Energy Storage

Or Stashing Ether

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What’s new in the world of energy?

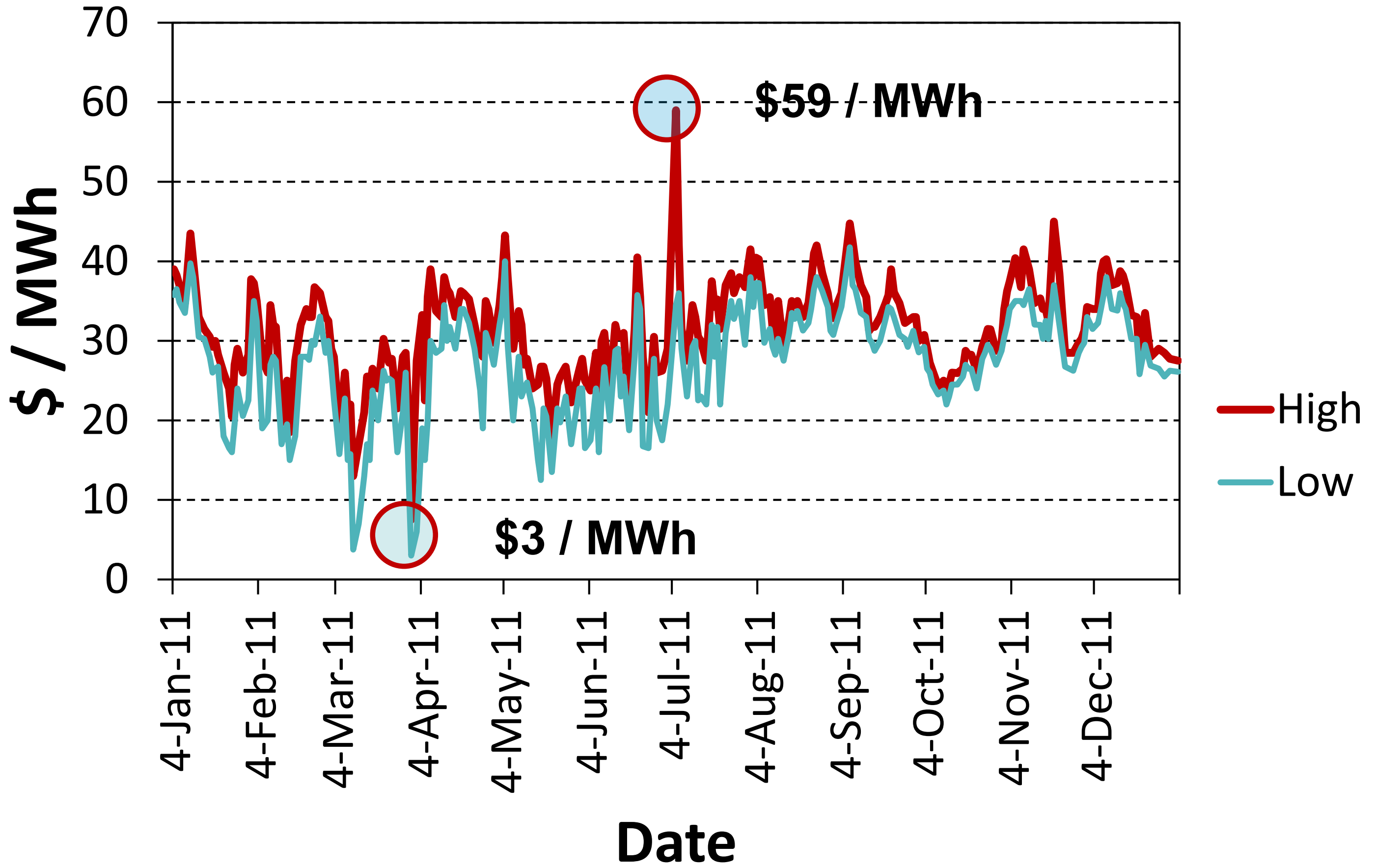
- Any updates / questions on projects?

