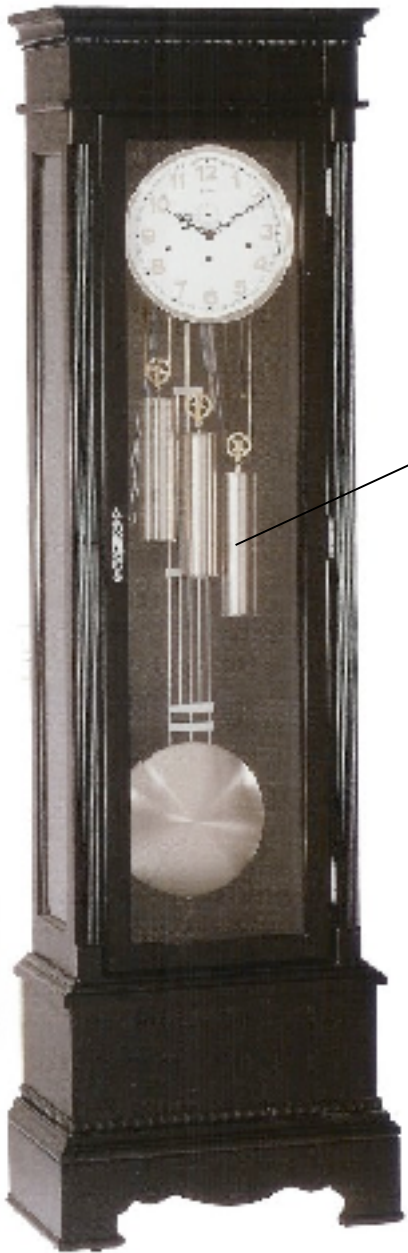




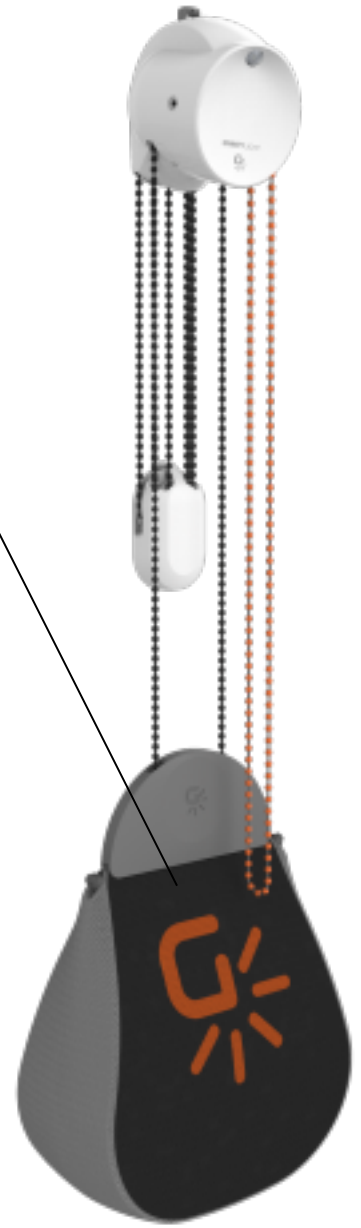
energy storage

Energy
NYU / ITP / Feddersen

Energy can be stored in many forms



Suspended mass





Chemical bonds (in food, firewood, fuel)





