BRIEF OVERVIEW: NEXT GENERATION, LARGE-SCALE ENERGY STORAGE TECHNOLOGIES

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Will McNamara

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Definitions

- **Next Generation Large Scale Energy Storage (a/k/a "Long Duration Energy Storage")** is not a singular concept but in fact refers to a diverse technology class with a range of potential system types.

- These technology types typically classified under four technology categories or "families": electrochemical, mechanical, chemical, and thermal energy storage technologies.

- Within these categories are literally hundreds of technologies in varying levels of development and deployment, from early-stage research and development to a comparatively mature level of market readiness (i.e., commercialization).

- Perhaps the simplest way to consider these technologies is the minimum benchmark of 10 hours + in duration (DOE definition).

- Increasingly, distinctions based on durations have emerged to designate:
  - ✓ "Diurnal (or intra-day)" referring to 10 hours up to 20 hours, which may be primarily used to reconcile daily cycles of generation surpluses and deficits with services such as peak-shifting;
  - ✓ "Seasonal," referring to those technologies with ability to provide 20 hours + duration, particularly in the 100 hour + range.

Overview

Electrochemical	*Battery systems that can store electricity through electrochemical reactions.*	*Types:* Lithium-ion, redox flow, metal anode (e.g., Zn-air, Fe-air, Al-air, Zn-Br, molten Na, liquid metal, metal-H2, Pb-acid, etc.) *Duration:* Hours to days
Mechanical	*Systems that store potential energy through physical forces, using compressors, turbines, & other machinery.*	*Types:* Pumped hydro, compressed air, liquid air, gravity *Duration:* Hours to days
Thermal	*Systems that store thermal energy (through heat or cold) that can be output as heat or regenerated electricity.*	*Types:* Sensible heat, latent heat, thermo-chemical *Duration:* Hours to days
Chemical	*Storage in high energy-density chemicals that can be accessed as fuels.*	*Types:* Hydrogen, ammonia, hydrocarbons, alcohol *Duration:* Seasonal

Historical Context

- Applications of pumped storage hydropower (PSH) and compressed air energy storage (CAES) have been used at scales suitable for LDES for decades, and are vital in their unique application spaces.

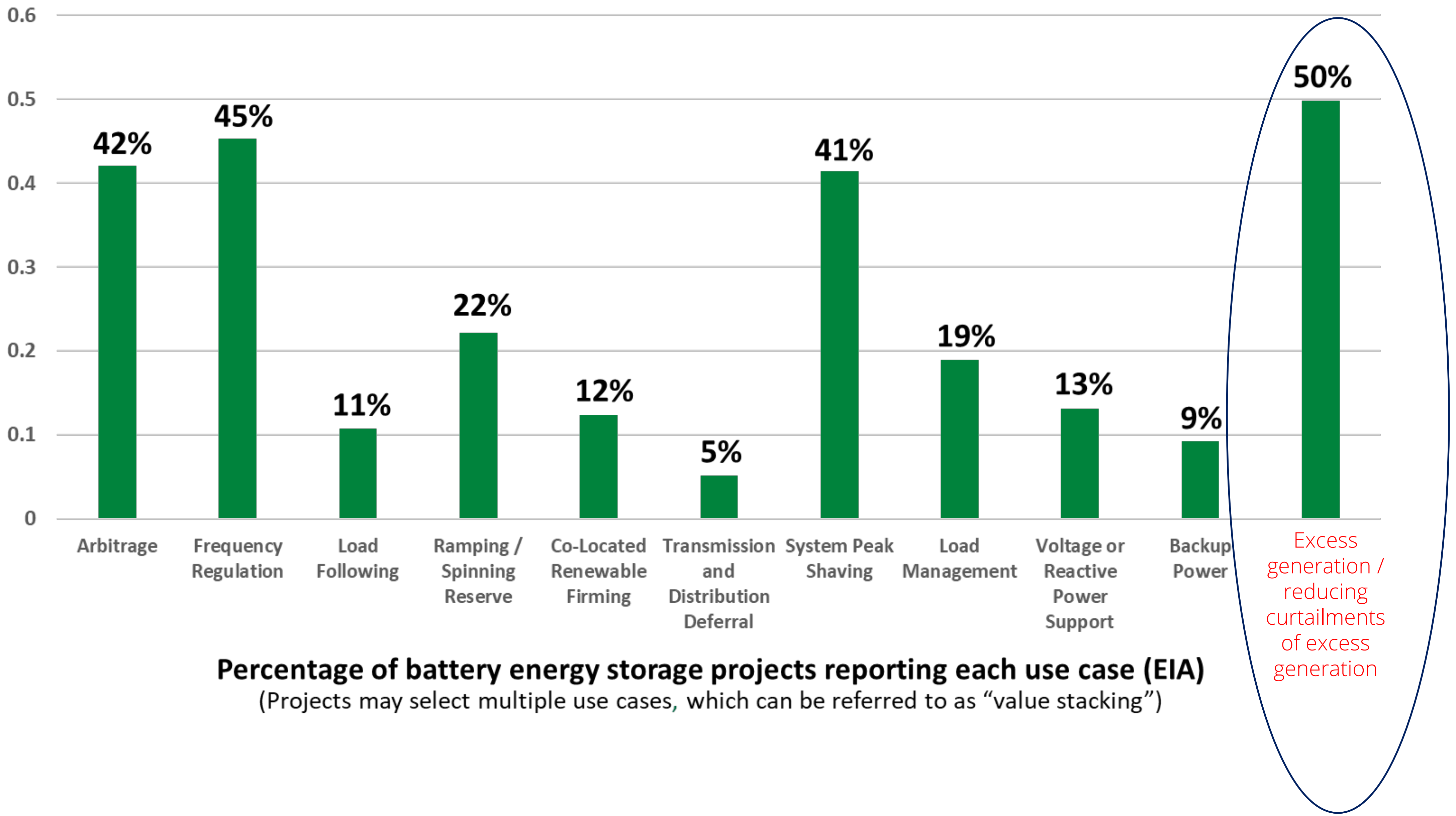
- The new emerging technologies stand to expand this precedent with greater versatility and flexibility to meet the evolving, as-yet-unknown challenges of the grid.