Four Factors in Energy Storage of Electricity

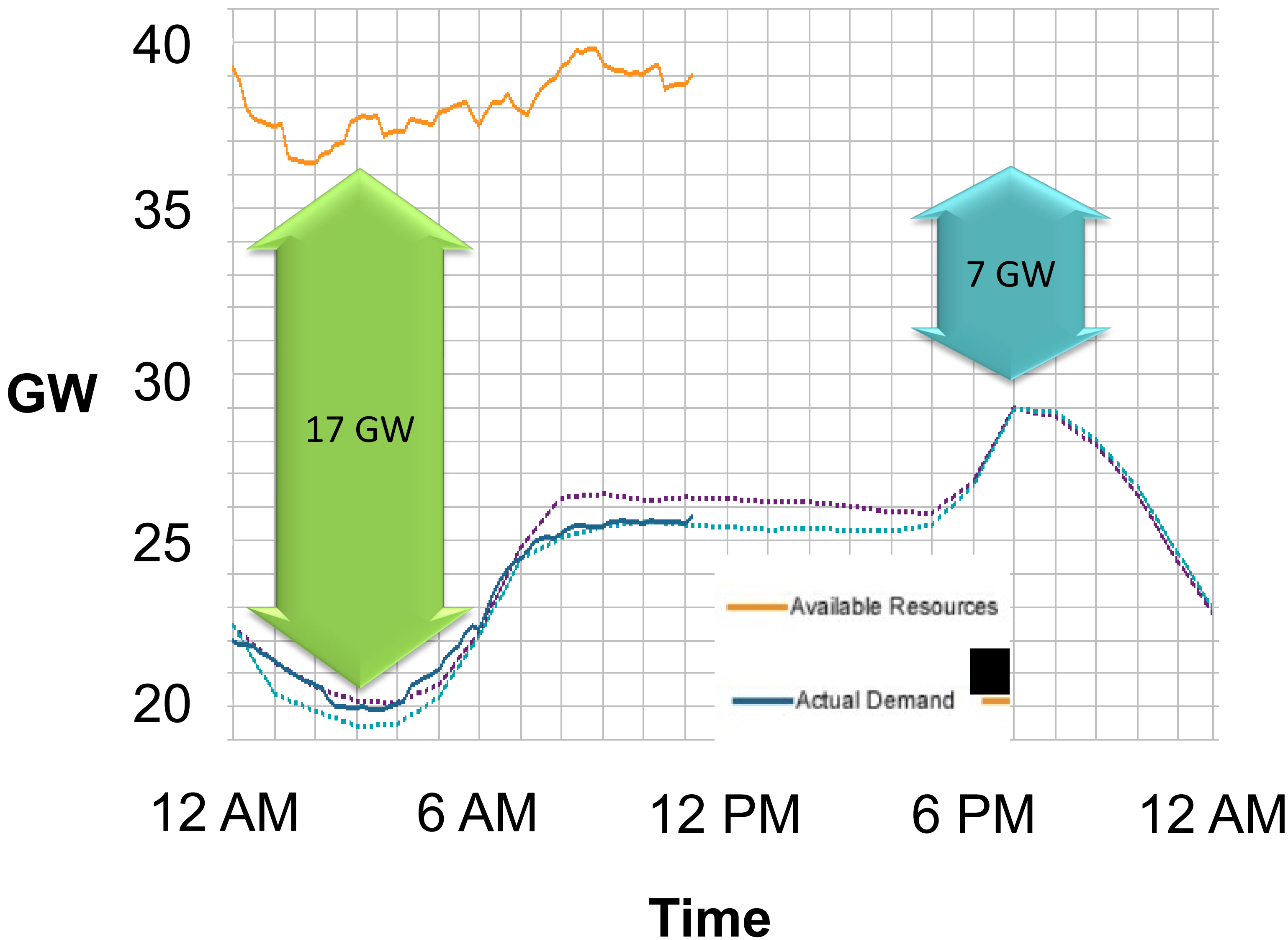
Time (hr)	When and How Long?
Service (MW, MWh)	Energy or Power?
Value ($)	Economics?

Recall that electricity also requires A, V, Hz, for us to use. We need to 'store' those attributes as well.

