Grid-Scale Energy Storage

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NPRE 498: Energy Storage Systems

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About Myself

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- Power and Energy Systems Group
  - Advisor: Thomas J. Overbye
- Research Area
  - Modeling of Equivalent Systems to Preserve Transient Characteristics of Large-Scale Power Systems

GCEP
Global Climate & Energy Project
STANFORD UNIVERSITY

TCIPG

NSF

Outline

1. Goals
2. Renewable Energy Sources
3. Effects of Intermittent Renewables and Storage
4. Energy Storage Devices
5. Summary

Goals

- Survey renewable energy sources, recent progress, associated problem areas, and grid interfacing
- Understand system level effects of intermittent renewables and energy storage
  - Motivate the necessity of storage in integration of intermittent renewables with the grid
- Survey grid-scale storage technologies
- Evaluate possible solutions

Forms of Renewable Energy

- Wind

- Hydro

- Biofuel

- Solar

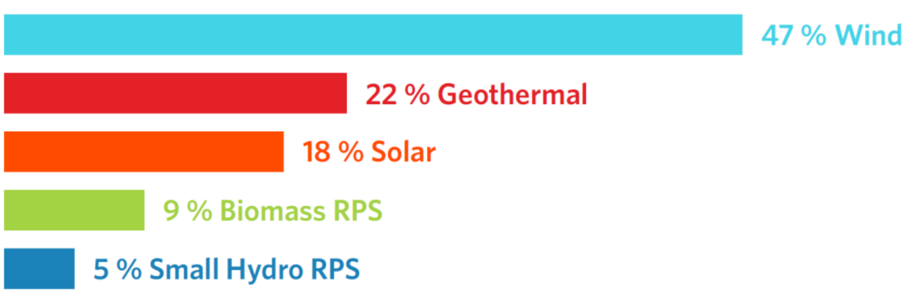
- Biomass

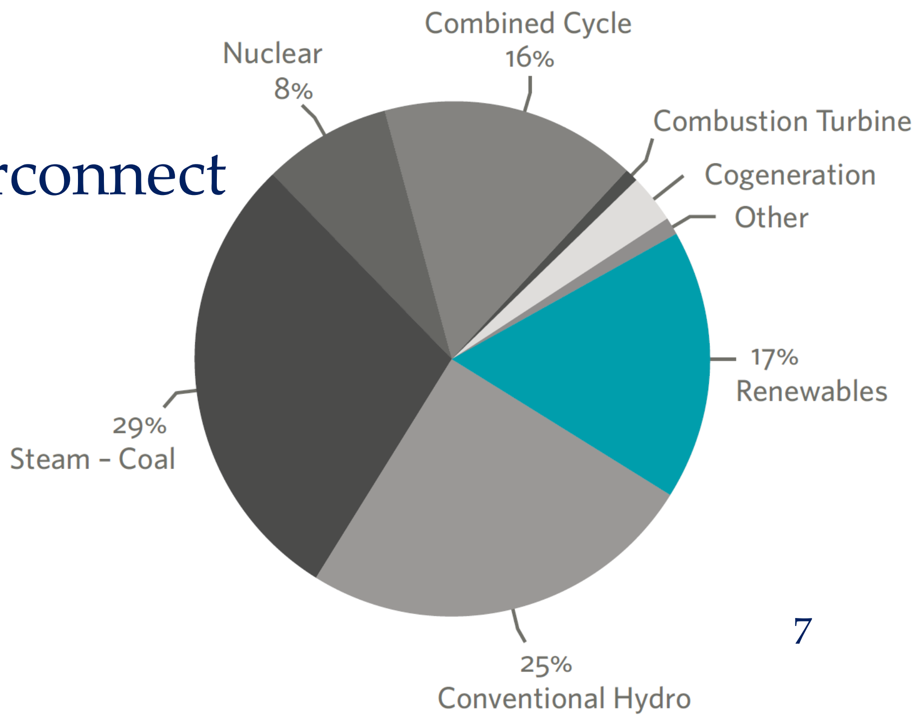
- Geothermal

Renewable Portfolio Standard (RPS)

- A regulation that requires an established level of production or purchase of energy from renewable energy sources, such as wind, solar, biomass & geothermal

- Renewables in Western Interconnect
  - 17% of generation by 2020

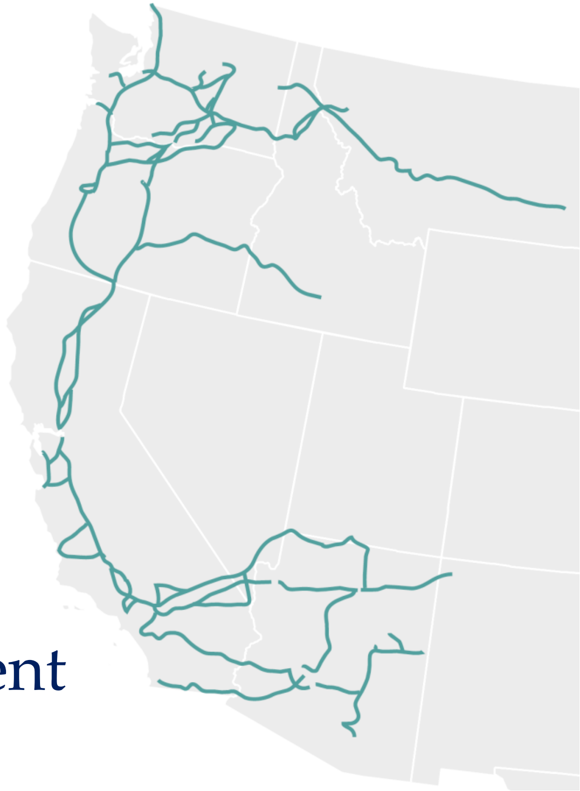




Western Interconnection: Predicted Generation (2010 – 2020)

- Dispatchable generation capacity: small increase

- Renewable generation capacity: increase of 33,000 MW
  - Mainly nondispatchable
  - Will require balancing by conventional sources.



