Utility Scale Energy Storage Systems

Presented by:

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Acknowledgment

- This presentation is based on a report prepared for the Indiana Utility Regulatory Commission
- My fellow authors on the report were
  – Rachel Carnegie
  – Paul Preckel
  – David Nderitu

Thomas Edison, 1883

- *"The storage battery is, in my opinion, a catchpenny, a sensation, a mechanism for swindling the public by stock companies. The storage battery is one of those peculiar things which appeals to the imagination, and no more perfect thing could be desired by stock swindlers than that very selfsame thing. ... Just as soon as a man gets working on the secondary battery it brings out his latent capacity for lying. ... Scientifically, storage is all right, but, commercially, as absolute a failure as one can imagine."*

Thomas Edison, 1901

- Develops the nickel-iron battery
- Forms the Edison Storage Battery Company

- “If you get long-term energy storage, it obviates the need for significant energy infrastructure” – David Owens, Executive Vice President for the Edison Electric Institute, October 28,2013

Also Last Month...

- California adopted an energy storage mandate
- Three IOUs (PG&E, SCE, SDG&E) are required to have 200 MW next year and 1,325 MW by 2020.
- Non-utility suppliers must have an amount equal to 1 percent of their peak load.

Why Energy Storage?

- Electricity cannot be stored directly
- Supply of electricity must always equal demand
- This has significant cost implications
- Storage systems can act as either a source of supply or a load depending on which is more valuable

Drivers

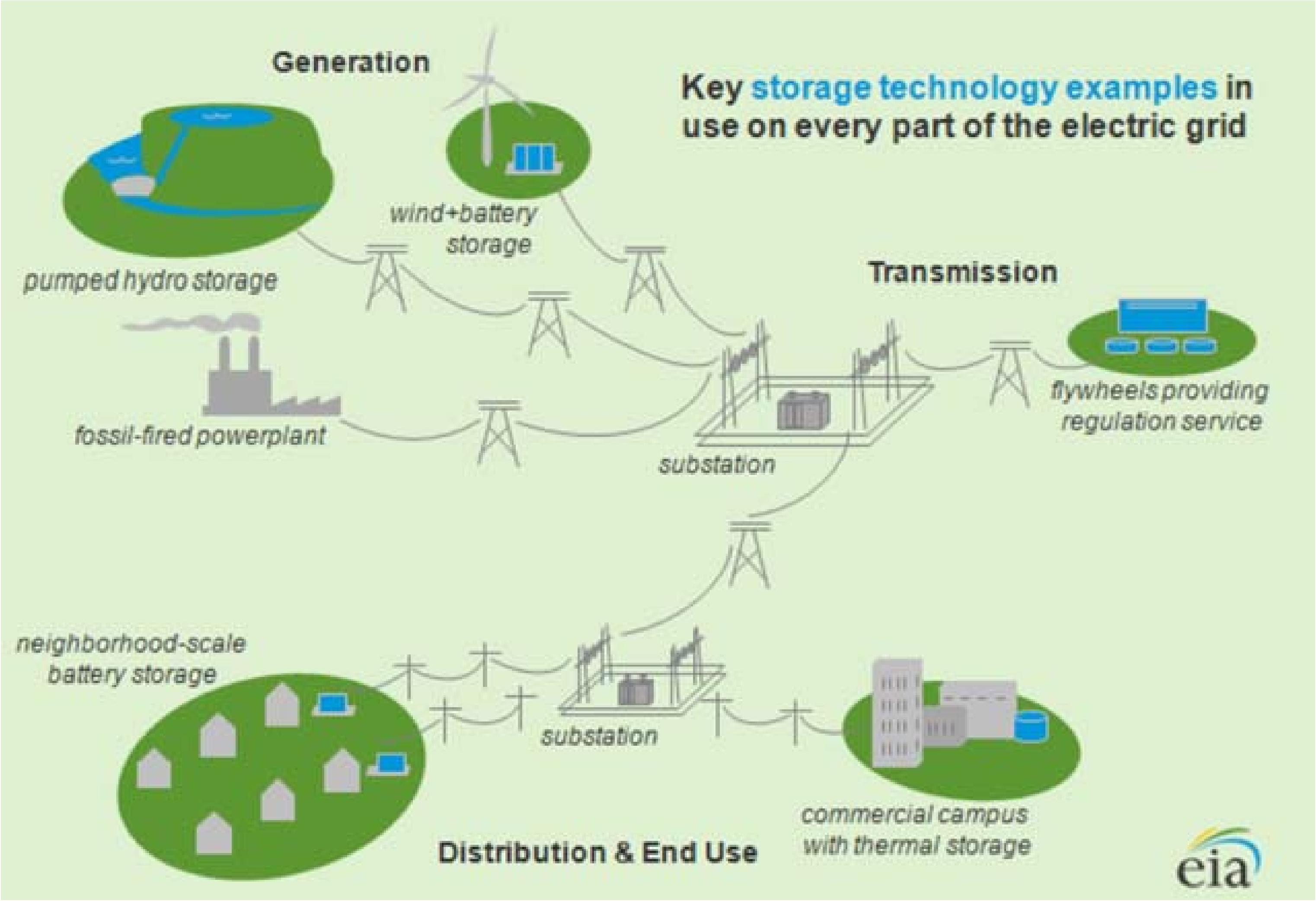
- The potential to reduce system peak demand and the costs associated with designing a system to meet extreme events
- The need to integrate distributed and intermittent renewable energy resources
- The increasing level of congestion in transmission and distribution systems

Drivers

- The provision of ancillary services that are critical to the efficient and reliable operation of the grid
- The need for high quality, reliable power with the increased use of devices and systems that are sensitive to fluctuations

The Real Driver ($$$)

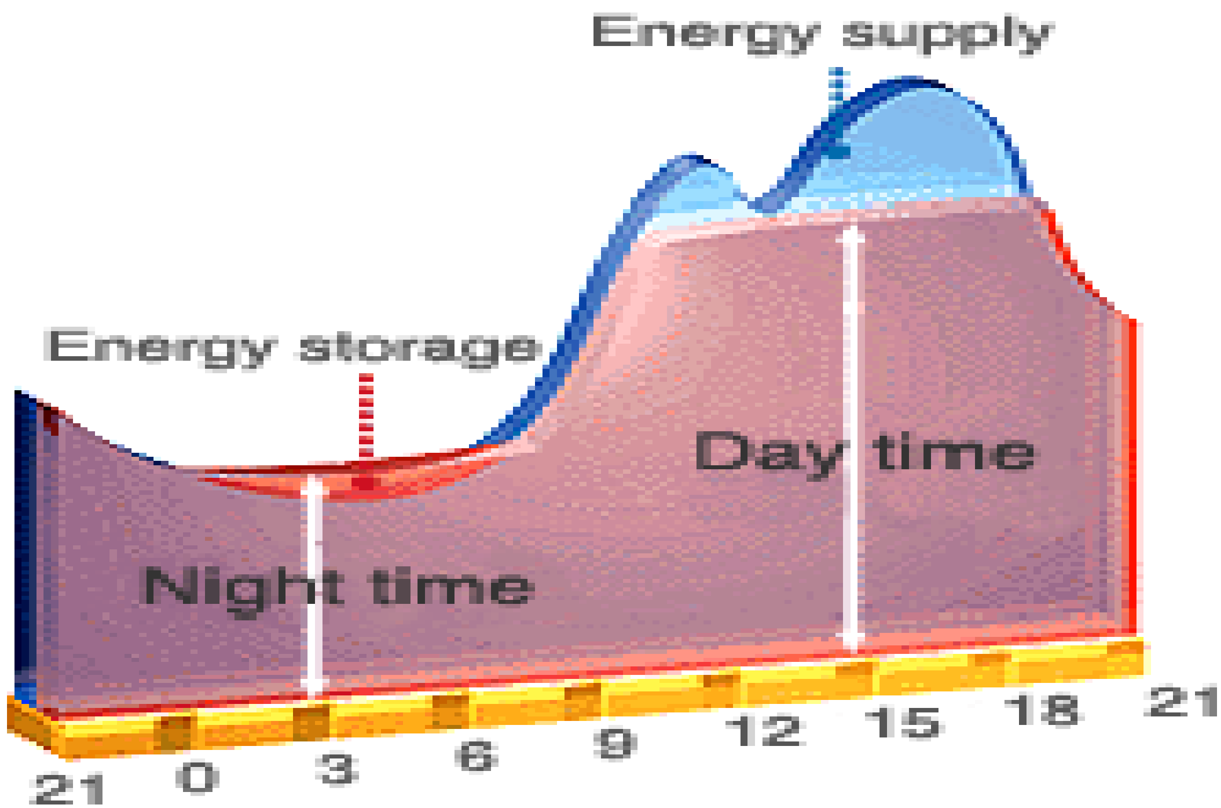
- These are all things that we can (and do) deal with today
- But we end up using the power grid in a manner that is less efficient and more costly
- Energy storage technologies have the potential to allow us to operate the system better