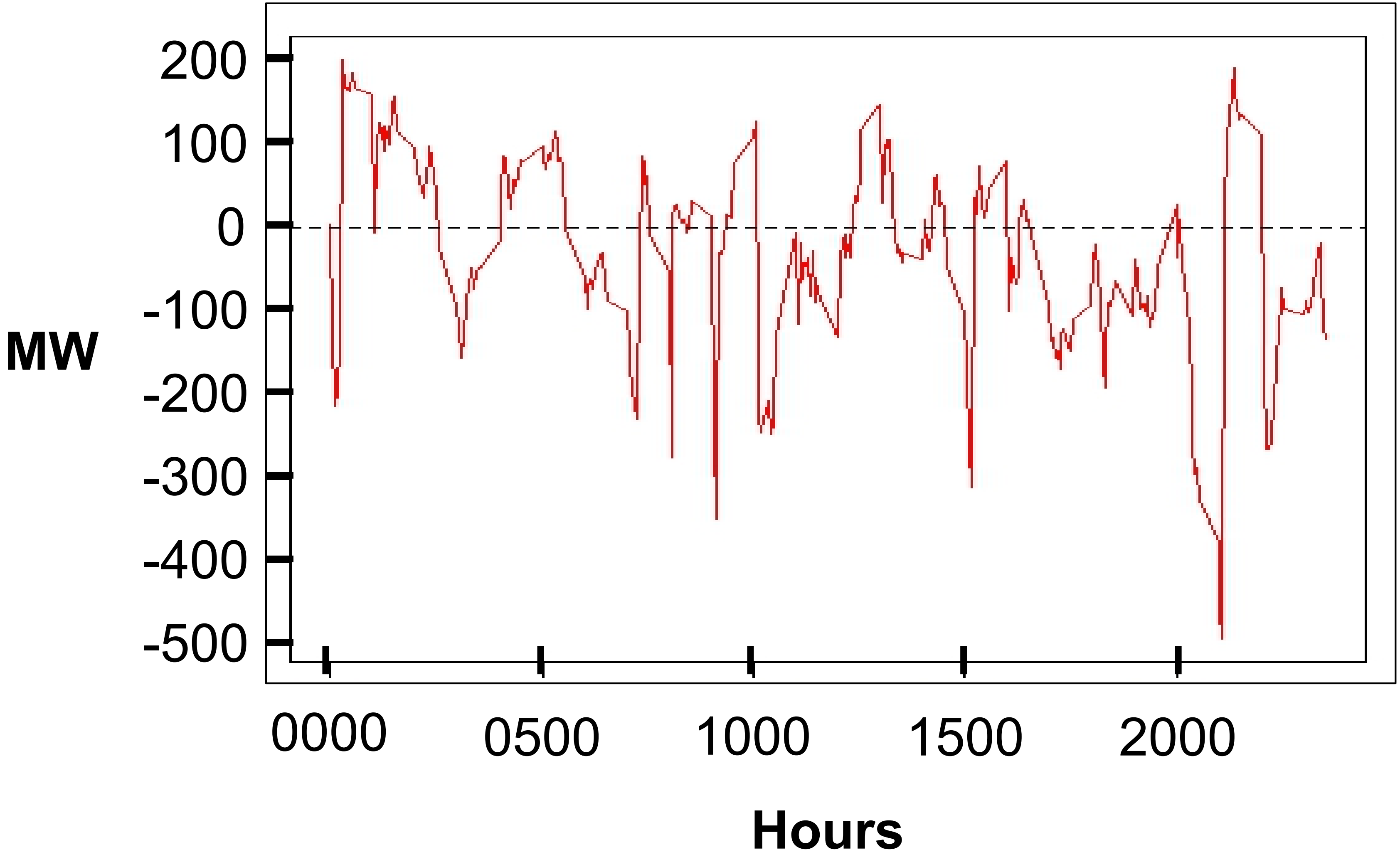
Wholesale Market Mid-Columbia



5/7/2012 CAISO Load Curve



4/29/2012 Hourly Wind Variability

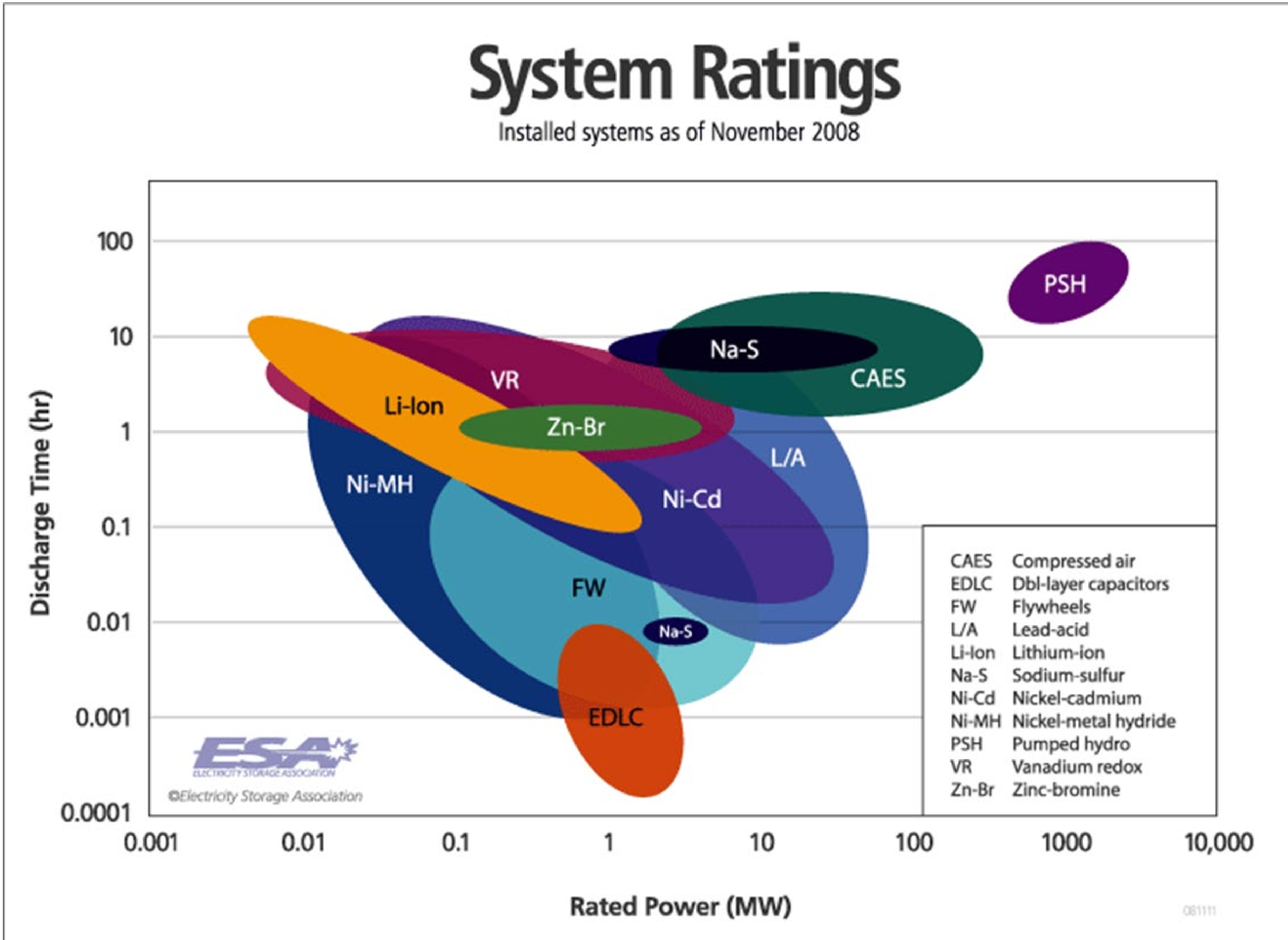


http://transmission.bpa.gov/business/operations/wind/default.aspx

Three Potential Solutions

- Supply Side: Store Energy when abundant, dispatch when scarce *(eg, batteries)*

- Demand Side: Use energy when abundant, conserve when scarce *(eg, demand response, peak load management)*


System Ratings
Installed systems as of November 2008
Discharge Time (hr)
100
10
1
0.1
0.01
0.001
0.0001
0.001
0.01
0.1
1
10
100
1000
10,000
Rated Power (MW)
PSH
Na-S
CAES
VR
Li-Ion
Zn-Br
L/A
Ni-MH
Ni-Cd
FW
Na-S
EDLC
CAES Compressed air
EDLC Dbl-layer capacitors
FW Flywheels
L/A Lead-acid
Li-Ion Lithium-ion
Na-S Sodium-sulfur
Ni-Cd Nickel-cadmium
Ni-MH Nickel-metal hydride
PSH Pumped hydro
VR Vanadium redox
Zn-Br Zinc-bromine
©Electricity Storage Association

Chemical Energy Storage

Supercapacitors