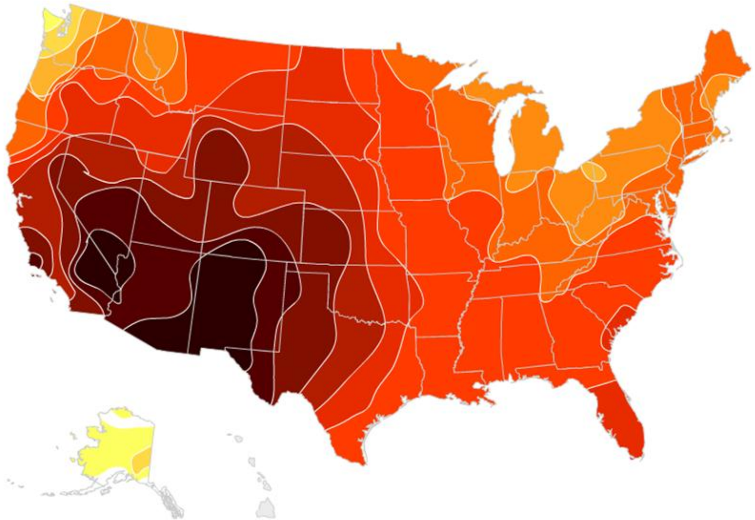
- Grid-scale storage units can essentially be coupled with intermittent sources to create hybrid dispatchable generation

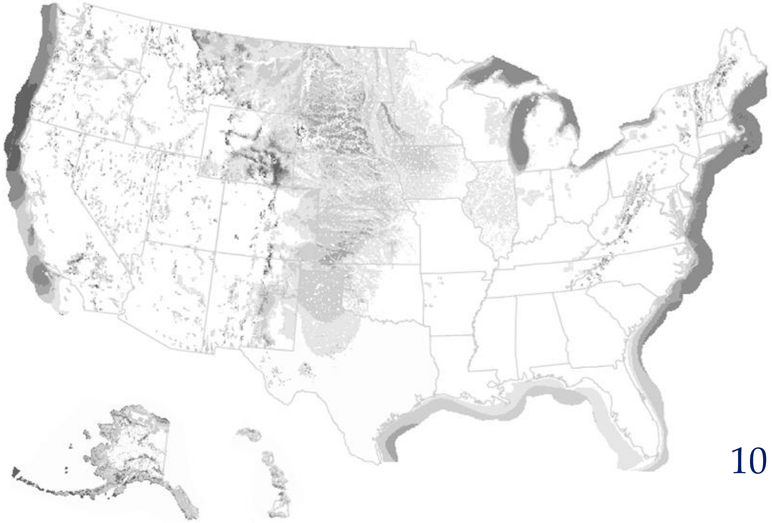
Effect of Intermittent Renewables on the Western Interconnect

WECC Large Generation Drop Simulation Using PowerWorld version 16 (1/3 real-time playback)

Grid Interfacing of Renewables

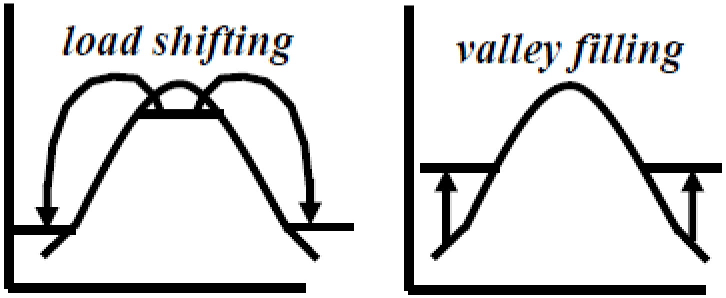
- Good locations are distant from existing transmission networks
  - Solar and wind corridors
- Improper placement of solar/wind farms will most likely affect stability of electric grid
  - Planning studies are essential





Benefits of having Storage Capacity on the Electric Grid

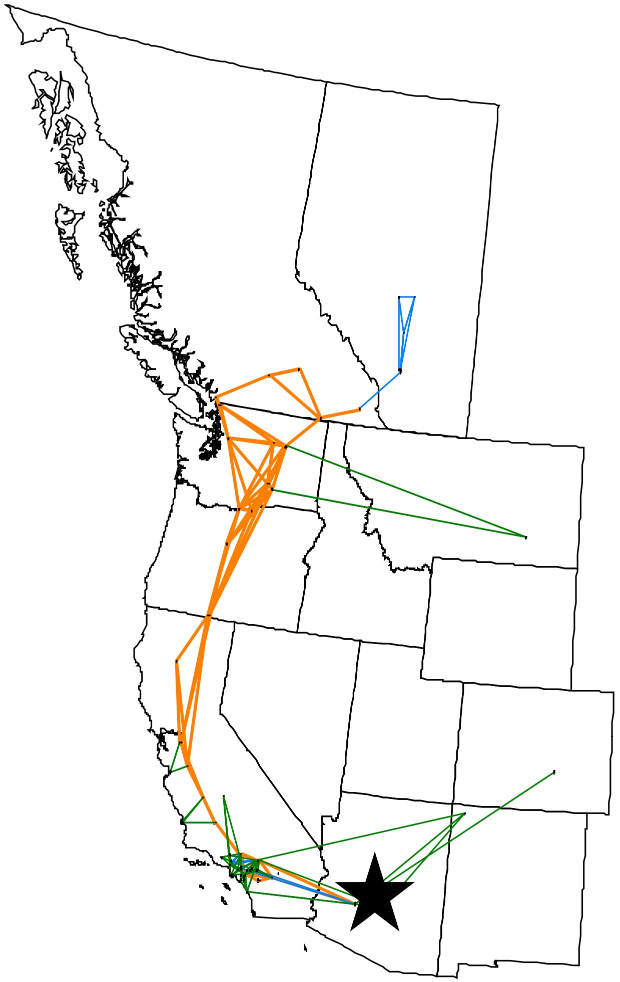
- Mitigate intermittency of renewables
- Possibly eliminate the need for new transmission and distribution lines
  - Better use of existing branches during non-peak conditions



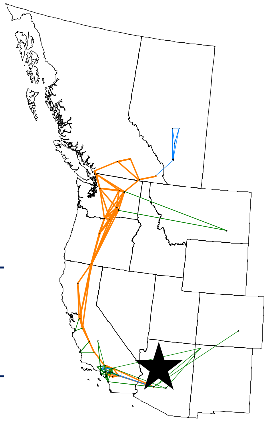
- Provide regulation services
- Quickly deployable, typically in a few quarters
  - Fossil plants take years (almost impossible to site in urban areas)