Generation
Key storage technology examples in use on every part of the electric grid
wind+battery storage
pumped hydro storage
Transmission
fossil-fired powerplant
substation
flywheels providing regulation service
neighborhood-scale battery storage
substation
commercial campus with thermal storage
Distribution & End Use
eia

Benefits

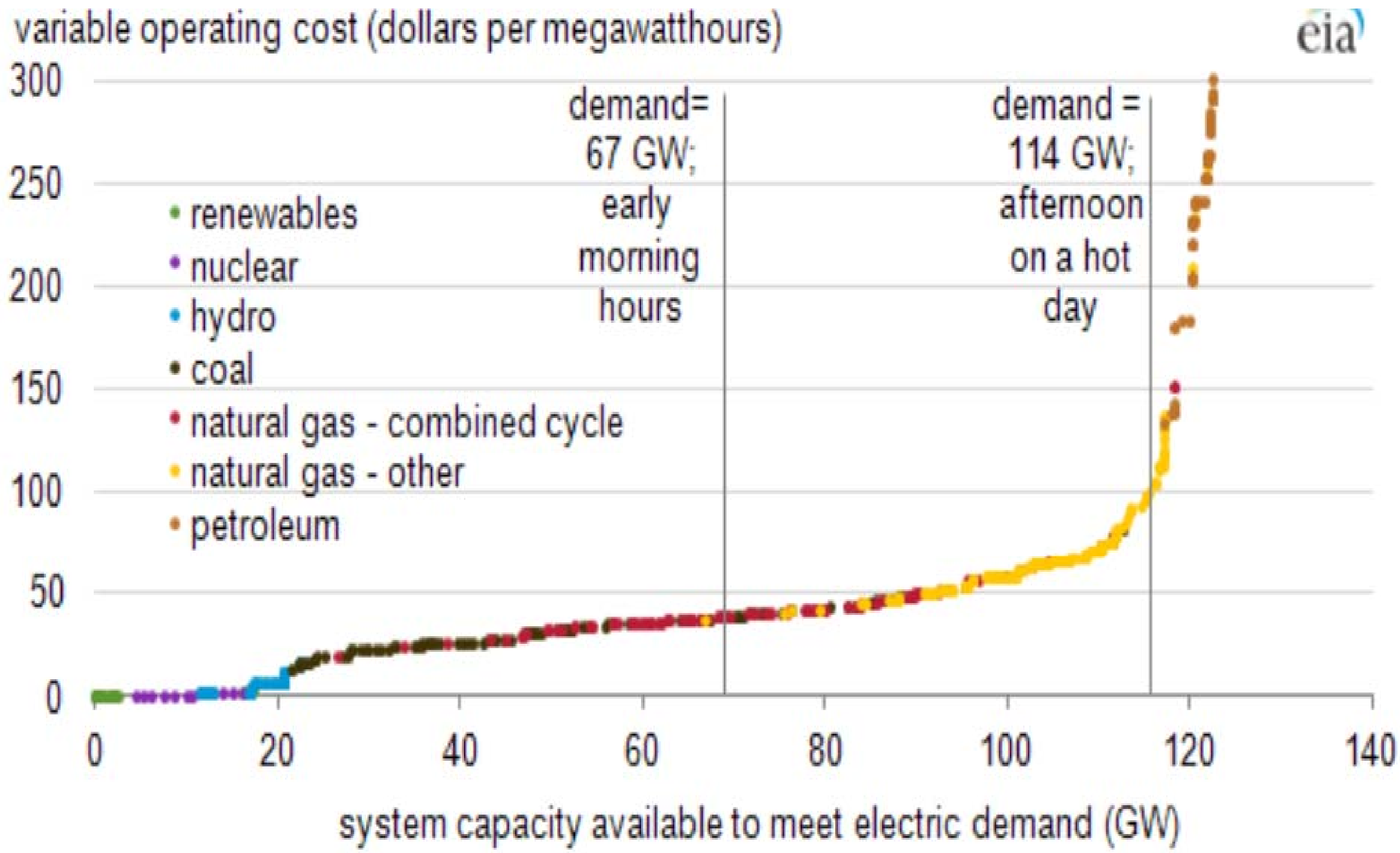
- Time shift of energy delivery
- Capacity credit
- Grid operational support
- Transmission and distribution support
- Power quality and reliability
- Integration of intermittent resources