High Power delivered over a **Short Time**
with a **Rapid Recharge** and a **Long Service Life**

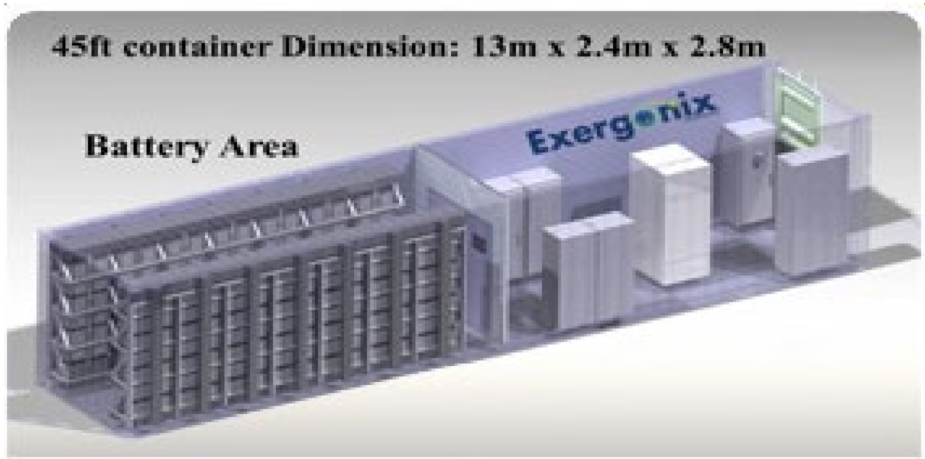
Bridges the gap between batteries and electrolytic capacitors

Material:	All kinds of metals & advanced materials
Energy Density:	10% that of conventional batteries 10,000 that of electrolytic capacitors
Power Density:	10-100 that of conventional batteries 50% that of electrolytic capacitors
To Power 1,000 Homes for Day:	1,000 to 60,000 tons $600 million dollars
Applications:	Energy fluctuation damping ("filtering") Many cycles of charging & release Rapid power delivery Safe & forgiving even if abused

Lead-acid battery

- **Pros**: Supplies high surge currents, large power-to-weight ratio
- **Cons**: Low energy-to-weight ratio, low energy-to-volume ratio
- **Uses**: Car engines
- **Issues:** Corrosion, lead is not healthy

LITHIUM-ION BATTERY STORAGE



MATERIALS

- lithium cobalt oxide ($LiCoO2$) or lithium iron phosphate ($LiFePO4$)
- carbon(graphite)

