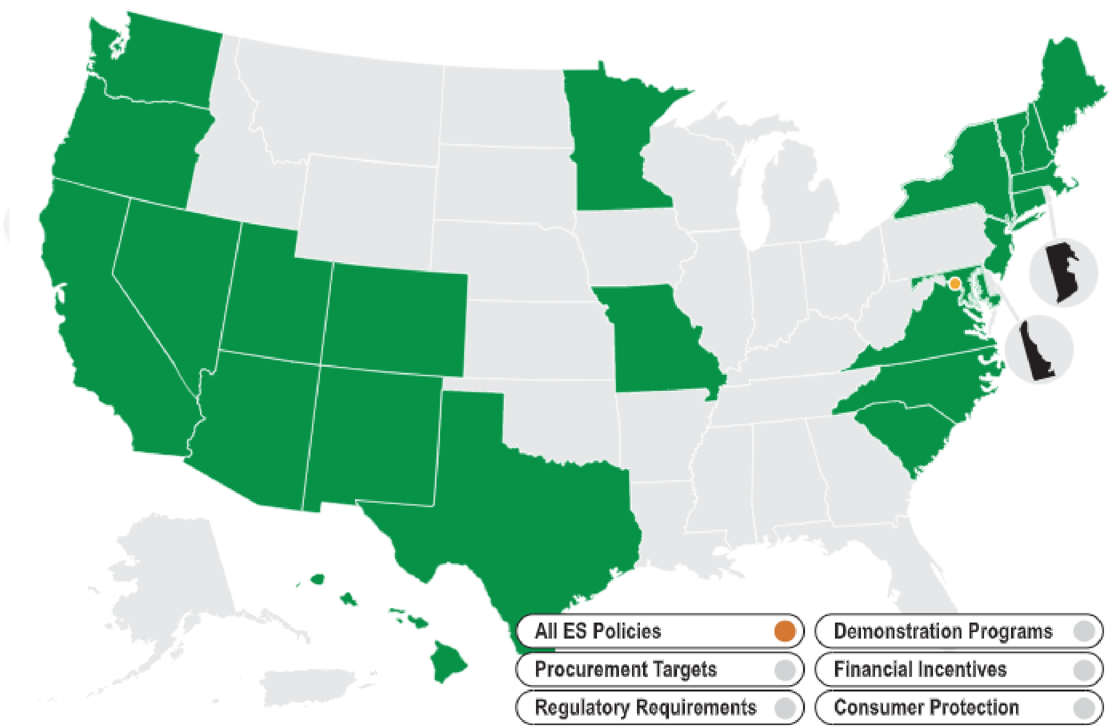
2020
- Federal: BEST Act
- VA: 3,100 MW target; plan requirements
- AZ: 5% of 2035 peak target; aggregation; res. pilot
- MA: Clean peak implemented
- NM: Grid modernization
- WA: Storage in PACE
- PR: Storage for backup power
- OR: Resolution on long-term storage
- MD: Storage as economic dev.
- CA: Storage for local RA and equity
- CT: Storage interconnection
- NH: Storage for T&D avoidance
- RI: Tax credit for solar+storage

Report on energy storage policy types available at
https://link.springer.com/article/10.1007/s40518-019-00128-1

Energy Storage Policy Database

In recent years, several states have begun to identify and address barriers to energy storage. PNNL tracks these policies in an interactive database available at https://energystorage.pnnl.gov/regulatoryactivities.asp.

Energy Storage Policy Database



The policy database tracks five types of state-level energy storage policies:

- Procurement targets
- Regulatory adaptation
- Demonstration programs
- Financial incentives
- Consumer protection

Arizona: A procurement target is much more than a number.

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Target:

- Under the state constitution, the Arizona Corporation Commission has broad authority over state energy policy.
- A majority (4-1) of commissioners supported a storage target of 5% of 2035 peak load in November 2020, as part of a vote to decarbonize the Arizona grid by 2050.
- The proposal is now subject to a formal rulemaking proceeding.

Additional steps in place:

- **Commercial incentives**: $2 million for commercial behind-the-meter (BTM) storage projects (rate case settlement)
- **Residential incentives:** APS pilot incentive program for residential energy storage
- **Storage aggregation:** In Dec. 2020, the ACC ordered APS to develop a tariff to permit third-party aggregation of distributed demand-side resources, including storage, and provide compensation for multiple values. The tariff is under development (Docket E-01345A-19-0148).

Additional steps proposed:

- **Target disaggregation:** The proposed target would require 40% of the storage to be customer-owned or customer-leased.
- **Decarbonization link:** Proposed reporting requirements would include documentation of the charging energy for storage.
- **Planning reforms:** The proposal would provide more transparency in load forecasting and identifying resource needs.
- **Procurement reforms:** All-source RFIs would be required to inform planning assumptions.