- Emerging technologies run the range of market readiness from R&D to pilot projects to fully commercialized.

- The scale and diversity of these technologies is a distinct advantage for the future needs of the grid:

    - Different technologies serving different customers in different locations through different applications.

How is energy storage is being used?



Percentage of battery energy storage projects reporting each use case (EIA)
(Projects may select multiple use cases, which can be referred to as "value stacking")

Emerging Use Cases

- As noted, there is increasing emphasis on developing projects that demonstrate the capability of these technologies to support high-priority use case applications identified by the DOE.
- Guiding Principles articulated by Secretary of Energy Chris Wright in "Unleashing the Golden Era of American Energy Dominance" Secretarial Order (February 5, 2025).

Energy Addition, Not Subtraction	Unleash American Energy Innovation	Unleash Commercial Nuclear Power	Strengthen Grid Reliability and Security	Streamline Permitting
Enabling the integration of more energy sources into the grid without requiring the removal of existing power plants.	Bolstering America's manufacturing competitiveness and supply chain security.	Enabling nuclear power plants to operate more flexibly, allowing them to adjust their output based on grid demands, potentially increasing their overall value to the grid.	Directly supporting grid reliability and security through storing excess electricity low-demand periods and releasing it during peak demand periods (balancing supply and demand, mitigating blackouts, and ensuring a consistent energy supply even during disruptions or extreme weather events).	Due to critical grid benefits, these technologies warrant faster review processes and less complex permitting requirements, ultimately accelerating project deployment.

Use Case Examples

- ***Reducing curtailment of excess generation:*** California Energy Commission (CEC) study (prepared by E3 and Form Energy) concluded that curtailment are positively impacted by increasing LDES deployment in each modeled year, particularly through multi-day LDES. https://www.energy.ca.gov/sites/default/files/2024-01/CEC-500-2024-003.pdf

- ***Nuclear integration:*** 1) Consumer Energy's **LUDINGTON PUMPED HYDRO STORAGE FACILITY** in Michigan is one of the longest-standing examples of nuclear integration with energy storage as it has an expressed operational objective to help baseload sources in Michigan (where nuclear energy comprises about 21 percent of the state's portfolio) to run efficiently during off-peak hours and make the electricity more dispatchable https://www.consumersenergy.com/about-us/electric-generation/renewables/hydroelectric/pumped-storage-hydro-electricity; and 2) **TERRAPOWER's** project in Wyoming is an example of pairing thermal energy storage example is TerraPower's Natrium nuclear reactor, which would couple molten salt energy storage with a nuclear power plant. https://www.terrapower.com/natrium/

- ***Resilience & Reliability:*** 1) **PACIFIC GAS & ELECTRIC** using iron-air energy storage system to support grid reliability and resilience by supplying up to an unprecedented 100 hours of continuous power during extreme weather conditions and grid outages. https://formenergy.com/form-energy-awarded-30m-grant-from-the-california-energy-commission-to-deploy-first-multi-day-energy-storage-project-in-california/ and 2) **DEPARTMENT OF DEFENSE** planning to build zinc-hybrid LDES system at Camp Pendleton, providing Marine Corps Base with back-up power for up to 14 days https://www.energy.ca.gov/news/2024-12/cec-awards-42-million-grant-long-duration-energy-storage-project-camp-pendleton

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Will McNamara
jwmcnam@sandia.gov
505-206-7156