ENERGY DENSITY

- 3.7V = >200 wh/kg

SIZE

- Picture shows 1MW

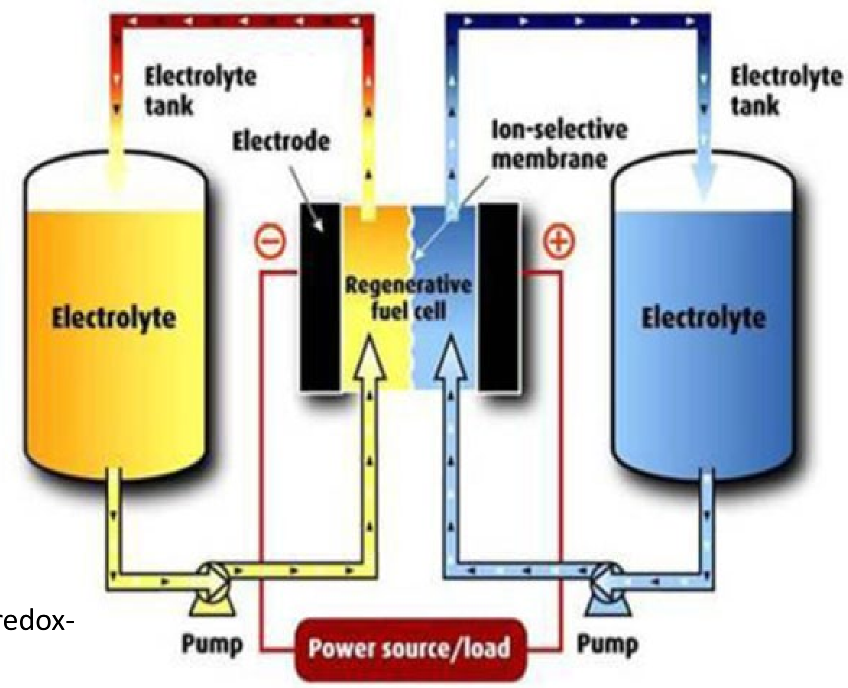
COST

- Approx. $27M

Vanadium Redox Battery:

- Vanadium occurs naturally in ~65 minerals and fossil fuel deposits. It is produced from steel smelter slag, from flue dust of heavy oil processing, or as a byproduct of uranium mining.
- Also mined, ex: open pit, heap leach Gibellini project mine in Nevada
- Energy Density: 15-25 Wh/L (currently 25 Wh/kg)
- 1.2-2Million Liters, or ~16-26 40' shipping containers to power 1000 homes for 1 day
- Currently $0.08 per KWh per cycle, target $0.04. Above example: $2400 per day (target $1200)

*storage and power levels can be scaled independently, as energy storage duration is a simple function of how much electrolyte its tanks hold



http://spectrum.ieee.org/energywise/energy/renewables/vanadium-redox-gaining-ground-in-energy-storage

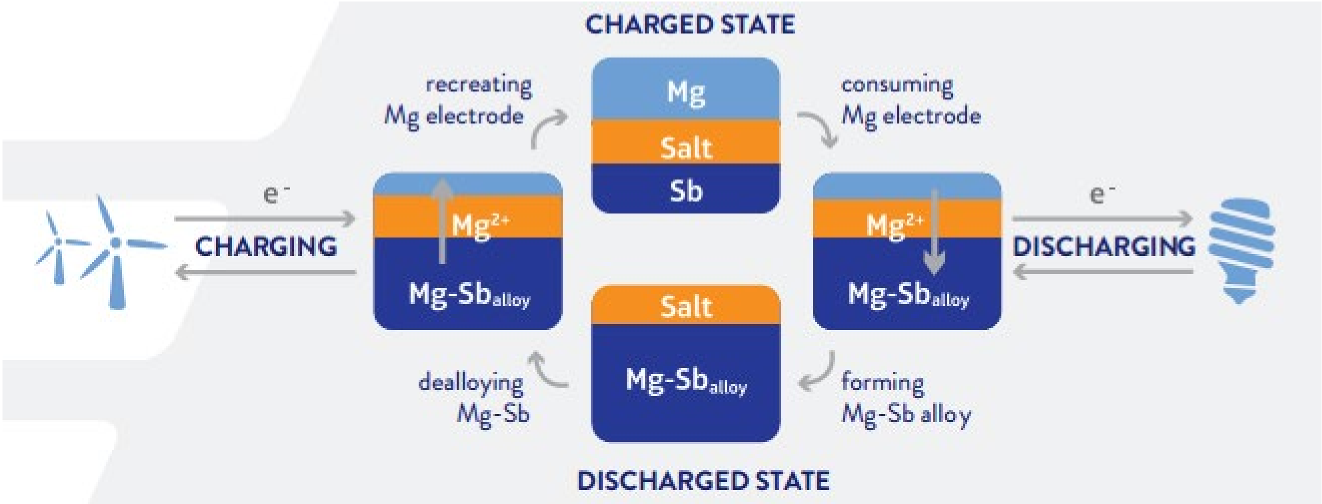
Liquid Metal Batteries

Electrochemical cells made from cheap, abundant natural resources: *"If you want something to be dirt cheap, make it out of dirt – American dirt!"* – Donald Sadoway, MIT