Washington: Low-cost BTM storage financing through PACE mechanism

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Property-Assessed Clean Energy (PACE) programs:

- Allow property owners to finance clean energy investments on their property tax bills, secured by a county lien
- Enable long-term, low-cost financing of capital projects that might otherwise be cost-prohibitive
- For commercial or residential properties, or both (see *Lessons in Commercial PACE Leadership: The Path from Legislation to Launch*; *Assessing the PACE of California residential solar deployment*)
- Require state legislation and local action

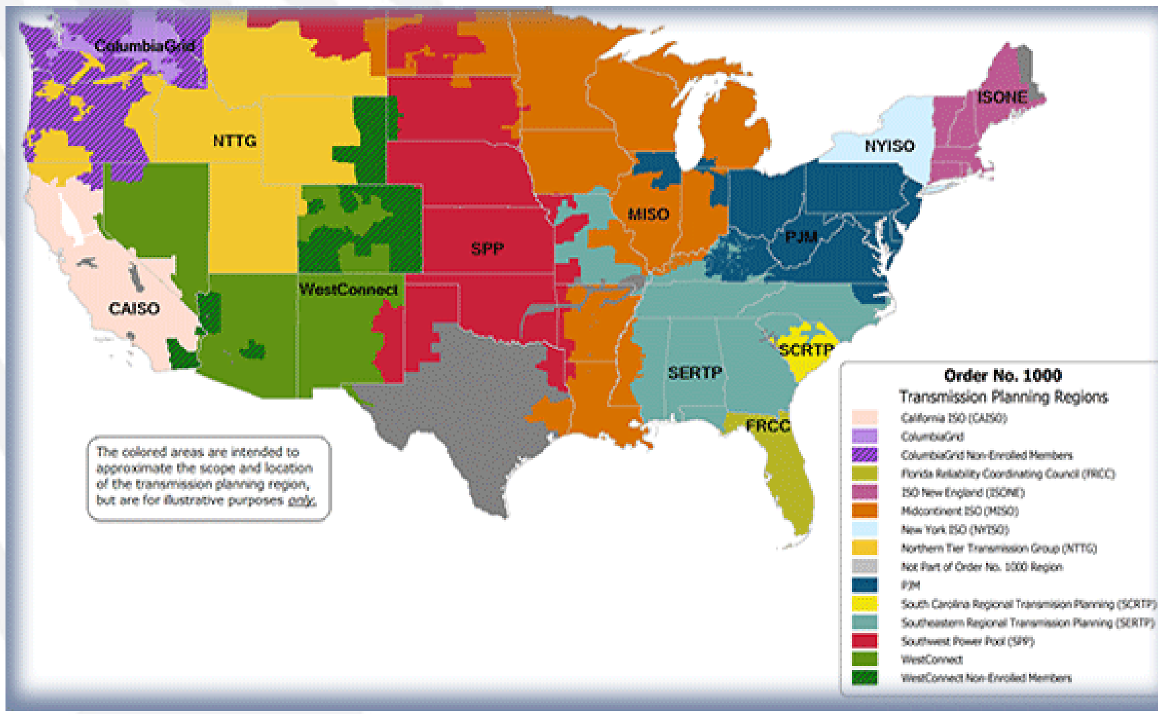
Washington created a statewide Commercial Property-Assessed Clean Energy and Resilience (C-PACER) program in 2020 that counties can voluntarily join.

- Open to all agricultural, industrial, commercial, and multifamily residential facility owners
- Unique focus on resilience investments supports investments in a broader array of technologies and facility retrofits; in addition to energy efficiency and distributed generation, it includes energy storage, microgrids, seismic retrofits, floodwater management, and wildfire resistance.
- Includes greenhouse gas reductions as a prescribed metric for project evaluations
- Allows counties to contract with public or private entities for program management

California: Storage in Regional Transmission Planning

Background:

- [FERC Order 1000](#) (2011) requires utilities with interstate transmission systems to participate in coordinated regional transmission planning processes (note: this applies to vertically integrated utilities as well)
- Order 1000 also requires transmission planners to consider non-transmission alternatives at the request of stakeholders
- Recognizing the multi-faceted capabilities of energy storage, FERC issued a policy statement in 2017 encouraging the deployment of energy storage as a dual-use (transmission and generation) asset



California: Storage in Regional Transmission Planning

- **The California Independent System Operator (CAISO) became the first region to identify storage in a regional transmission plan, identifying two projects (one as transmission, one in place of transmission) in its 2018 plan.**
- **Storage as Transmission: Dinuba, CA**
  - 2010 Plan: A potential contingency scenario that would overload the local transmission system would require $16M to reconductor for 10 miles.
  - 2018 Plan: Overloads could be managed by an energy storage system at an estimated cost of $14M.
- **As a transmission asset, the storage system's costs will be recovered through CAISO's FERC-approved transmission system rates, and it will not participate in energy markets.**