Peak Shaving

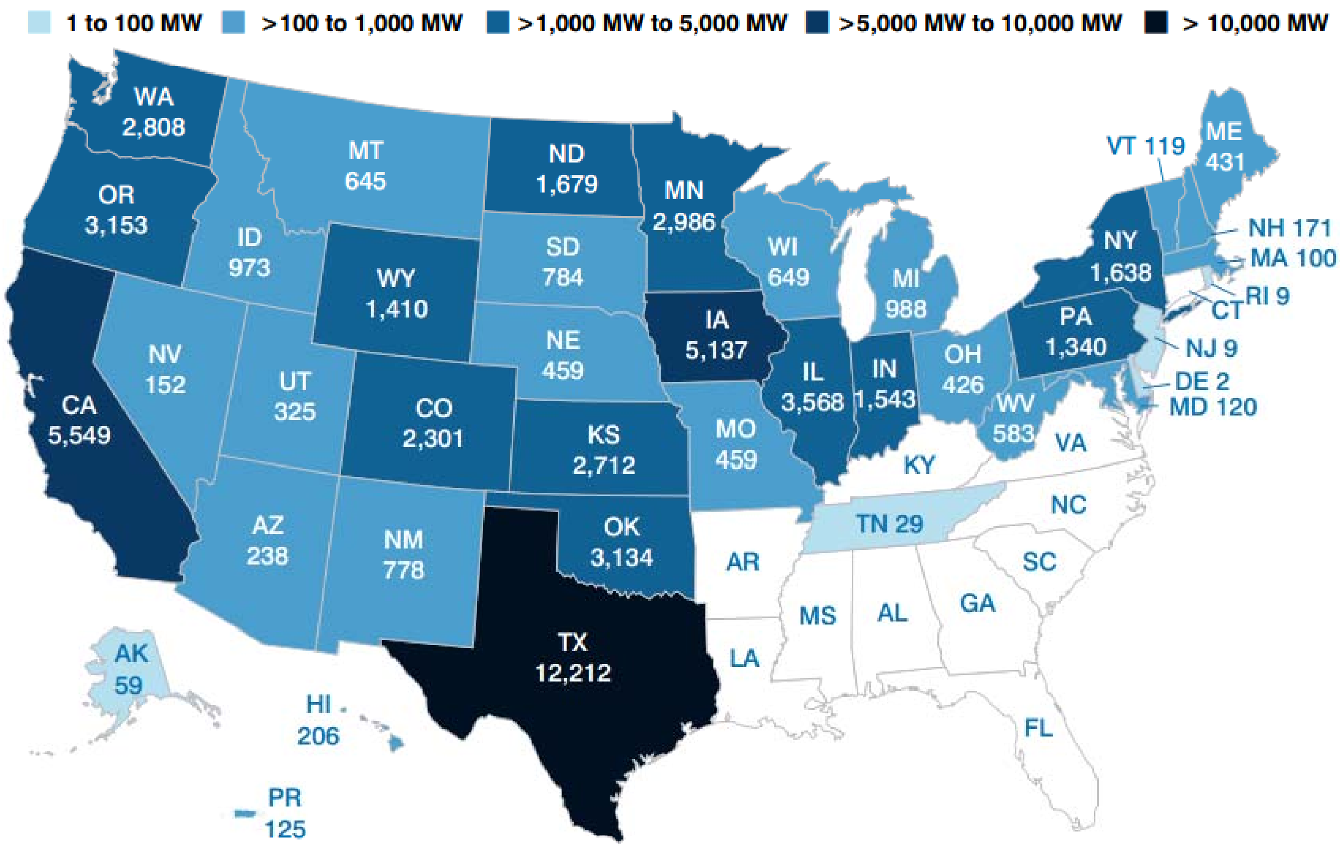


Source: NGK Insulators

Hypothetical Dispatch Curve

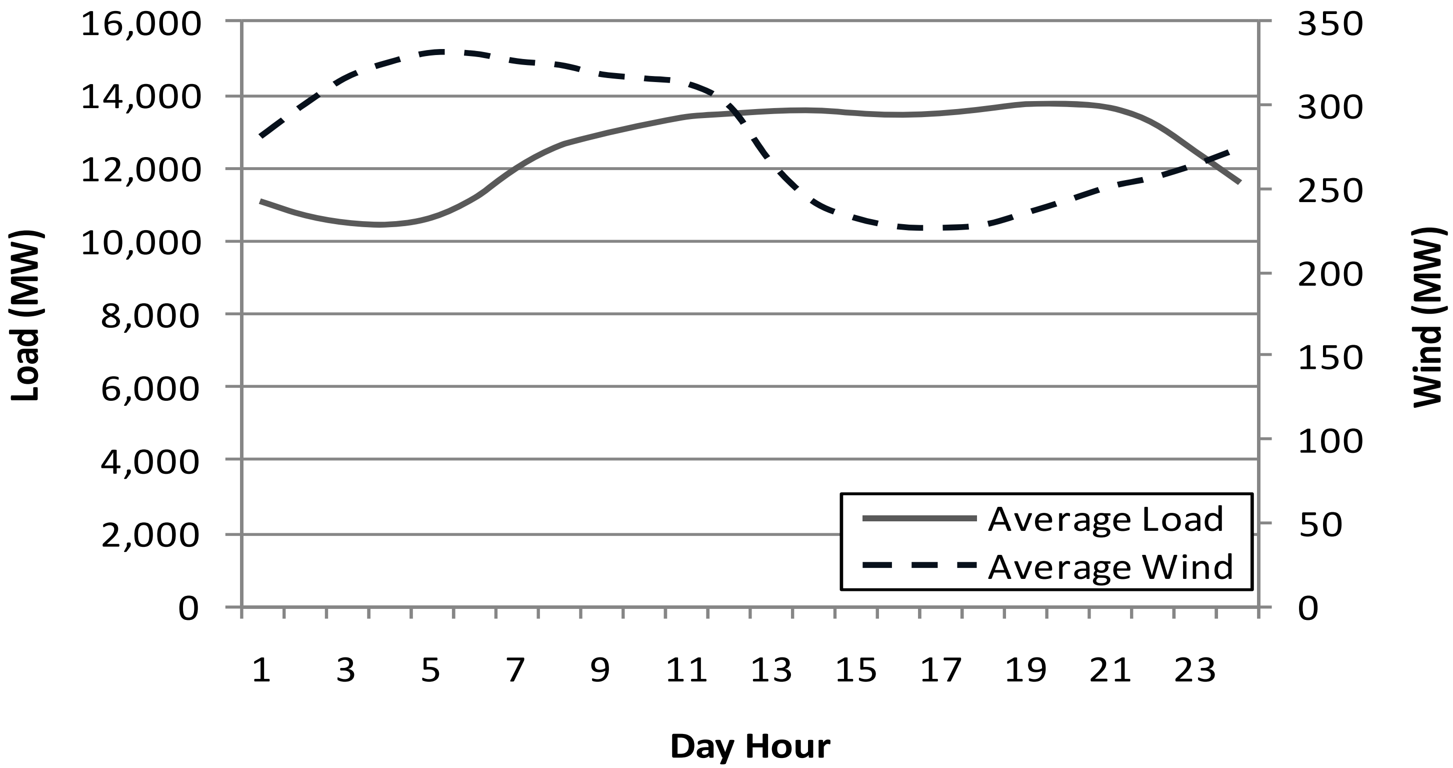


Installed Wind Capacity (2012)



Source: American Wind Energy Association

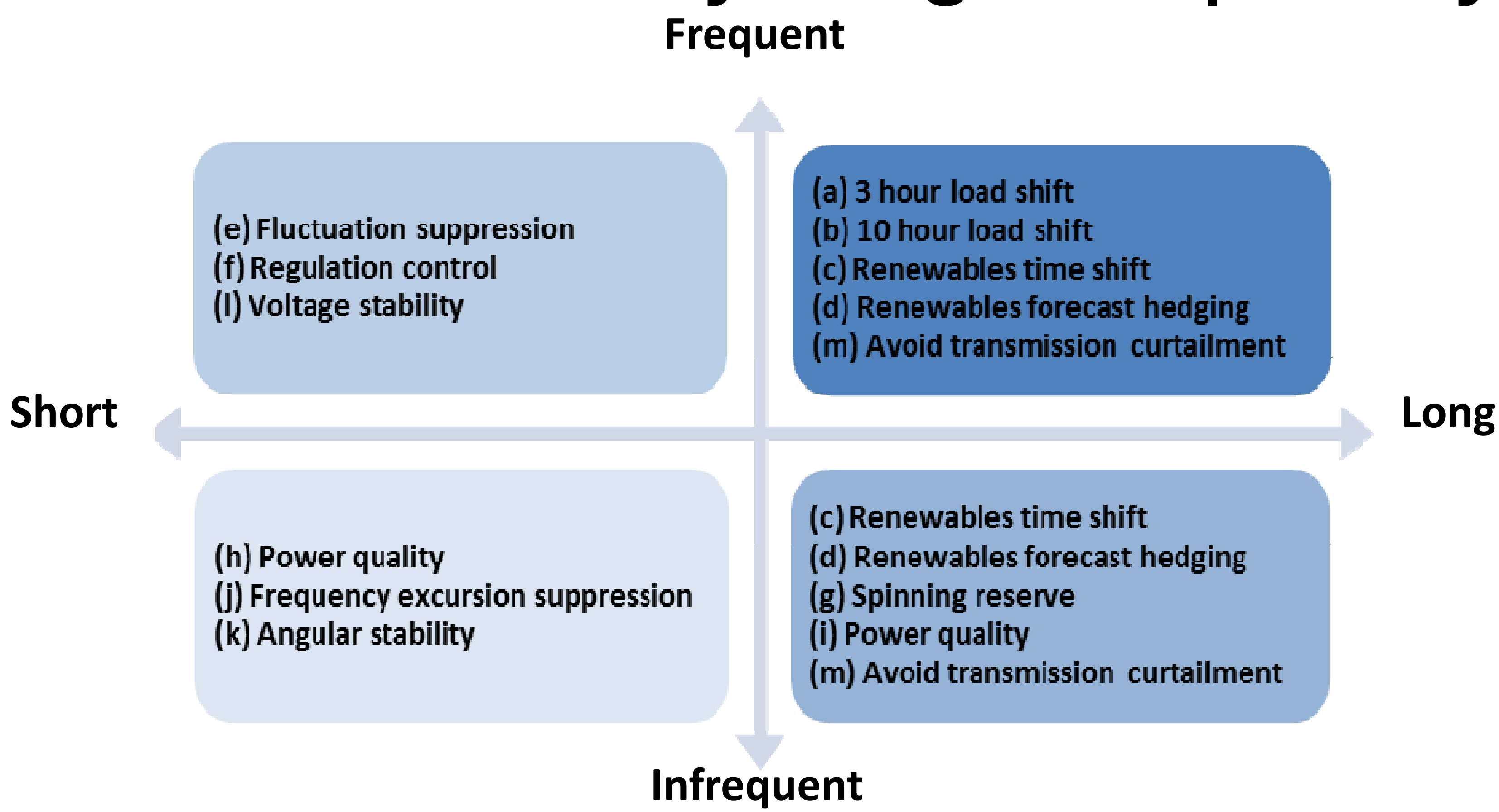
Average Indiana Load vs. Wind Output (2004-2006)