Magnesium, Salt, Antimony, TBD by ARPA-E

Power density is around 6 kW per cubic meter

- 1000 hh x 1 kW = 1 MW discharge capacity
- 1000 hh x 30 kWh = 30 MWh storage capacity
- Size ~15x 40 ft shipping containers (2 MWh each)
- Cost ~$300 per kWh = $9,000,000 CapEx



Interlude

- http://www.youtube.com/watch?v=fILdYrxnrf8

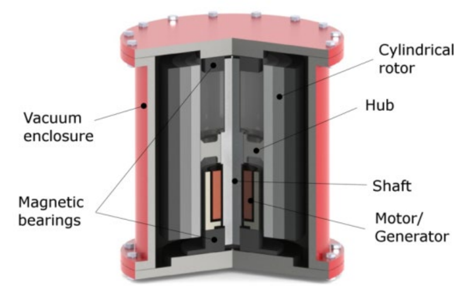
Mechanical Energy Storage

http://www.thisiscolossal.com/2013/11/the-writer-automata/

Flywheel

or you spin me round round baby round round

How It Works: Flywheel energy storage works by accelerating a cylindrical assembly called a rotor (flywheel) to a very high speed and maintaining the energy in the system as rotational energy. The energy is converted back by slowing down the flywheel. The flywheel system itself is a kinetic, or mechanical battery, spinning at very high speeds to store energy that is instantly available when needed. Advanced FES systems have rotors made of high strength carbon filaments, suspended by magnetic bearings, and spinning at speeds from 20,000 to over 50,000 rpm in a vacuum enclosure.



Energy Density: 100–130 W·h/kg

1000 Home Power: using the flywheel project in NY as a direct comparison you'd need 300 flywheels

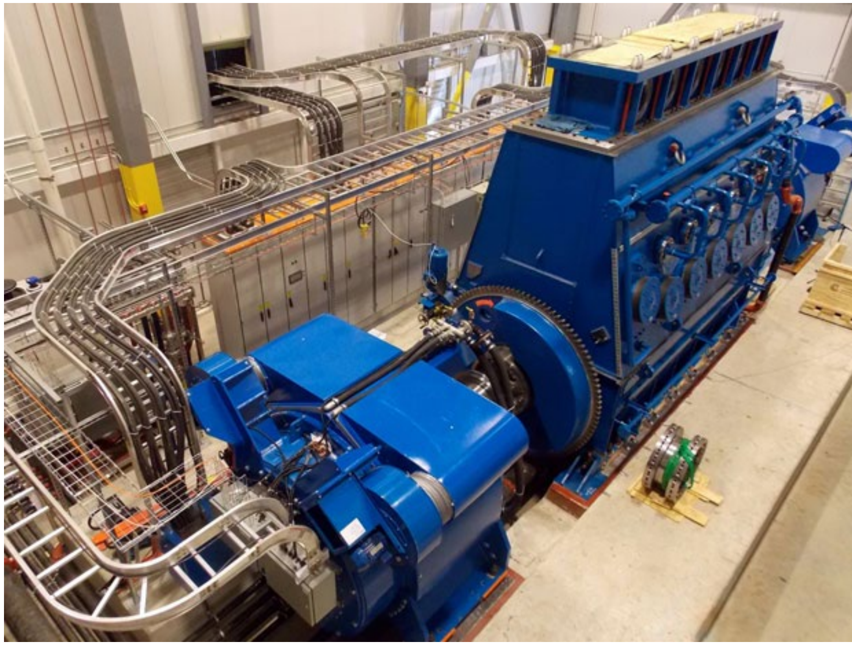
Cost: Costs of a fully installed flywheel UPS are about $330 per kilowatt. In combination with a diesel generator set or integrated design, it supplies continuous power as long as there is fuel. (Wiki)

New Flywheel Raises Hopes for Energy Storage Breakthrough:
http://www.scientificamerican.com/article/new-flywheel-design/

Compressed Air Energy Storage (CAES)

Method of storing energy using the basic principles of physics:
as air is compressed, heat is generated and stored

- "The appeal of this technology is that it's relatively low cost and can store many kilowatt-hours of energy."
- Energy Density = 100 kJ/m^3
- SustainX produces1.65 megawatts w/a $5.4 million investment from DOE
- 18.18x the SustainX unit to power 1,000 homes for 1 day



http://en.wikipedia.org/wiki/Compressed_air_energy_storage
http://spectrum.ieee.org/energywise/energy/the-smarter-grid/compressed-air-energy-storage-makes-a-comeback

Technology: Pumped Hydro

• What is the material and where does it come from?

•The method stores energy in the form of potential energy of water, pumped from a lower elevation reservoir to a higher elevation.

•Materials are same as for a conventional hydroelectric dam (e.g., a lot of steel and concrete).

• What is the energy density?