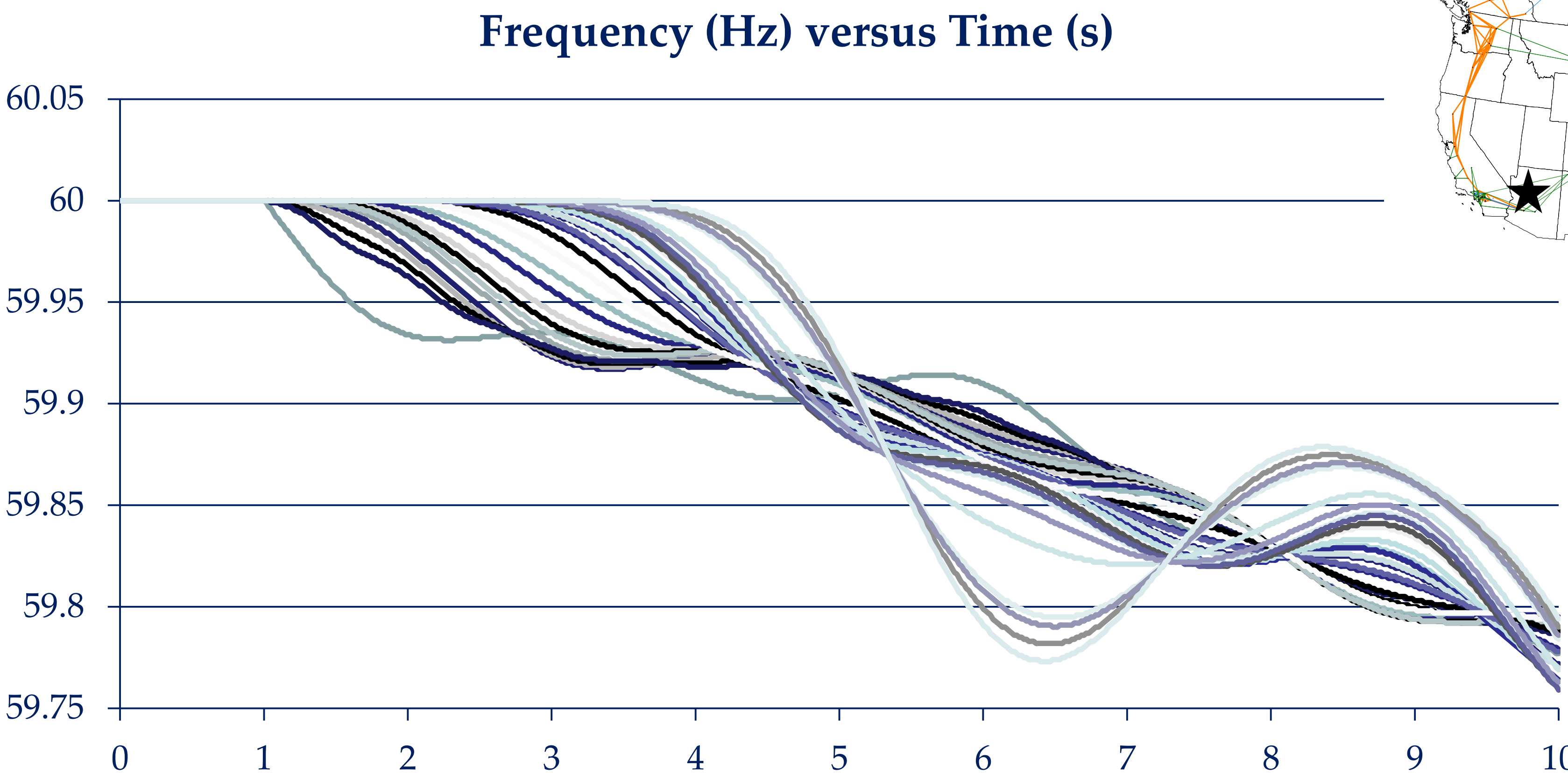
Including Storage while Modeling Generation Intermittency

- Small-scale model of the Western Interconnect
- Model loss in generation at a fictitious wind farm in the southern part of the system
- Evaluate effect and location of storage placement