Storage Characteristics

- Discharge duration
- Response time
- Discharge depth
- Cycling frequency
- Cycle lifetime
- Energy
- Power
- Efficiency
- Cost

Applications by Discharge Duration and Cycling Frequency



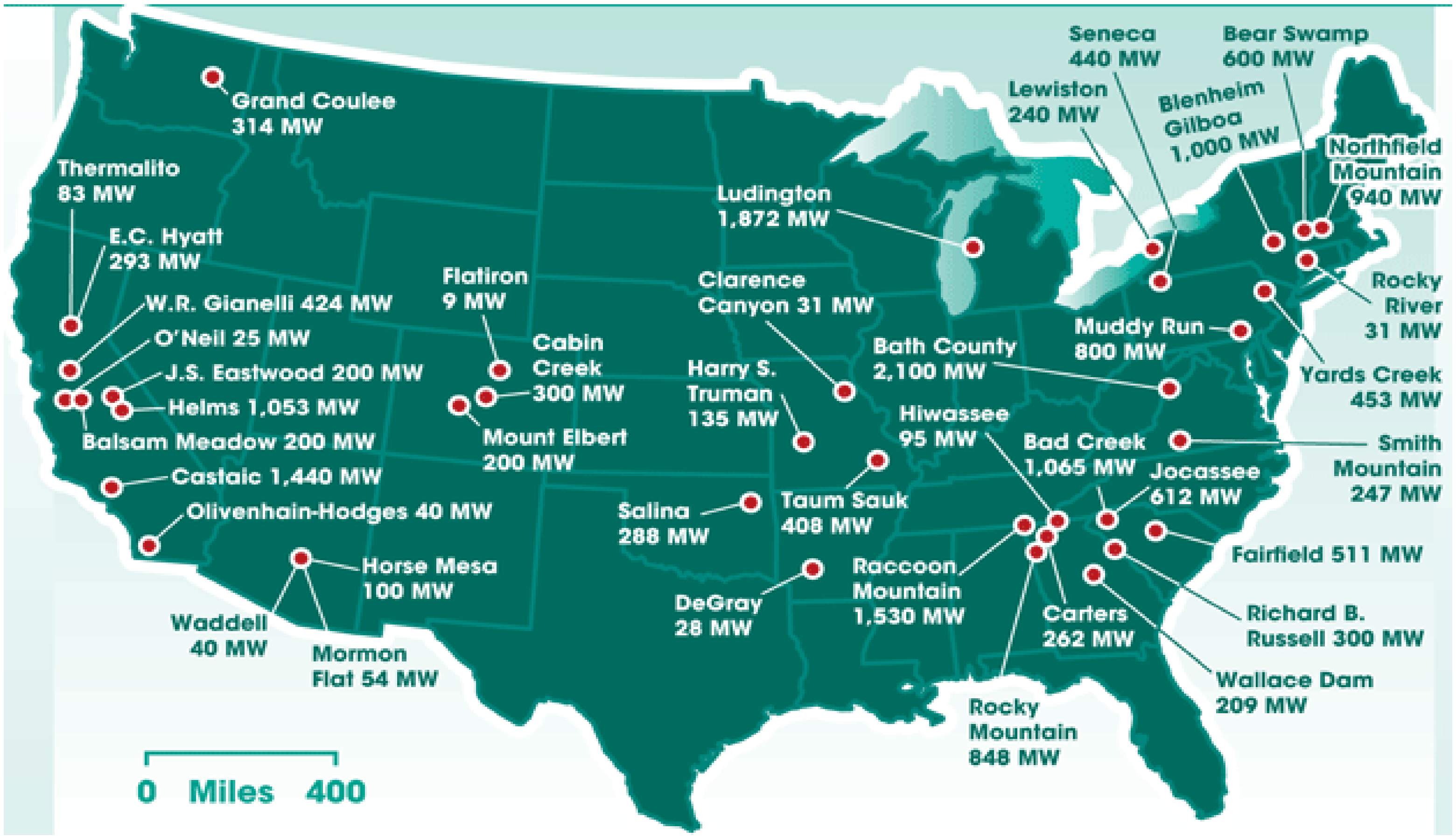
Energy Storage Systems

- Mechanical
  - pumped hydro
  - compressed air
  - flywheel
- Chemical
  - hydrogen
- Electric field
  - capacitor
- Magnetic field
  - SMES
- Electrochemical (batteries)
  - conventional (lead acid, NiCad, lithion ion)
  - high temperature (NaS, ZEBRA)
  - flow (vanadium redox, ZnBr)
- Thermal
  - molten salt

Pumped Hydro

- 22 GW of U.S. capacity (>99% of all bulk storage)
- Potential sites depend on topography
- Round trip efficiency 75-78%
- High power, high energy, long discharge

U.S. Pumped Hydro Sites



Source: www.hydroworld.com

Compressed Air Energy Storage

- Charge by pressurizing air, discharge by using compressed air in a combustion turbine
- Large systems can be in the 100s of MW with 10-30 hours of storage, usually in underground formations
- Small systems often 10-20 MW with less than 5 hours of storage, usually in manmade vessels
- Efficiency varies by type, 73-89%

Flywheels

- Energy is stored in the kinetic energy of a spinning mass
- Motor draws energy to spin the rotor, acts as a generator to discharge
- Immediate response applications (UPS)
- Power and energy are a function of the mass and speed
- Roundtrip efficiency 70-80%, standby losses 1-2%

Electrochemical Storage

- Conventional batteries
  - cathode and anode with electrolyte in a sealed container
- High temperature batteries
  - molten electrodes
- Flow batteries
  - electrolyte stored in an external tank

Lead Acid Batteries

- Mature (used in the 1870s for load leveling)
- Low energy and power density, short cycle life, high maintenance, toxicity
- Low cost
- About 35 MW in use for power applications worldwide

