Long-Duration Energy Storage as a Decarbonization Enabler

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Executive summary

- Long-duration energy storage (LDES) will become increasingly important as energy systems decarbonize
- The duty cycle and markets for LDES systems will be different than storage today
- Technologies with cost and performance different than lithium-ion are needed
Storage applications today

Examples of other applications:

- Frequency regulation
- Flexible ramping
- Power quality
- Distribution upgrade deferral
- Demand charge management

CODA Energy
LDES value unlocked at high VRE deployment levels

Firming Output of Variable Renewables

10-100 hours of discharge at 5 ¢/kWh-cycle

Ensuring System Resiliency
TECHNOLOGY-TO-MARKET
Higher VRE levels = longer storage durations

See also: M.S. Ziegler, et al., Joule 3, 2134-2153 (2019)

P. Albertus, J.S. Manser, S. Litzelman, Joule 4, 1-12 (2020)
Understanding LDES value: stakeholder outreach

Financial Partners
- ANZU PARTNERS
- Munich RE
- GENERATE CAPITAL
- Schlumberger
- evok INNOVATIONS
- VOLTA ENERGY TECHNOLOGIES
- Breakthrough Energy
- CONGRUENT VENTURES
- Shell

OEMs
- SIEMENS
- MITSUBISHI POWER
- GENERAC
- Solar Turbines

Trade Groups
- CESA
- ESA
- Energy Storage Association
- NRECA
- EPRI

Market Researchers
- luxresearch
- NREL

Energy Buyers
- SKYALAR ENERGY
- PENINSULA CLEAN ENERGY
- EAST BAY COMMUNITY ENERGY
- Google

Utilities
- conEdison
- enel
- PG&E
- Southern Company
- Xcel Energy
- Exelon

Public Partners
- THE WORLD BANK
- NEW YORK STATE OF OPPORTUNITY
- NYSERDA
- MASSACHUSETTS CLEAN ENERGY CENTER
- ESTCP

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Assessing system value, especially capacity

Factors comprising system value of 4-hour storage in the Northeast U.S. under different renewable and storage penetration levels

D.S. Mallapragada, N.A. Sepulveda, J.D. Jenkins, Applied Energy 275, 115390 (2020)

Recent capacity substitution examples

Oakland to Swap Jet-Fuel-Burning Peaker Plant for Urban Battery

The deal with Vistra will be the largest standalone storage facility contracted for a community-choice aggregator in California.

California Community Choice groups seek up to 500MW of long-duration energy storage

8-16 hours duration, in service by 2026

Peaker plant in Oakland replaced with 20 MW / 80 MWh of lithium-ion storage

https://www.greentechmedia.com/articles/read/oakland-to-swap-jet-fueled-peaker-plant-for-urban-battery
Another value: risk mitigation

- Power purchase agreements have risks
  - Resource variability
  - Demand uncertainty
  - Price volatility

- LDES reduces different types of exposure
  - Basis risk (price spread)
  - Volume risk (forecasted v. actual production)
  - Shape risk (output vs. user’s load shape)

vPPAs for wind farms in SPP, based on 2 years of data and optimized day-ahead and real-time bids

<table>
<thead>
<tr>
<th>Wind Farm</th>
<th>Storage technology</th>
<th>Optimal Duration (hrs)</th>
<th>Optimal Power (MW)</th>
<th>Mean virtual PPA NPV (MM USD)</th>
<th>Worst Case NPV (MM USD)</th>
<th>Downside risk</th>
<th>Downside risk variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Storage</td>
<td>N/A</td>
<td>N/A</td>
<td>18.6</td>
<td>9.2</td>
<td>51%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Pumped Hydro</td>
<td>13</td>
<td>36</td>
<td>19.2 (+3%)</td>
<td>9.7</td>
<td>49%</td>
<td>-2%</td>
</tr>
<tr>
<td>2</td>
<td>No Storage</td>
<td>N/A</td>
<td>N/A</td>
<td>16.9</td>
<td>8.2</td>
<td>51%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Pumped Hydro</td>
<td>17</td>
<td>108</td>
<td>19.0 (+12%)</td>
<td>10.2</td>
<td>46%</td>
<td>-6%</td>
</tr>
<tr>
<td>3</td>
<td>No Storage</td>
<td>N/A</td>
<td>N/A</td>
<td>13.9</td>
<td>6.1</td>
<td>56%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Pumped Hydro</td>
<td>23</td>
<td>106</td>
<td>20.7 (+49%)</td>
<td>11.1</td>
<td>46%</td>
<td>-10%</td>
</tr>
</tbody>
</table>
Other LDES pathways to market