Storage in Microgrids

Storage and Microgrids: A New Resilience Paradigm

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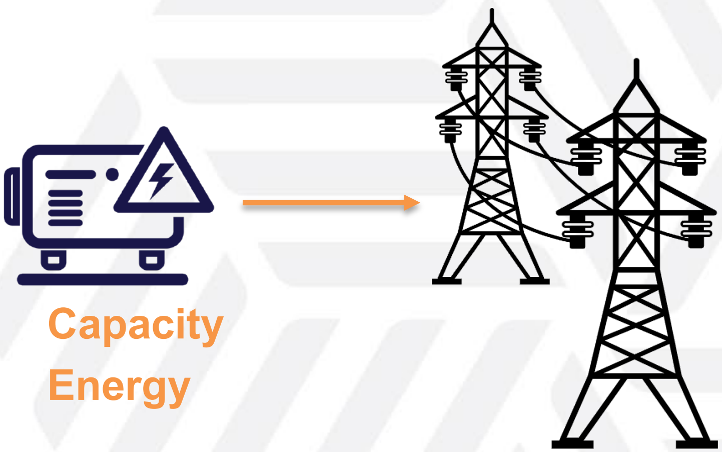
The advent of cost-competitive energy storage options has enabled us to go from:

Mission-critical Resilience

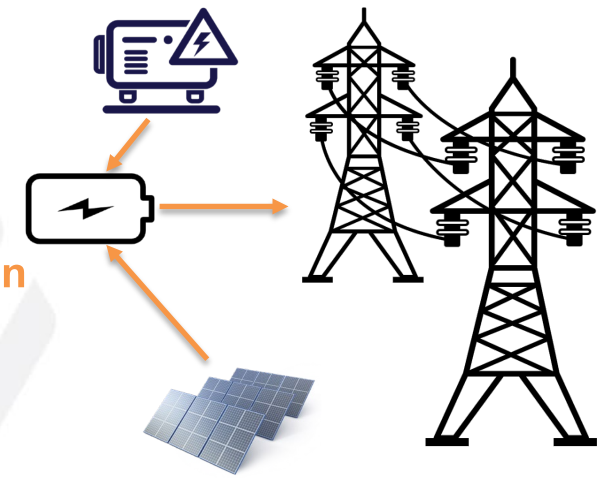


- **Capacity**
- **Energy**

to

Economic Resilience

- **Capacity**
- **Energy**
- **Regulation**
- **Reserves**
- **Arbitrage**
- **…**



Mission-critical Resilience:

- Limited opportunities for grid participation
- High cost
- Limited to facilities in which resilience is mission critical

Economic Resilience:

- Increased opportunities for grid participation
- Offsetting revenues reduce system costs
- Viable resilience for broader range of facilities

Questions States Can Ask

- Are planning tools accounting for the granular values and operational characteristics of energy storage technologies?
- Are tariffs and rates in place to incent customers who deploy storage and other distributed energy resources to use those assets in a way that benefits the grid and reduces system costs?
- Can tariffs be used to incent development and grid-beneficial use of microgrids?
- What plans are in place for end-of-life disposal of battery assets?
- Absent resilience metrics, how can planning processes be adapted to meet resilience goals in a cost-effective manner?
- Are there opportunities for furthering state goals through increased engagement in regional planning processes?

Resources for More Information

- Y Xu, CC Liu, KP Schneider, FK Tuffner, DT Ton, Microgrids for Service Restoration to Critical Load in a Resilient Distribution System
- Schneider et al., Preliminary Design Process for Networked Microgrids
- M Armendariz et al., Coordinated Microgrid Investment and Planning Processes Considering the System Operator
- JB Twitchell, RS O'Neil, MT McDonnell, Planning Considerations for Energy Storage in Resilience Applications
- B Ward et al., The Advanced Microgrid: Integration and Operability
- Schwartz, Lisa C, and Greg Leventis. *Grid-Interactive Efficient Buildings: An Introduction for State and Local Governments*
- Eckman, Tom, Lisa C Schwartz, and Greg Leventis. *Determining Utility System Value of Demand Flexibility From Grid-interactive Efficient Buildings*
- Schiller, Steven R, Lisa C Schwartz, and Sean Murphy. *Performance Assessments of Demand Flexibility from Grid-Interactive Efficient Buildings: Issues and Considerations*

- PNNL energy storage site: https://www.pnnl.gov/energy-storage
- Sandia National Laboratories energy storage site: https://www.sandia.gov/ess-ssl/
- LBNL Electricity Markets & Policy Department: https://emp.lbl.gov/

Questions?

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