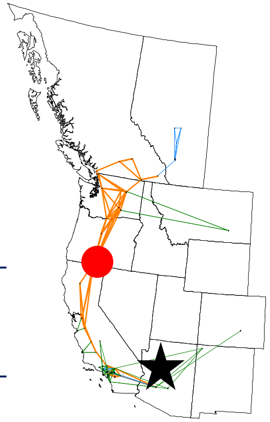


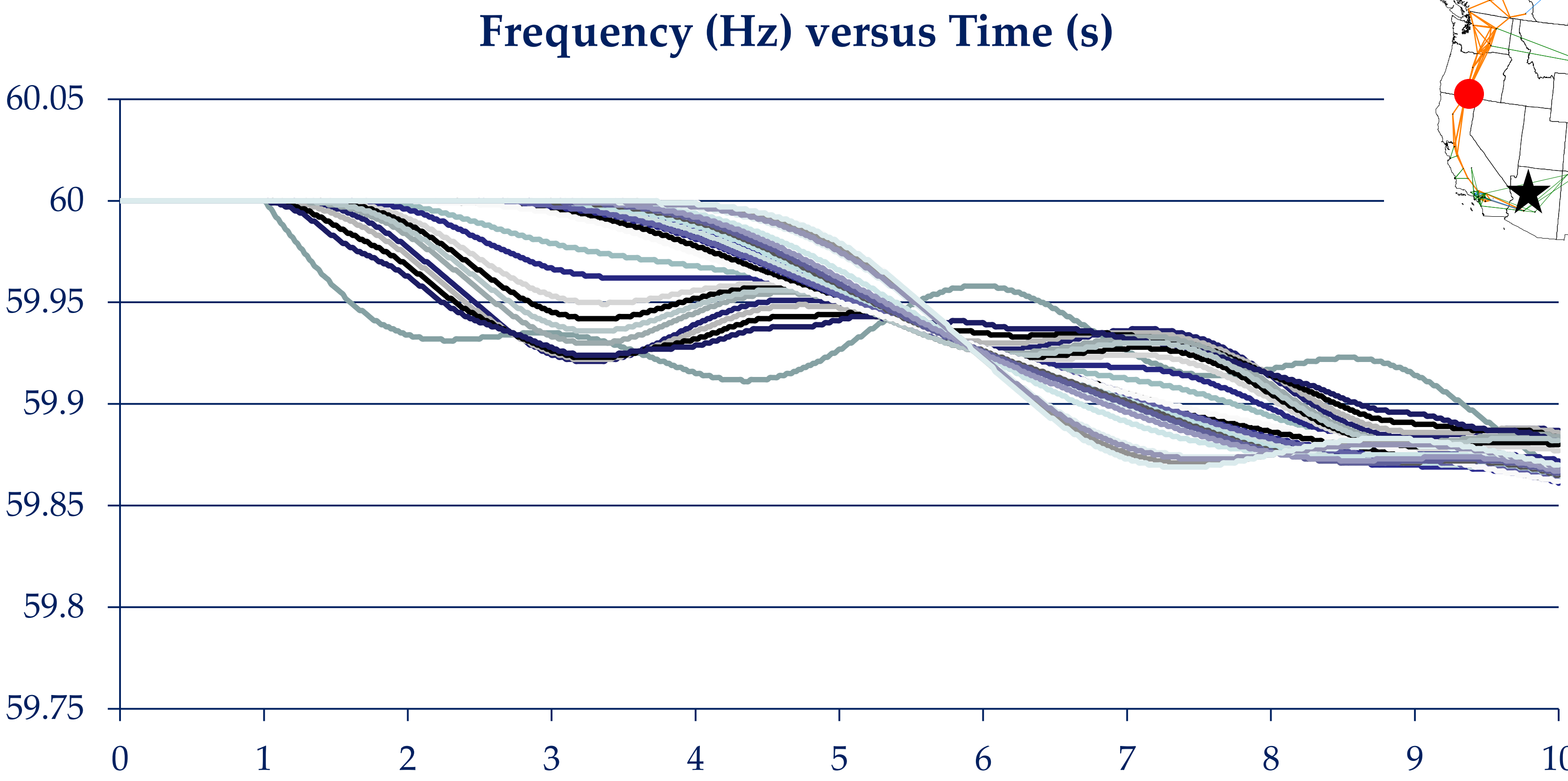
Case 1: No Storage



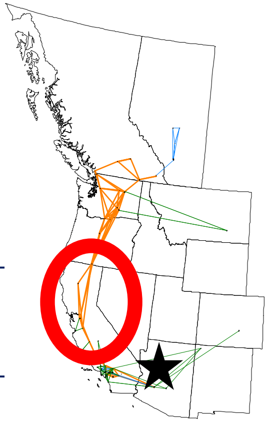


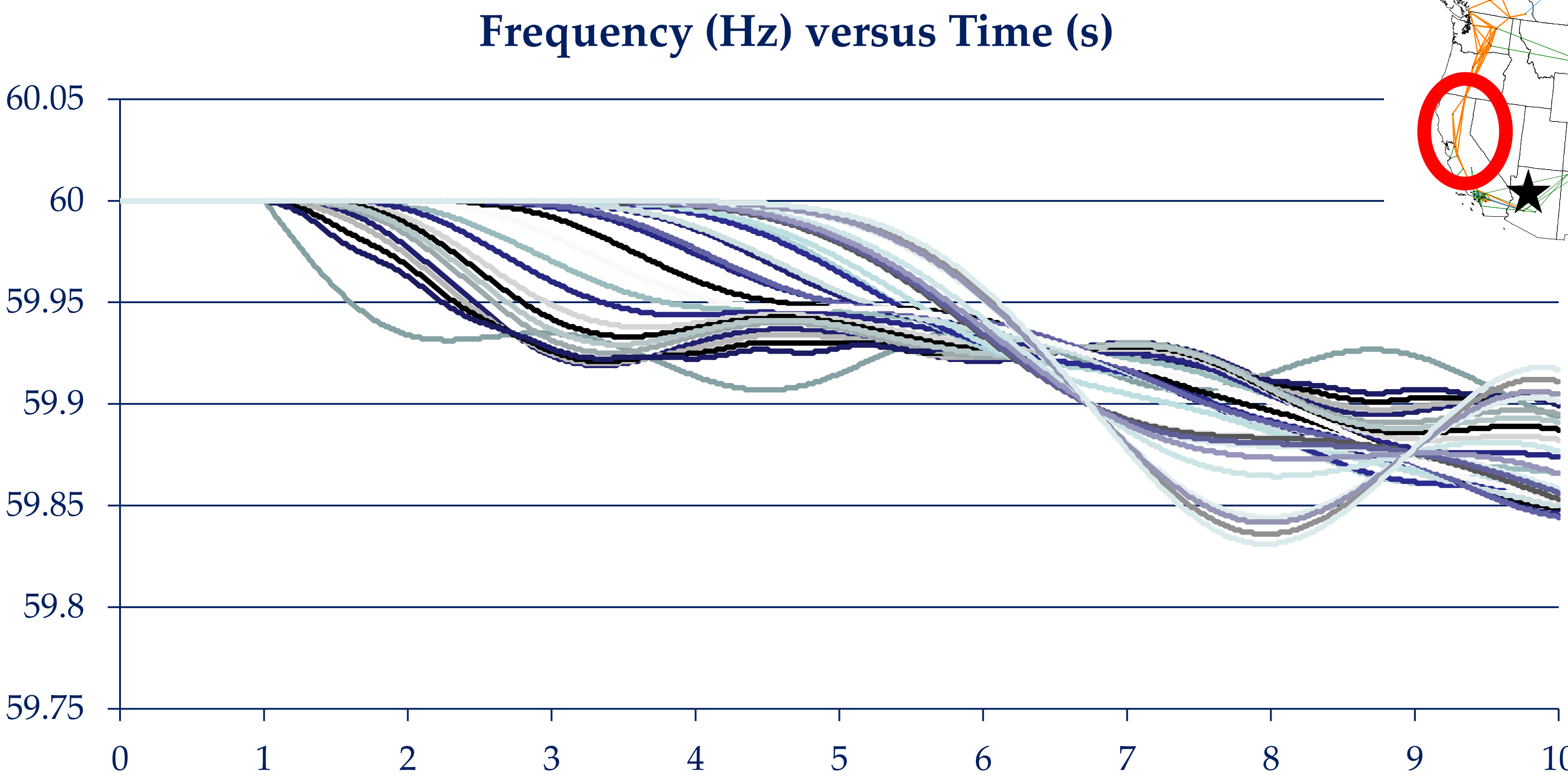
Case 2: 750MWh Storage – 1 Unit At One Location