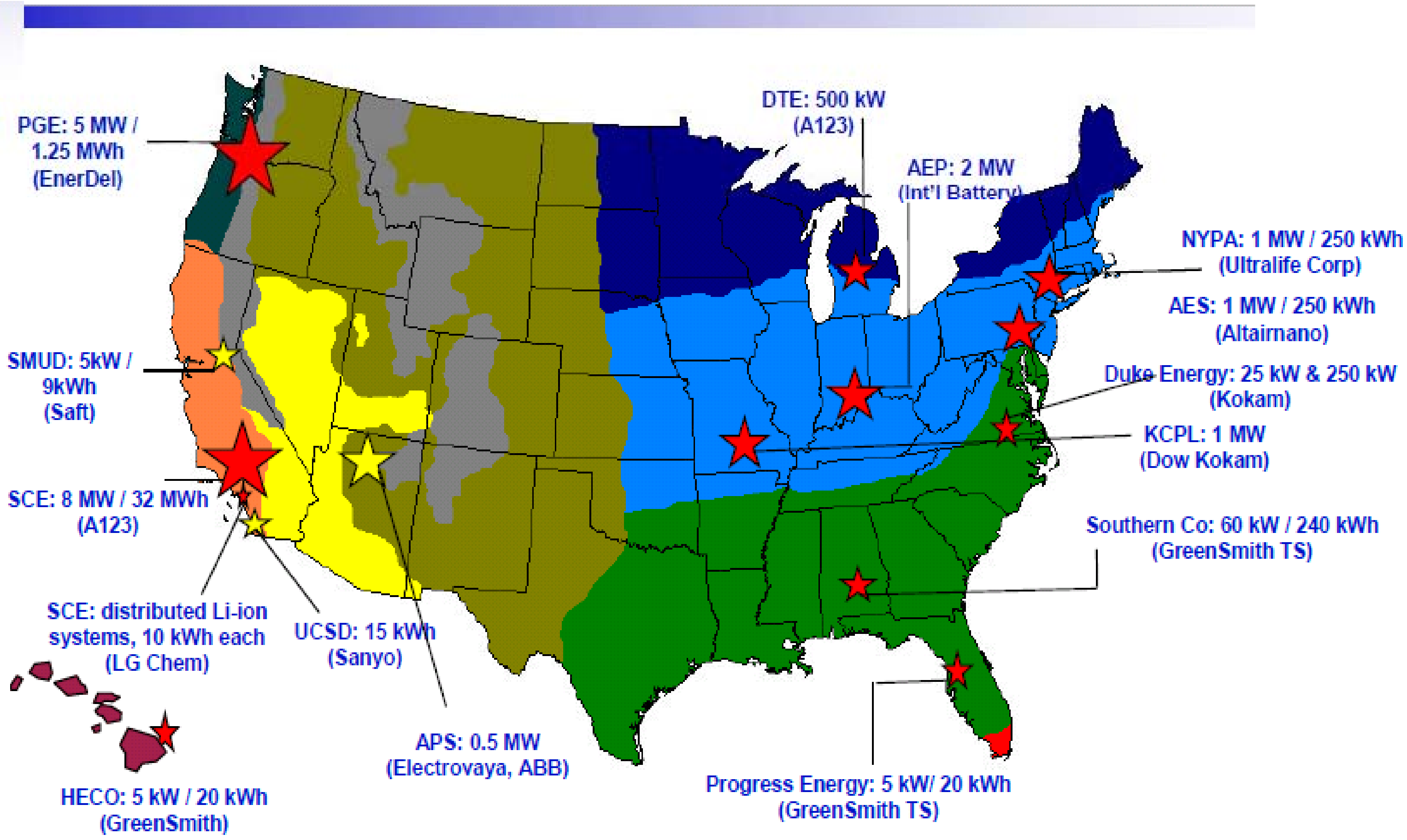
Nickel Electrode

- Nickel cathode and various materials for the anode (Cd, Fe, Zn, H, metal halides)
- NiCd and NiFe mature, NiCd most common for power applications
- Long cycle life, high energy and power density, reliability, but low efficiency
- Cost is higher than lead acid, but lower than many others (especially NiCd and NiFe)
- About 27 MW worldwide

Lithium Ion

- Metal-oxide cathode, carbon anode, organic electrolyte w/ lithium ions, and a polymer separator
- High energy density, low losses
- Less mature, does not tolerate full discharge, thermal instability, high cost
- Considerable work ongoing due to potential for automotive uses

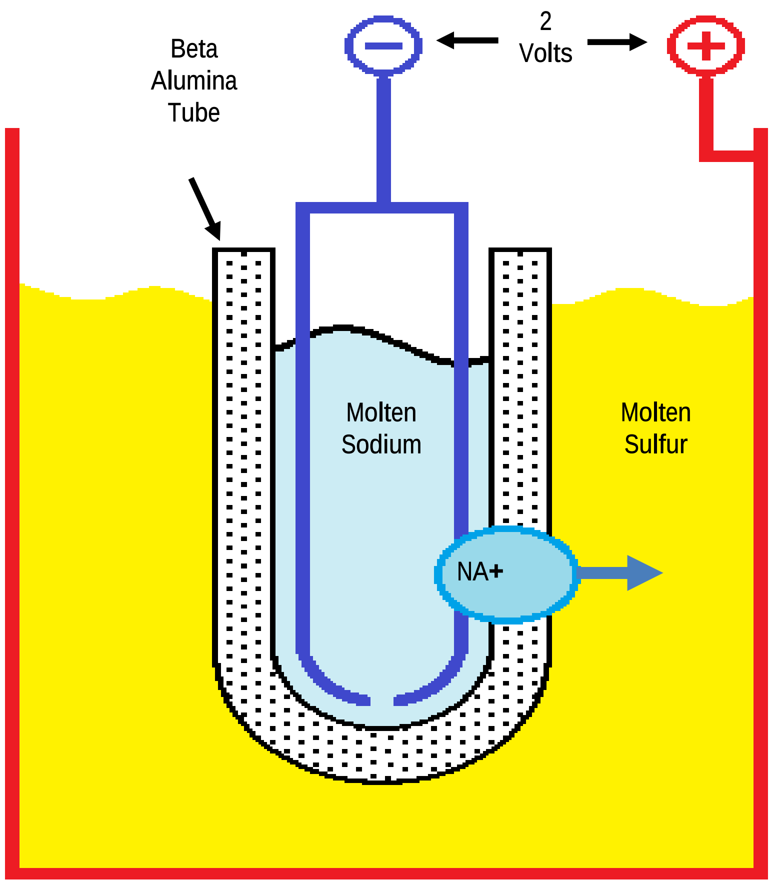
Lithium Ion Demonstrations



Source: D. Rastler, *Smart Grid: A 360 View of Battery Storage*

Sodium Sulfur (NaS) Batteries

- Molten sulfur cathode, molten sodium anode, solid ceramic electrolyte
- Quick response, good energy and power, efficiency 70-90%
- High cost, high temperature



Source: Sandia National Lab

Sodium Nickel Chloride Batteries

- ZEBRA (Zero Emission Battery Research)
- NiCl cathode, molten sodium anode
- Research has been focused on automotive applications
- High efficiency (85-90%), tolerant to overcharge/discharge, quick response
- High cost

Flow Batteries

- Separate storage of electrolyte allows flexibility in energy storage (need more energy, add more electrolyte)
- Decent efficiency (70-80%)
- High cost and complexity (adding pipes, pumps and tanks adds cost and leakage issues)
- Vanadium redox and ZnBr are most common (ZnBr patented in 1885)

Capacitors

- Known as double layer, ultra or super capacitors
- Energy stored in electric field
- Immediate response, high cycle life
- Energy and power characteristics depend on design, but usually one or the other
- Safety issues (fire and chemical hazards), high cost (in part due to disposal costs)

Superconducting Magnetic Energy Storage (SMES)

- Energy stored in magnetic field
- Immediate response, high efficiency (95%), high cycle life, high reliability
- Very high costs (refrigeration), low energy density