•requires either a very large body of water or a large variation in height.

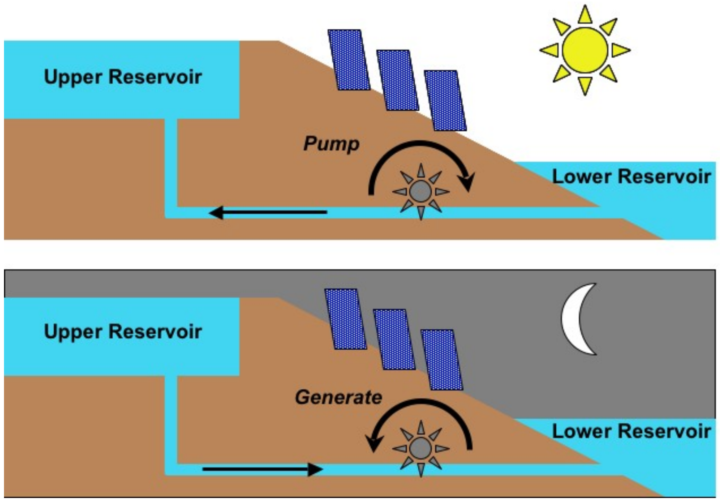
•For example, 1000 kilograms of water (1 cubic meter) at the top of a 100 meter tower has a potential energy of about 0.272 kW·h (capable of raising the temperature of the same amount of water by only 0.23 Celsius = 0.42 Fahrenheit).

•How large would it have to be to power 1000 homes for 1 day?

  ○ 30,000 kWh would require 110,294 m3

• What would be the estimated cost to build it?