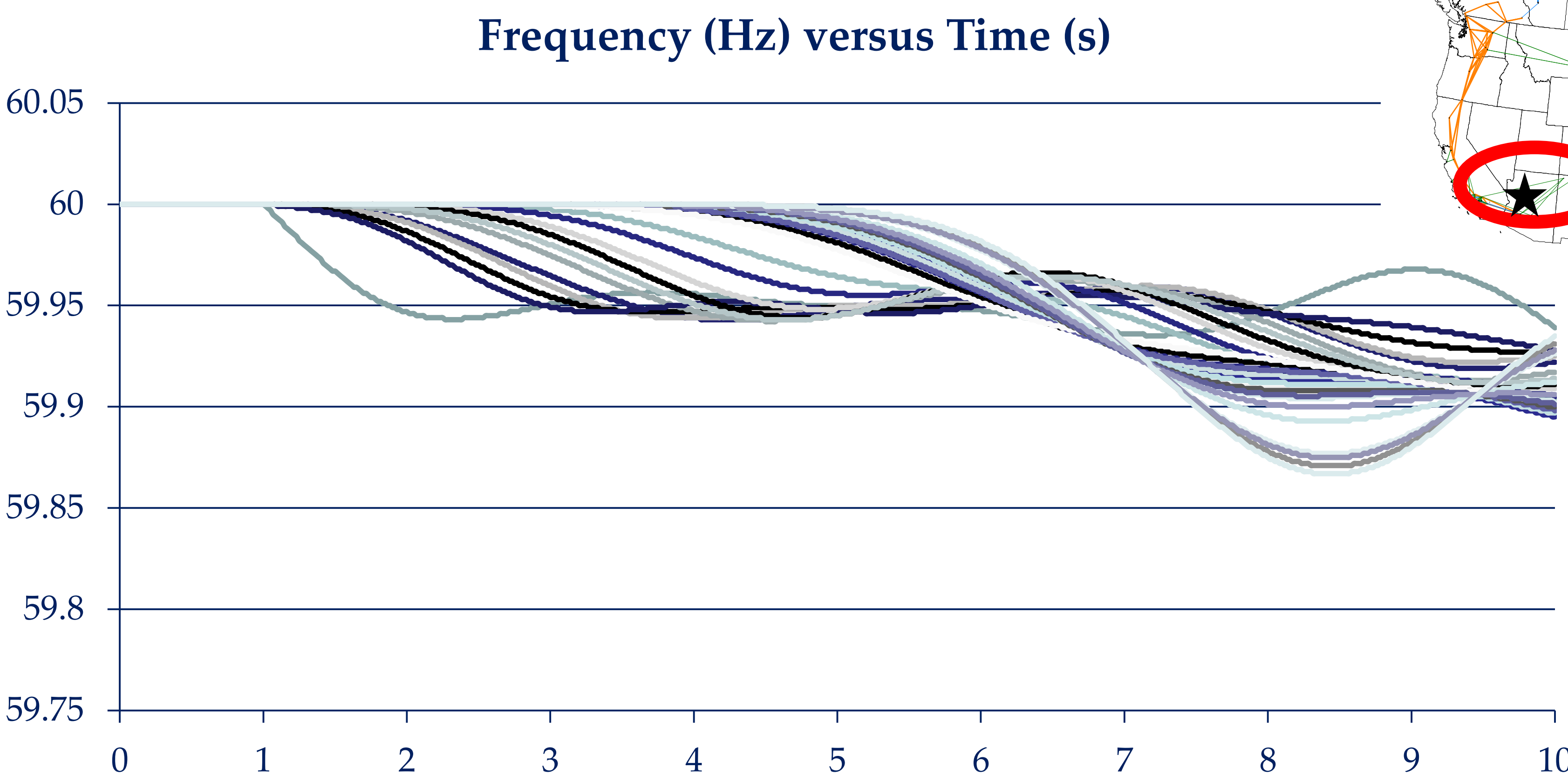


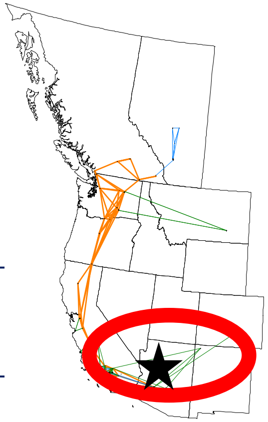
Case 3: 75MWh Storage - 10 Units Around Middle-Region





Case 4: 75MWh Storage - 10 Units Around Southern-Region





Energy Storage Devices

Storage Technology	Main Advantage (Relative)	Disadvantage (Relative)	Power Application	Energy Application
High-speed Flywheels (FW)	High Power	Low Energy Density	●	
Electrochemical Capacitors (EC)	Long Cycle Life	Very Low Energy Density	●	
Traditional Lead Acid (TLA)	Low Capital Cost	Limited Cycle Life	●	○
Advanced LA with Carbon Enhanced Electrodes (ALA-CEE)	Low Capital Cost	Low Energy Density	●	●
Sodium Sulfur (Na/S)	High Power and Energy Density	Cost and Needs to Run at High Temperatures	●	●
Lithium-ion (Li-ion)	High Power and Energy Density	Cost and Increased Control Circuit Needs	●	◐
Zinc Bromine (Zn/Br)	Independent Power and Energy	Medium Energy Density	◐	●
Vanadium Redox (VRB)	Independent Power and Energy	Medium Energy Density	◐	●
Compressed Air Energy Storage (CAES)	High Energy, Low Cost	Special Site Requirements		●
Pumped Hydro (PH)	High Energy, Low Cost	Special Site Requirements		●