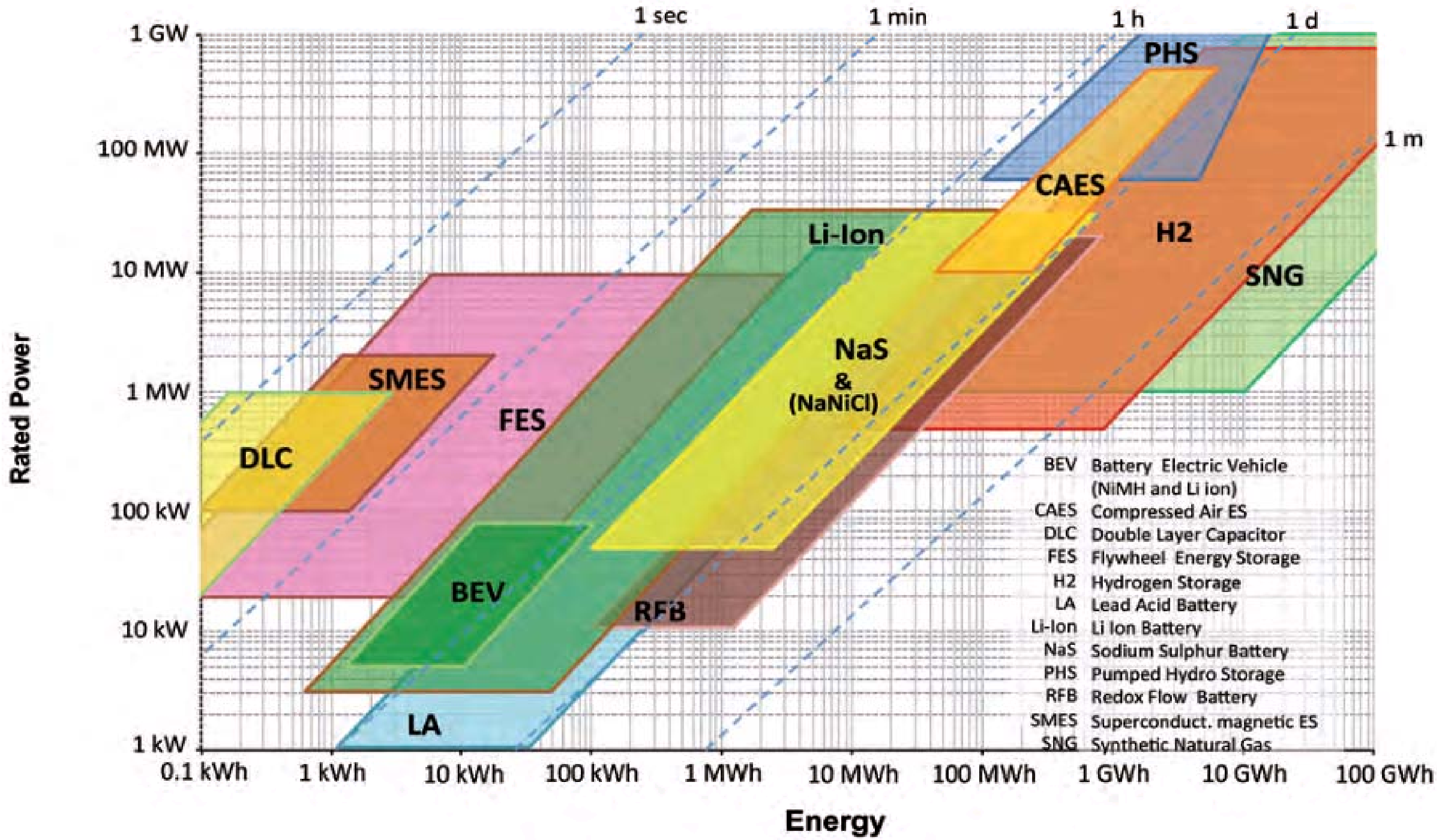
Thermal Energy Storage

- Can be cold (make ice at night for cooling during the day) or hot (heat bricks or water)
- Molten salt has been used with solar installations (concentrated sunlight melts salt, which is used to make steam when the energy is needed)
- High energy but slow response

Countless Others

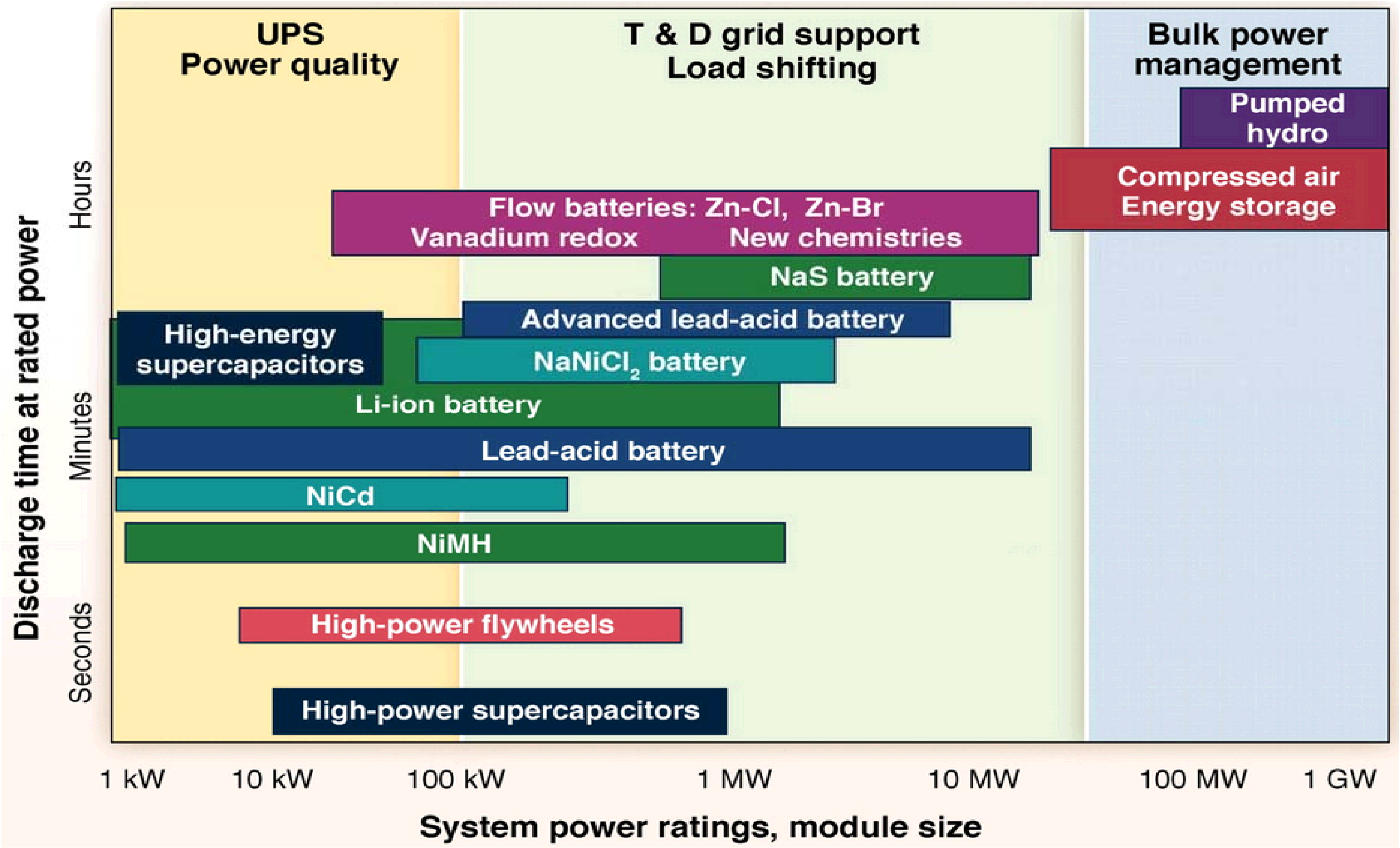
- There are many more ways to convert electricity to some other form of energy for storage
- For example, electrolysis of water and a fuel cell
- Aluminum plus water makes hydrogen and aluminum oxide, which can be converted back to aluminum using energy