•A pumped storage station costs in excess of US$1000/kW

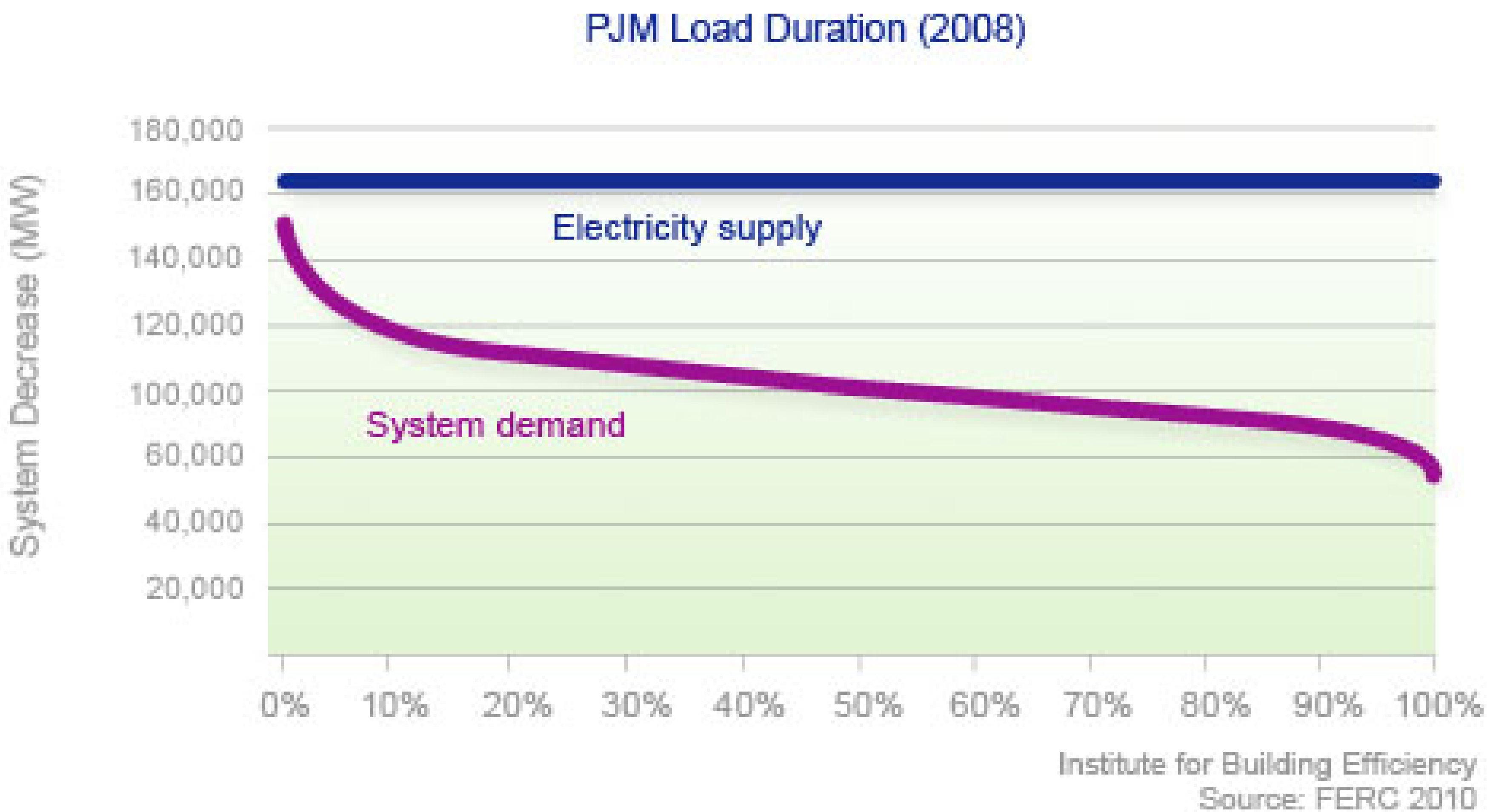


Item	Tumut 3 Costs (1967)	Current Estimate (2009)
Access roads		$60,000,000
Tunnels		$3,295,500,000
Surge shafts		$201,013,774
Steel tunnel lining (1,000m)		$498,257,125
Surface Pipes (500m)	$8,100,000	$494,700,428
Power station		$104,750,000
Generators	$3,426,465	$68,529,300
Turbines	$3,655,261	$73,105,220
Pumps	$1,651,298	$66,051,920
Transformers	$1,465,267	$29,305,340
Allowance for Other *		$200,000,000
Project Management (10%)		$483,019,933
Total excl. contingency		$5,574,233,040
Contingency (20%)		$1,114,846,608
Total Estimated Cost		**$6,689,079,648**

* Other includes: portal, intake and tailrace structures, access roads and highway modifications to allow equipment to be transported from Sydney to Blowering.

Sources: http://bravenewclimate.files.wordpress.com/2010/04/lang_ps_t1.jpg; https://www.wind-watch.org/documents/cost-of-pumped-hydro-storage/

Applications



Peak Load Management

- By encouraging the consumer to use less energy during peak hours or to move the time of energy to off-peak times, utilities could reduce costs by eliminating the need for peaking power plants. Peaking power plants can be more costly to operate, less efficient, and dirtier.
- By managing the load on a system, helped by smart meters a utility can better manage activities and bring the demand and supply closer to an optimum level.
- Federal Energy Regulatory Commission (FERC) governs rules and policies
- With the advancement of information and communications technology and power systems, Smart Grids have now become readily available to use in the management of peak load.

Demand Response

- In some markets, you can *sell* your avoided electricity consumption back into the market. AKA, you are paid to turn things off.

- In 2012, DR provided over 200 MW of capacity into the PJM system at a locational marginal price of $68 / MWh

- $8.7 million on DR revenue

Battery Backup Power for Energy Storage

"Bess", a grid-level battery backup in Fairbanks Alaska (GVEA)

Batteries produce electricity from chemical energy.

They can be recharged, by adding electricity to reverse the chemical process.

Batteries for large-scale storage often use lead and acid, similarly to car batteries, so are not environmentally benign.

Batteries produce direct current (DC) electricity, so inverters are needed to get AC energy into the grid. This creates a loss in efficiency.

Batteries may be connected in parallel (to increase current) and series (to increase voltage) in arrays that produce the necessary power.

Battery backup systems for grid or data centers include automatic failover switches, so that batteries start providing electricity with minimal or no delay.

Prolific: Home consumers have them for electronics; data centers use them for uninterruptible power; some utilities use them for generator backup.

Economic justification: When loss of grid or generator power is economically damaging.

Rules/policy: Some environmental regulations for battery disposal and safety; some regulated services (such as data centers for emergency management) require continuous uptime.

Energy

- Electricity → Electricity   Battery
- Electricity → Mechanical Flywheel, Compressed Air
- Electricity → Potential   Pumped hydro

- Peak Load Management → Capacity (kW) solution
- Backup Battery Power → Energy (kWh) solution

- Thermal storage (molten salt),
- Embodied energy storage (use energy when abundant)
- Financial storage (sell in surplus, buy in deficit)

Unknown – what will be the *form factor?*

Batteries: Volume and Density

- The chemistry of energy density affects the battery volume

Storage material	Specific energy (MJ/kg)
Uranium-235	83,140,000
Petrol	~46
Fat (animal/vegetable)	37
Coal	24
Carbohydrates (including sugars)	17
Protein	16.8
Wood	16.2
Lithium battery (non-rechargeable)	1.8
Lead-acid battery	0.17
Supercapacitor	0.018

Mechanical: Size and Scope

Japan

Pennsylvania

Flywheel in a Car

Basement CAES

Policy: California AB 2514

- The CPUC established a target for the procurement of 1,325 megawatts of energy storage for the three IOUs — PG&E, SCE, SDGE—by 2020

- "energy storage system" as a "commercially available technology that is capable of absorbing energy, storing it for a period of time, and thereafter dispatching the energy." An energy storage system must "be cost effective" and accomplish one of the following: reduce emissions of greenhouse gases; reduce demand for peak electrical generation; defer or substitute for an investment in generation, transmission, or distribution assets; or improve the reliable operation of the electrical transmission or distribution grid.

Thank you