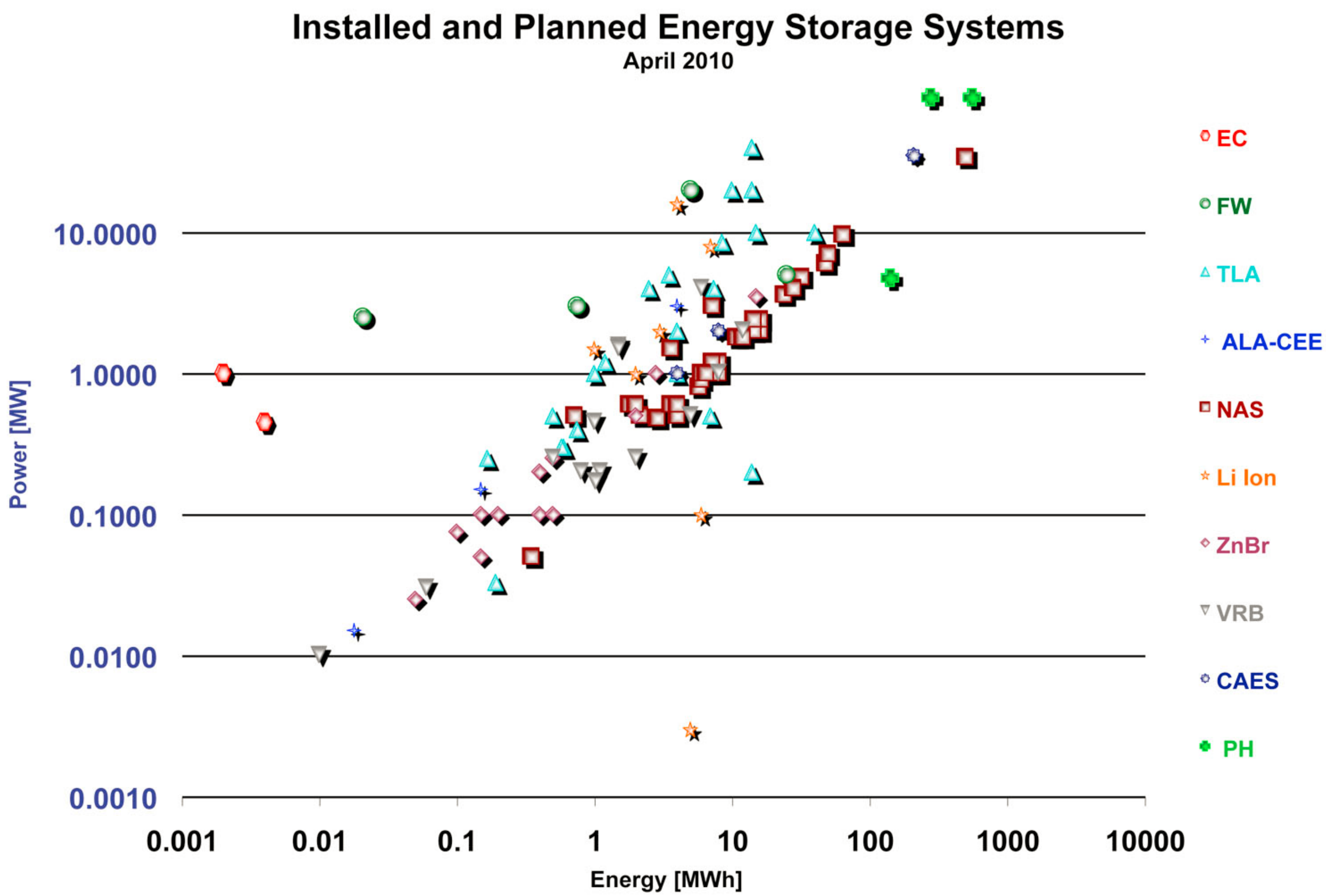
● Fully capable and reasonable ◐ Reasonable for this application ○ Feasible but not quite practical or economical NONE Not feasible or economical

Leading-Edge Technologies

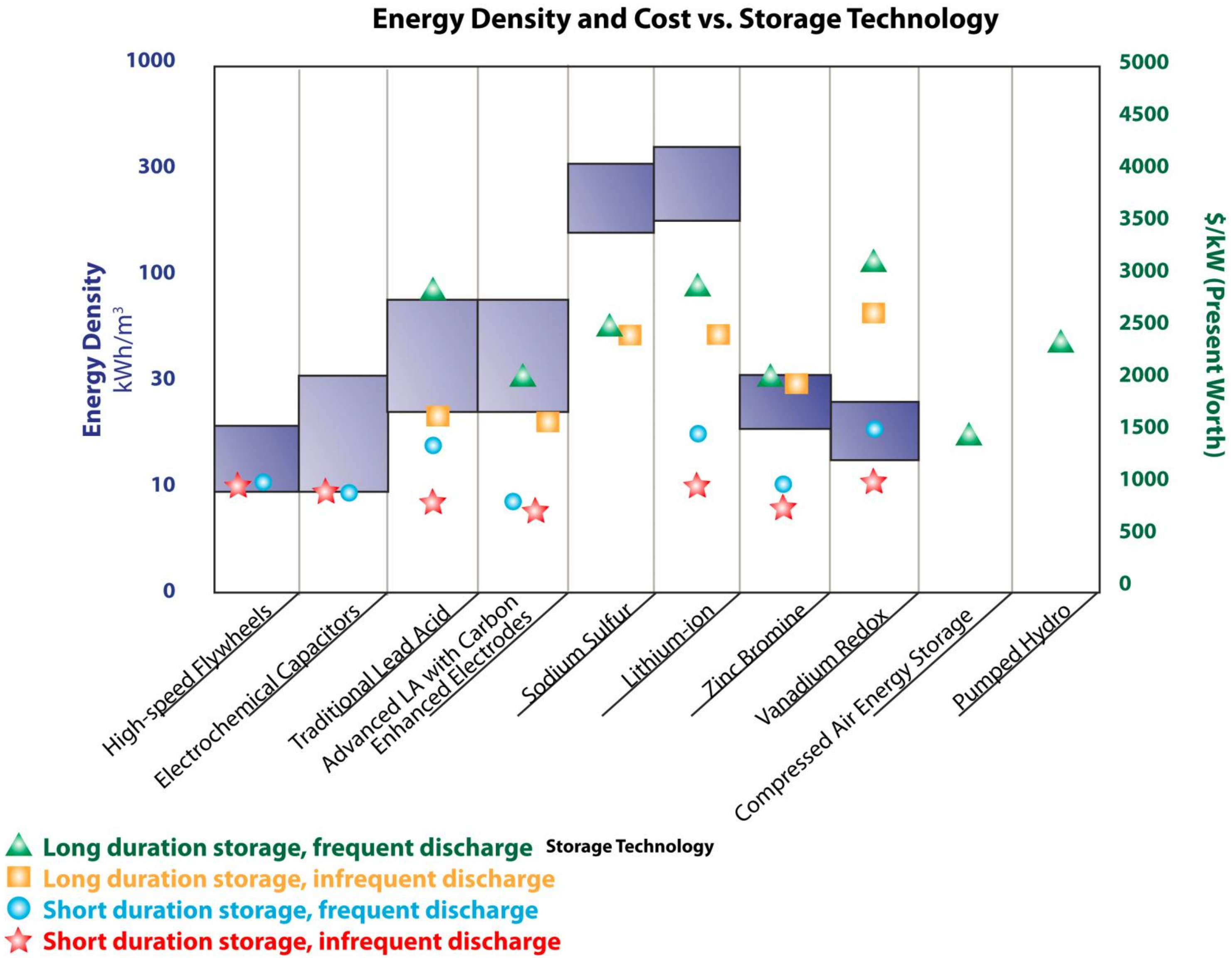
- Metal-air batteries
- Na/S cells
- Li-ion cells
- Lead-carbon batteries
- Na-ion / Na-halide batteries