Power vs. Energy vs. Discharge Duration



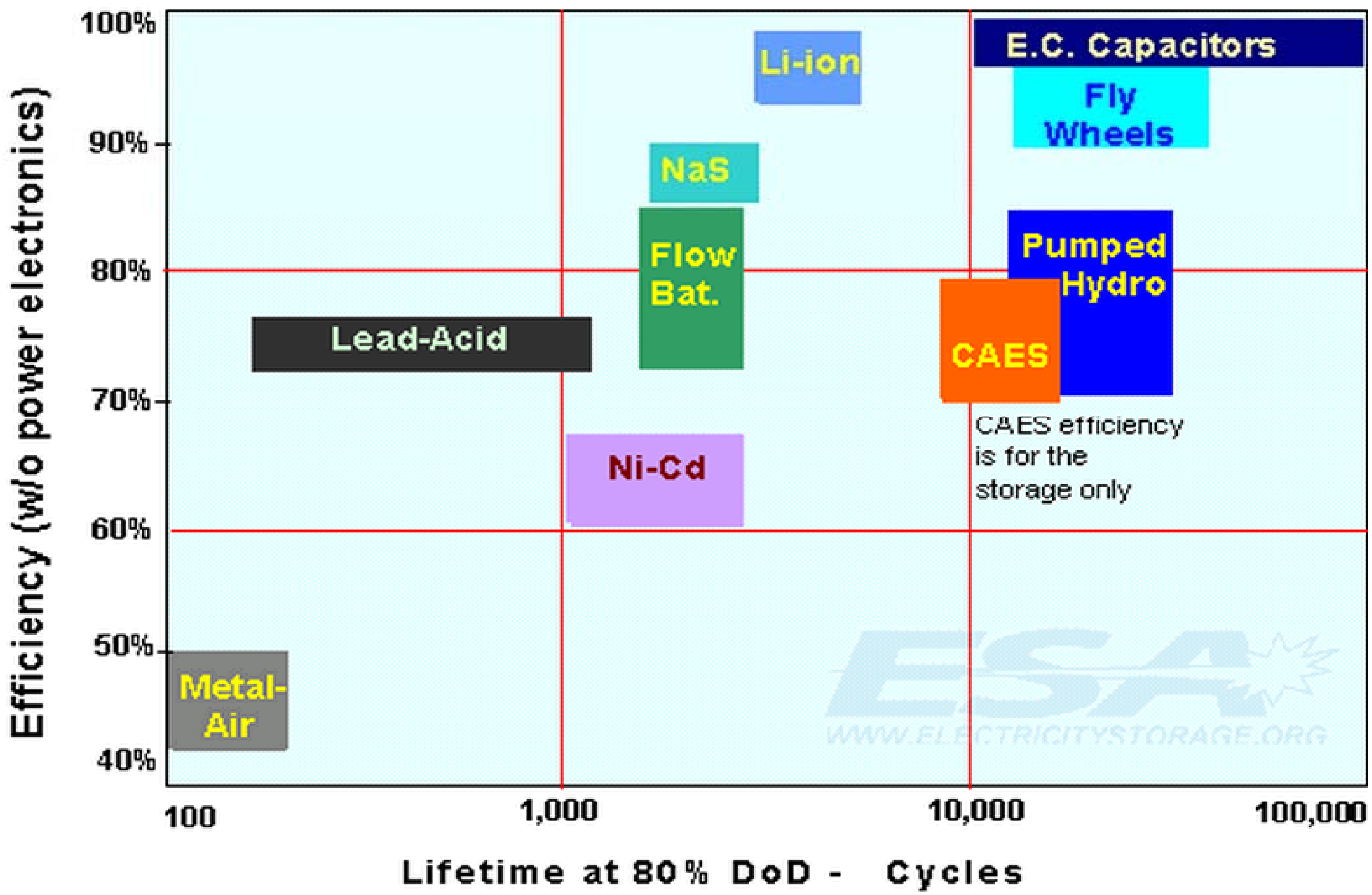
Source: International Electrotechnical Commission

Power vs. Discharge Duration



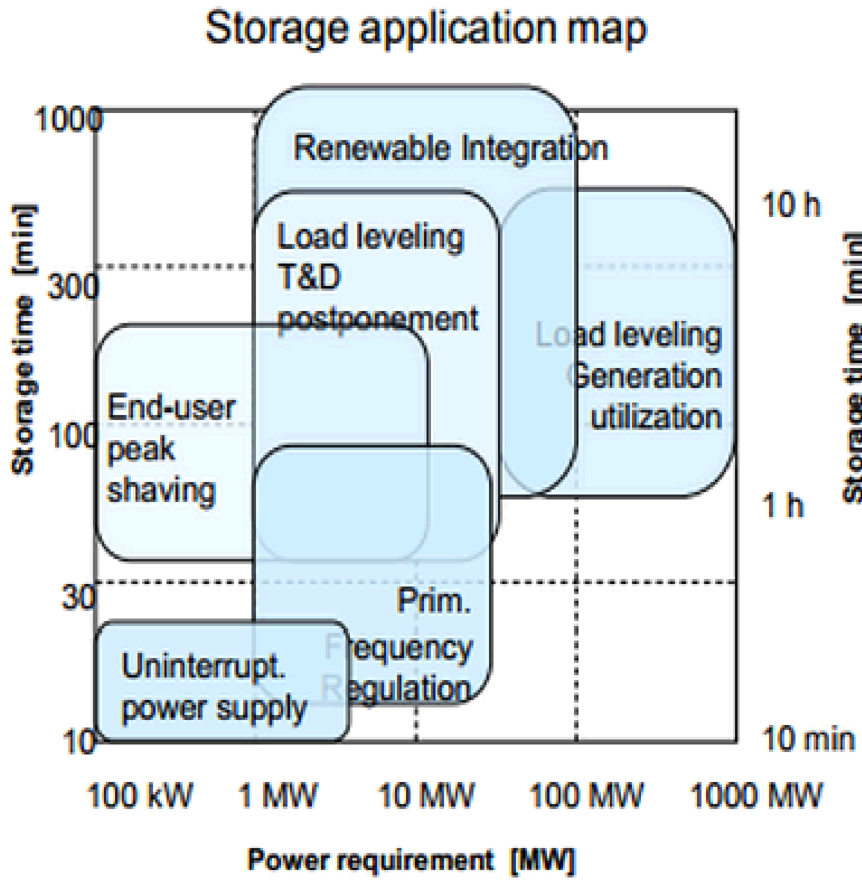
Source: V. Koritarov, Argonne National Lab