- Self-consumption maximization for behind-the-meter generation\(^1\)
- Clean backup power for critical loads\(^2,3\)
- T&D congestion relief for load pockets\(^4\)
- Interconnection maximization for developers\(^5\)

\(^1\)https://blog.aurorasolar.com/how-net-metering-is-evolving-three-changes-you-need-to-know
\(^4\)https://www.greentechmedia.com/articles/read/oakland-to-swap-jet-fueled-peaker-plant-for-urban-battery
TECHNOLOGY SOLUTIONS
Desired technology cost structure

### Assumptions
- $0.05/kWh differential per cycle
- Certain duty cycle
- $25/kW-yr capacity payment

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DAYS: pumped hydro-like costs but sited anywhere

![Graph showing the relationship between lifetime cost ($/kWh) and duration at rated power (h) for various energy storage systems. Current commercial installations have a higher cost (1 to 6 h, 350 to 1000 $/kWh). Future Li-ion and DAYS Target systems show lower costs with increased duration.](image-url)
The DAYS portfolio

Thermal energy storage

Thermophotovoltaic (TPV) storage

Geomechanical storage

Pumped heat energy storage (PHES)

Electrochemical storage
The DAYS portfolio

Thermal energy storage

[Logos: Michigan State University, NREL]

Pumped heat energy storage (PHES)

[Logos: Quidnet Energy, Echogen Power Systems, SwRI, Brayton Energy LLC]

Geomechanical storage

[Logos: Antora Energy, MIT, Columbia University, Form Energy, Raytheon Technologies, The University of Tennessee, Knoxville]

Thermophotovoltaic (TPV) storage

Electrochemical storage

[Logos: MIT, Columbia University, Form Energy, Raytheon Technologies, The University of Tennessee, Knoxville]
Example: Columbia U. / Primus Power / ICL-Americas

**Battery made of ZnBr₂, carbon, and cheap plastics**

- **Targets**
  - $0.05/kWh for 10-20 hour duration
  - 20 year materials specification
  - Minimal to no cooling required

- **Commercialization path**
  - Transition from bench-scale at Columbia to ICL-America in Tarrytown, NY (world’s largest producer of ZnBr₂ and halide flame retardants)
  - Develop low-cost, passive containment system

<table>
<thead>
<tr>
<th>Metric</th>
<th>Before ARPA-E</th>
<th>Current</th>
<th>Target</th>
</tr>
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<tbody>
<tr>
<td>Cell BOM</td>
<td>$120/kWh</td>
<td>$70/kWh</td>
<td>$25/kWh</td>
</tr>
<tr>
<td>Energy Density</td>
<td>8 Wh/L</td>
<td>60 Wh/L</td>
<td>120 Wh/L</td>
</tr>
<tr>
<td>RTE</td>
<td>60%</td>
<td>68%</td>
<td>75%</td>
</tr>
<tr>
<td>Self Discharge</td>
<td>20% / day</td>
<td>10% / day</td>
<td>5% / day</td>
</tr>
<tr>
<td>Cell Size</td>
<td>50 mWh</td>
<td>20 Whr</td>
<td>200 Wh</td>
</tr>
</tbody>
</table>
Example: Quidnet Energy

**Modular, long-duration storage**
1-10 MW per well, 10+ hours

**Structural cost position**
<50% capex of battery & pumped hydro, <$10 per marginal kWh

**Broad geological footprint**
100+ TWh across multiple US basins

**Mature execution supply chain**

1. **Charge.** Water pumped down the well into high-pressure storage lens
2. **Discharge.** High-pressure water flows up the well to drive a turbine
Quidnet’s progress in upstate NY

Current focus: exploration well to characterize resource

Next: Calibrate storage lens hydraulics with <100kW flow in and out; Develop 2MW field demonstration site

Regulatory engagement:
Well permit granted from EPA & NY State Dept. of Environmental Conservation

*Joint DOE-NYSERDA funding for test well

Generation-1 resource estimate: 6 TWh mapped (600 GW at 10 hours)
Summary

- LDES assists in decarbonization

- The ARPA-E DAYS program and others (see right) are developing technologies to do this

- LDES value proposition—such as capacity and risk mitigation—is different than lithium-ion today

- There are entry markets

- But also need policies to monetize these value streams (not ARPA-E’s mission!)