- Flow battery
- Above-ground CAES
- Mini-CAES
- Valve regulated lead-acid batteries with electromechanical capacitor

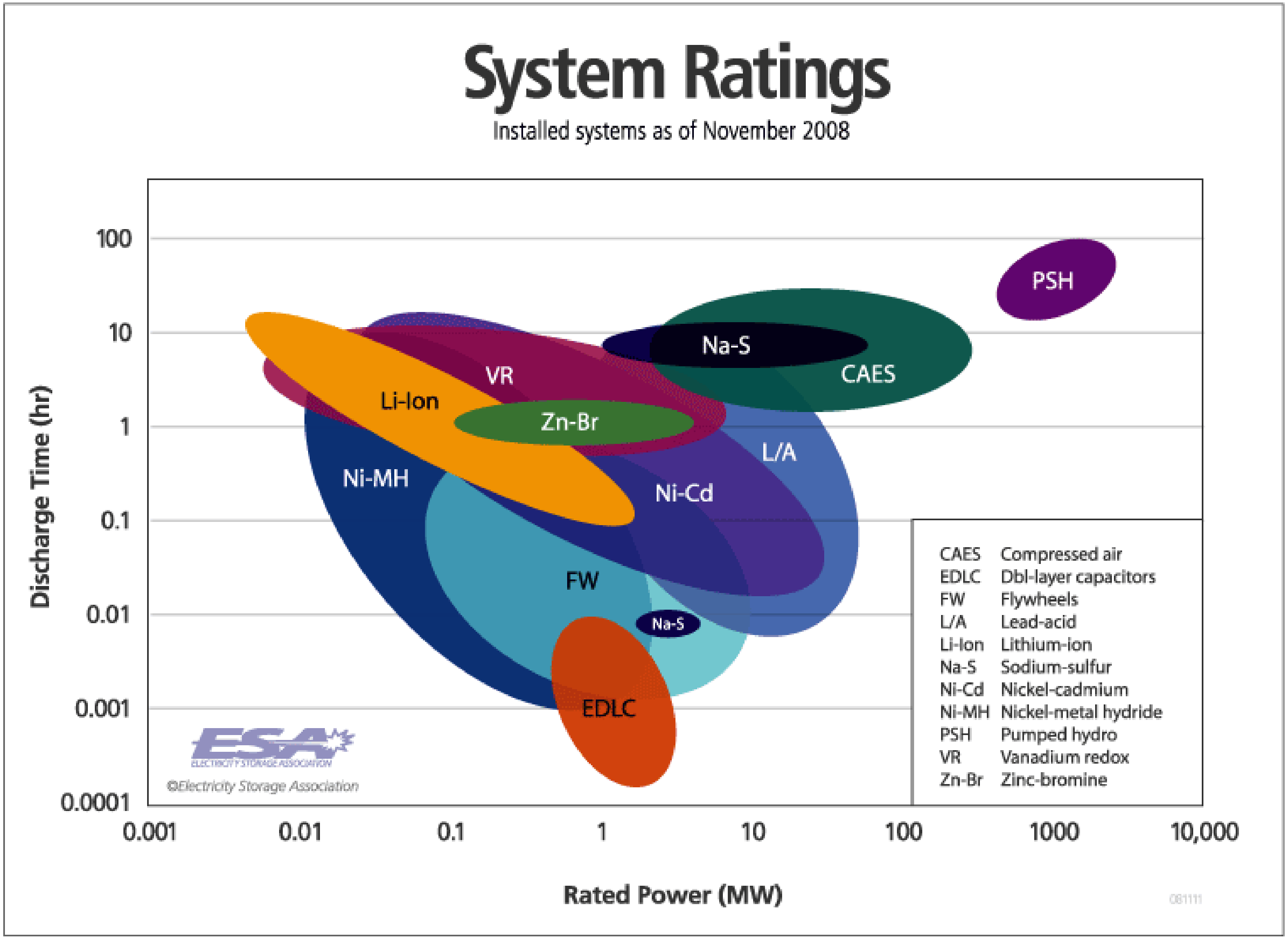
Global Installed Storage Capacity



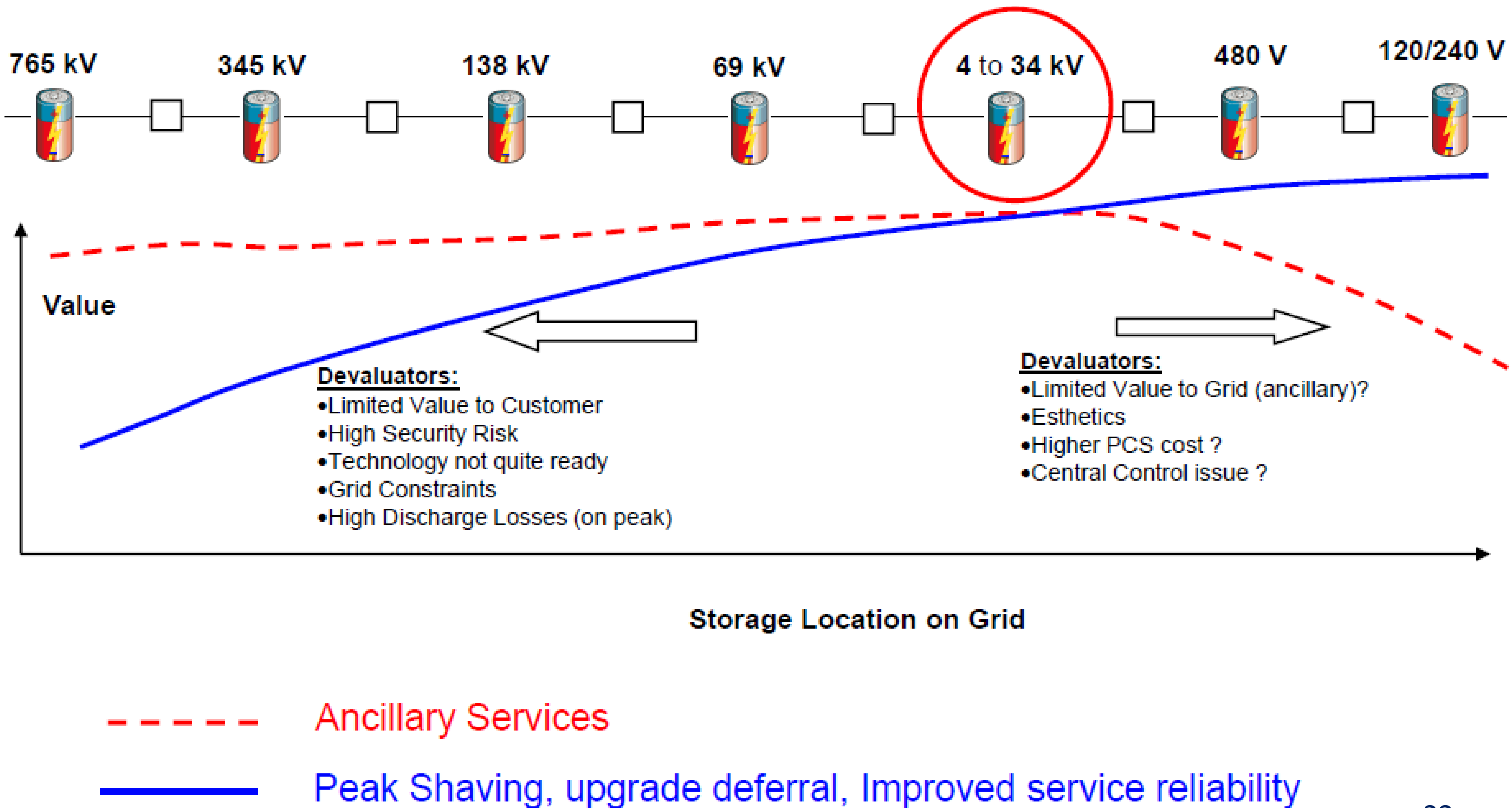
Cost Considerations



Mapping Technology to Usage

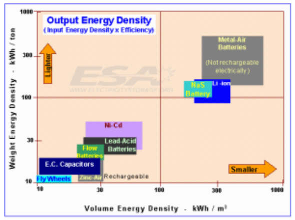


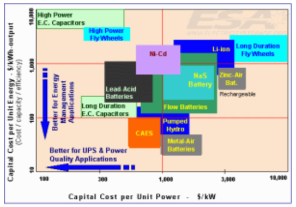
Storage Location on the Grid

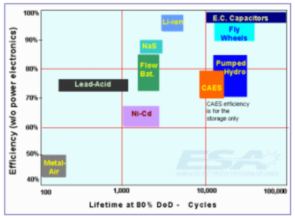


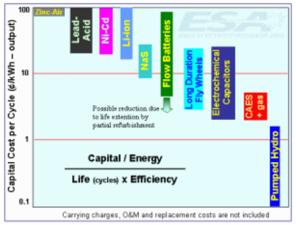
More Data on Website www.electricitystorage.org

- Weight energy density vs. Volume energy density
- Capital cost per unit energy vs. Capital cost per unit power
- Capital cost per cycle
- Efficiency vs. Lifetime



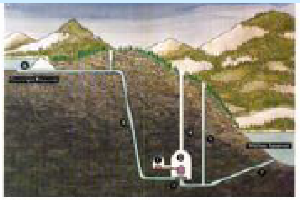




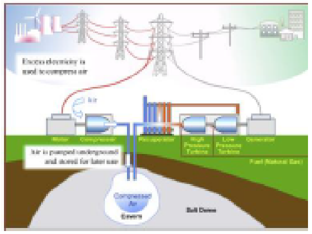


Recap of Technologies

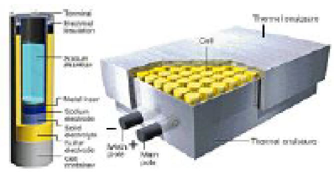
pumped storage



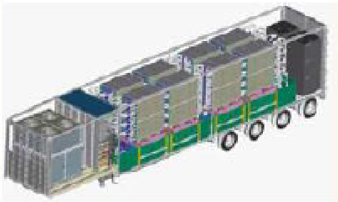
CAES



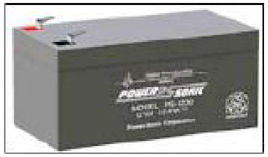
NaS battery



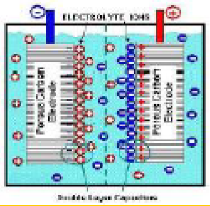
flow battery



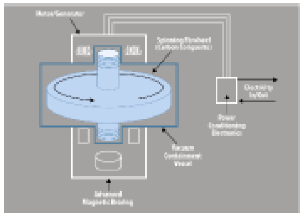
advanced lead acid battery



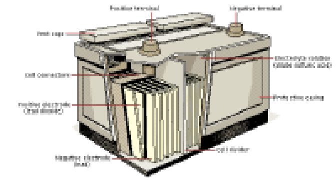
EC capacitor



flywheel



lead-acid battery



Li-ion battery

Ni-Cd battery

SMES

← *increasing energy*

increasing power →

Source: Electricity Storage Association

Summary

- Number of renewables directly connected to electric grid is on the rise
  - Environmental & political reasons
- Is the electric grid ready to handle the large penetration of intermittent renewables?
  - Energy storage and coordinated control are possible solutions
- Hybrid plants – couple generation capacity with storage
  - Concentrated solar plants with molten salt energy storage
  - Wind farms with compressed air energy storage
- Substation level storage for towns and cities
  - Flow batteries

Summary

- Substation level storage for frequency regulation
  - Flywheels, superconducting magnetic energy storage
- Community energy storage Units
  - Chemical batteries
- Combination of technologies will be used
  - Match time scale of intermittency being mitigated
  - Match energy storage and power needs
  - Charge and discharge capabilities
  - Cost considerations
  - Volume & weight
  - Efficiency
  - Lifetime

Selected References

[1] Western Electricity Coordinating Council. (2011, September 26). *Executive Summary 2011 WECC 10-Year Regional Transmission Plan* [Online]. Available: http://www.wecc.biz/library/StudyReport/Documents/ExecutiveSummary_Brochure.pdf

[2] National Public Radio. (2011, September 26). *Visualizing The U.S. Electric Grid* [Online]. Available: http://www.npr.org/templates/story/story.php?storyId=110997398

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