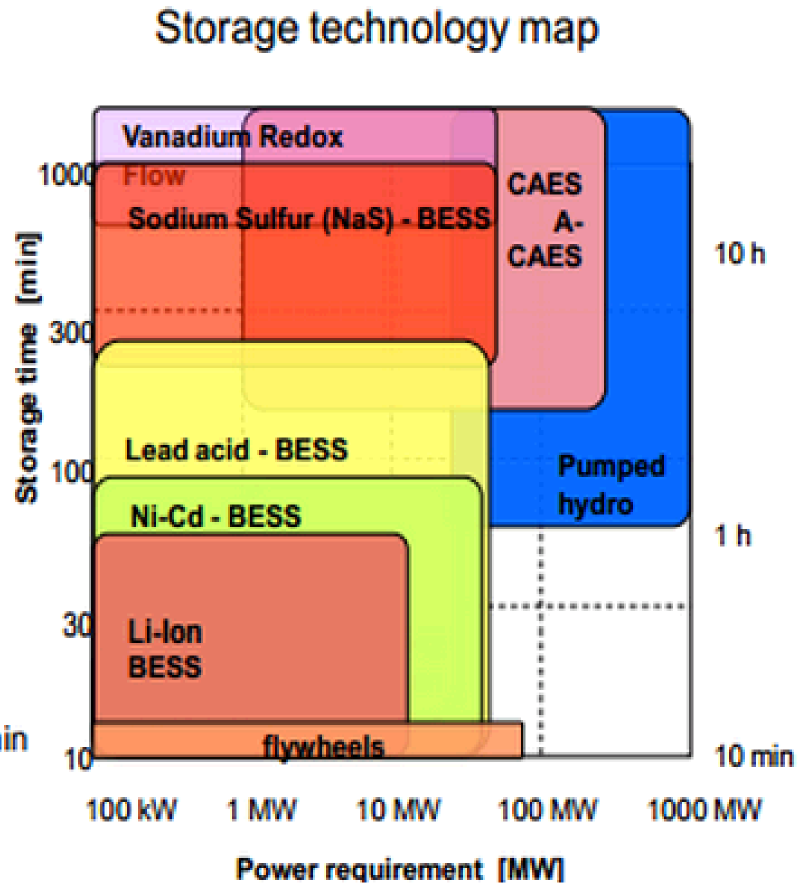
Efficiency vs. Cycle Life



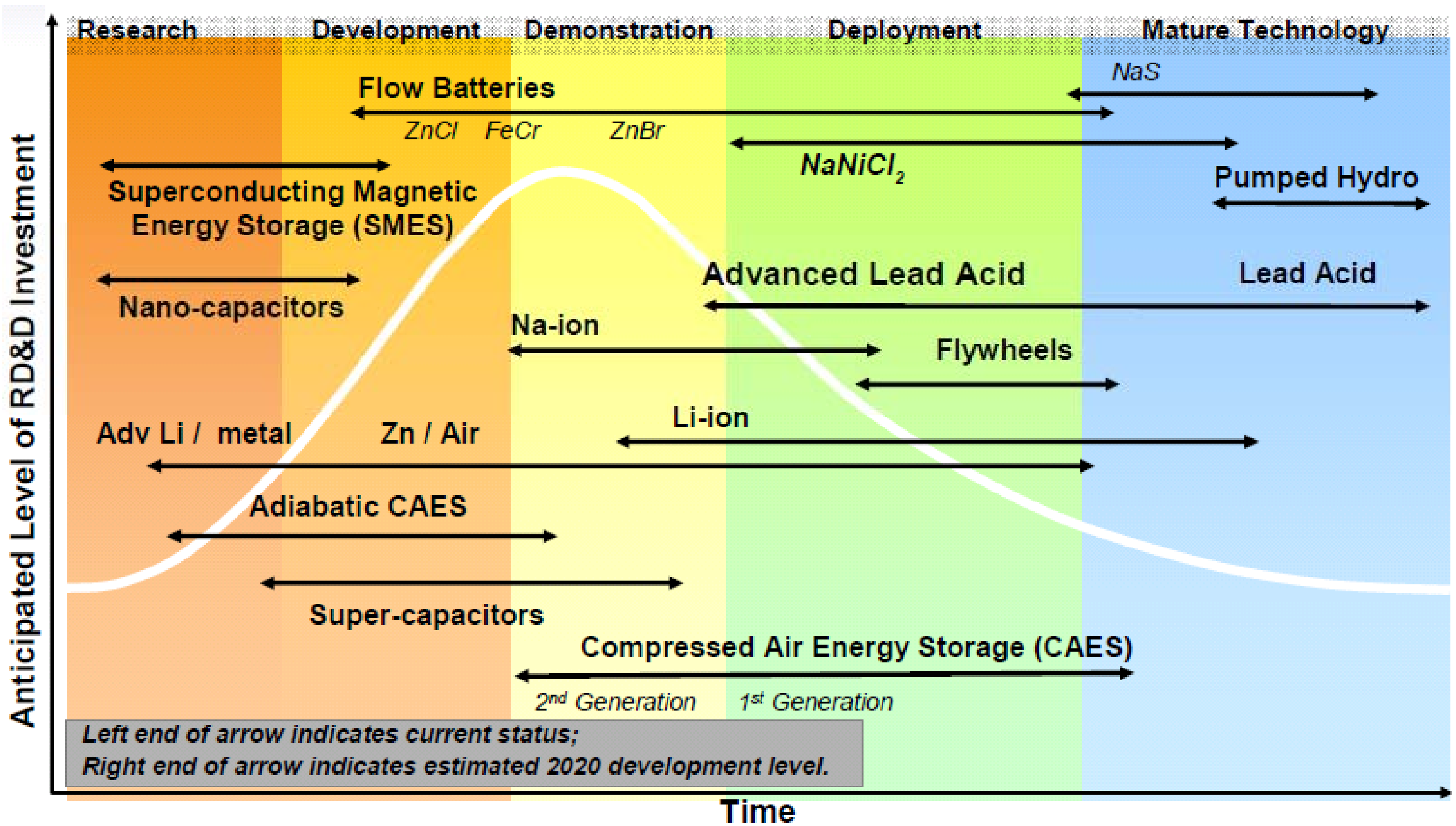
Source: Electricity Storage Association

Applications to Technologies Map



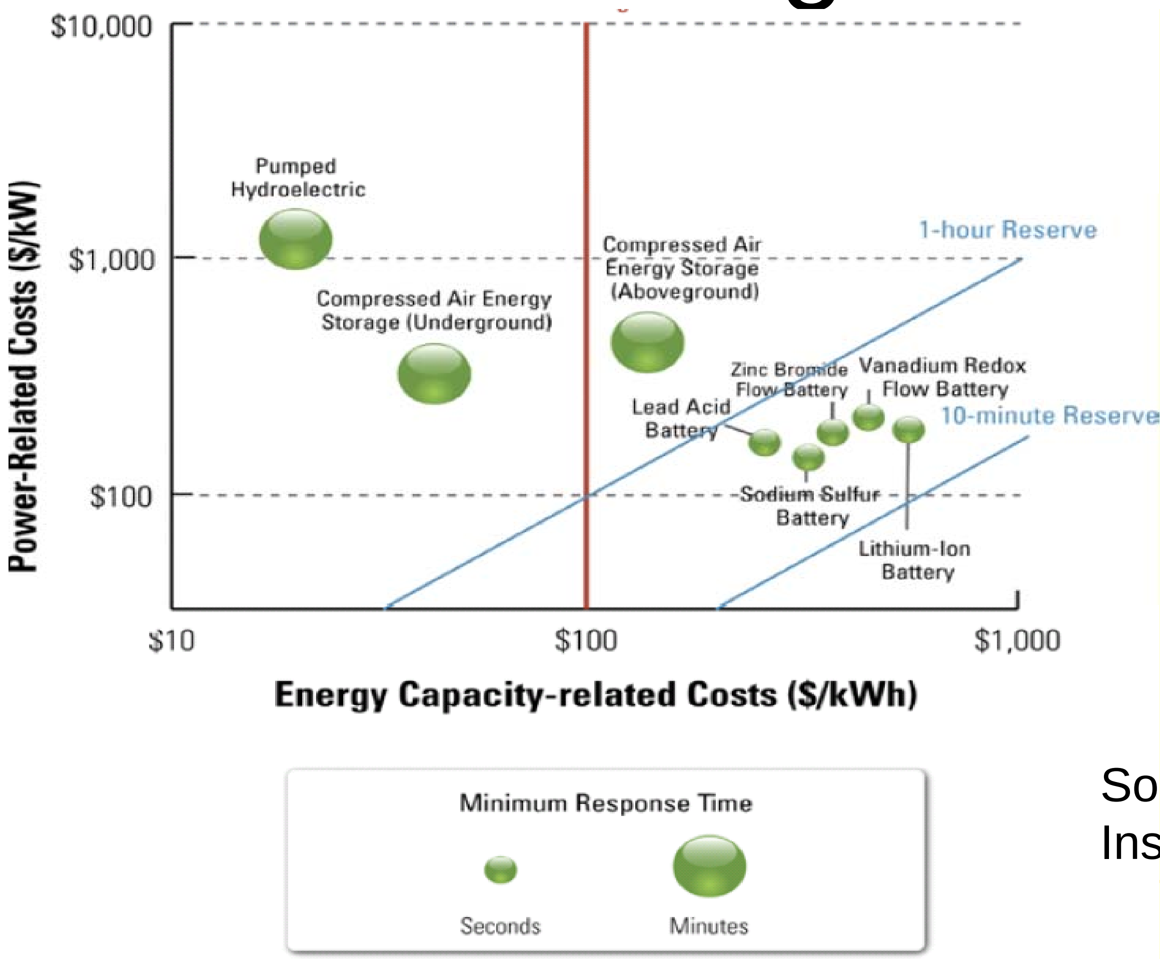


Maturity vs. R&D Expenditure



Source: D. Rastler, "Energy Storage Technology Status," in *Presentation at the EPRI Renewable Council Meeting*, 2011.

Power Cost vs. Energy Cost vs. Discharge Duration



Source: L. Shaw, Illinois Institute of Technology

Further Information

State Utility Forecasting Group

www.purdue.edu/discoverypark/energy/SUFG/

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