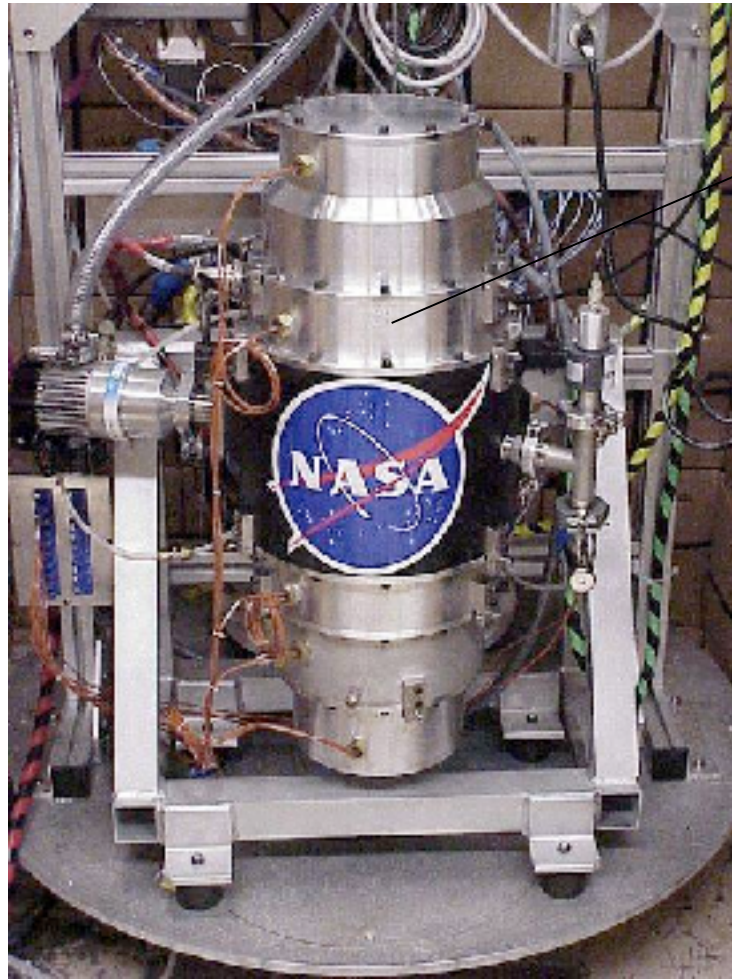
Elastic deformation





Compressed fluid



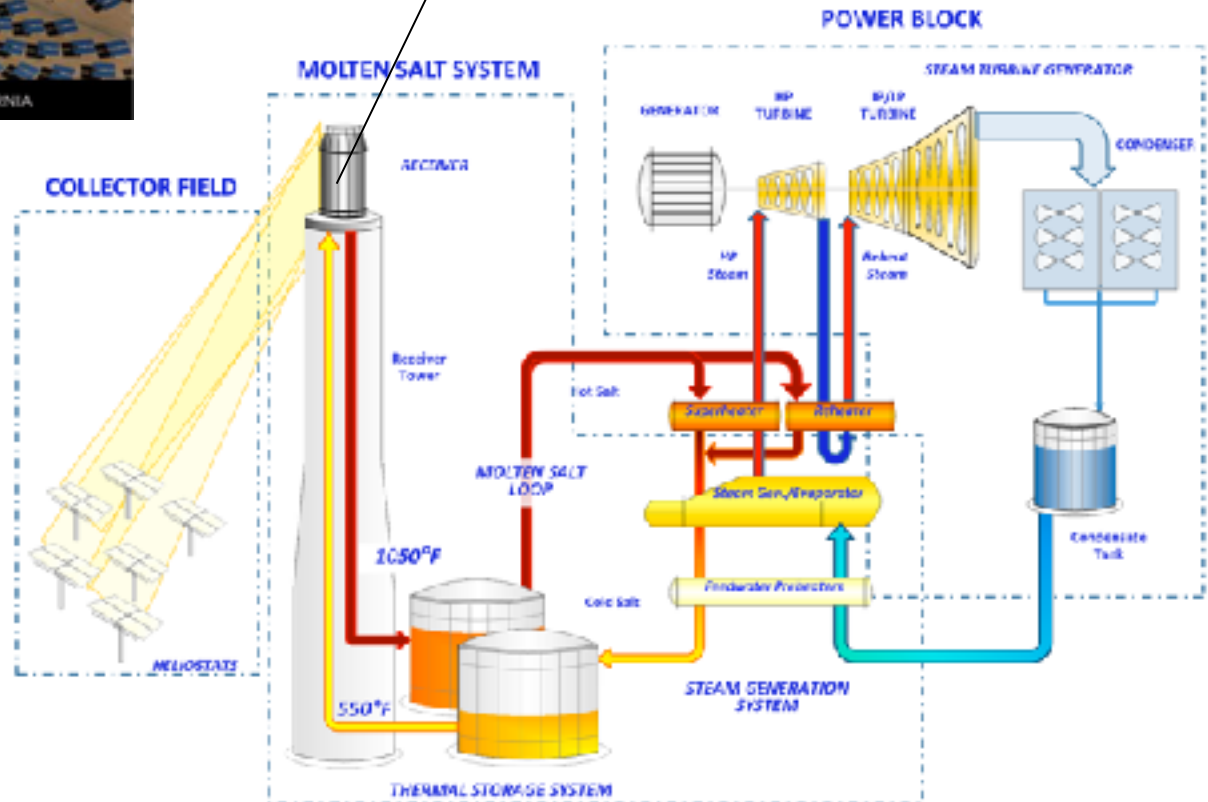


Rotating mass (flywheel)

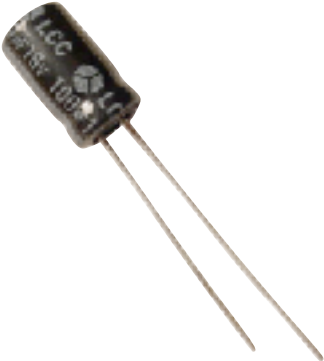




Heat



Electrical potential



Basic concepts for any energy storage:

Specific Energy : energy / mass

Energy Density : energy / volume

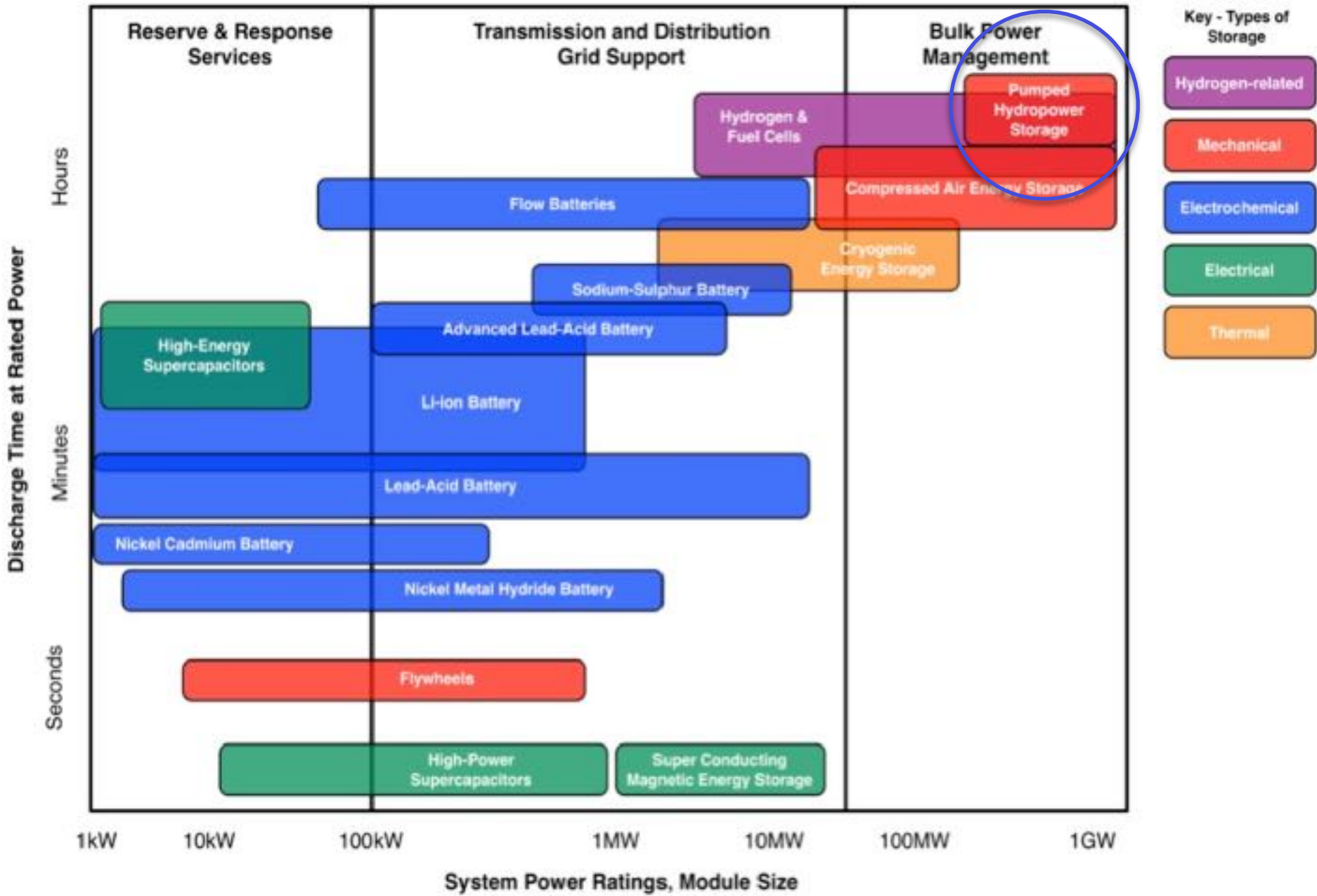
Specific Power : power (input or output) / mass

Power Density : power (input or output) / volume

Efficiency: energy in / energy out

Electrical Power & Energy Storage Comparison





Pumped Hydro



40 plants in US
22GW (2% of grid capacity)*
96% of global tracked storage**

*<https://www.eia.gov/>

** https://en.wikipedia.org/wiki/Pumped-storage_hydroelectricity

image: <https://www.masterbuilder.co.in/india-improve-renewable-power-storage-pumped-storage-system/>

Grid-tied batteries starting to make a dent

GTM forecast: 1.6GW in US by 2020

This was built in 2017 in West Caldwell, NJ

896kW solar

250kW/1MWh battery

An aerial photograph of a battery storage facility in West Caldwell, NJ. The facility features a large, rectangular, multi-bay battery storage structure in the foreground, which appears to be filled with a brownish material. To the left and in the background, there are several large solar panel arrays. The facility is surrounded by green grass and trees. A white arrow points from the bottom left towards the battery structure, with the text '250kW/1MWh battery' written along its length. In the upper right area, there is a label '896kW solar' pointing to a solar panel array. The overall scene is a mix of industrial infrastructure and natural greenery.

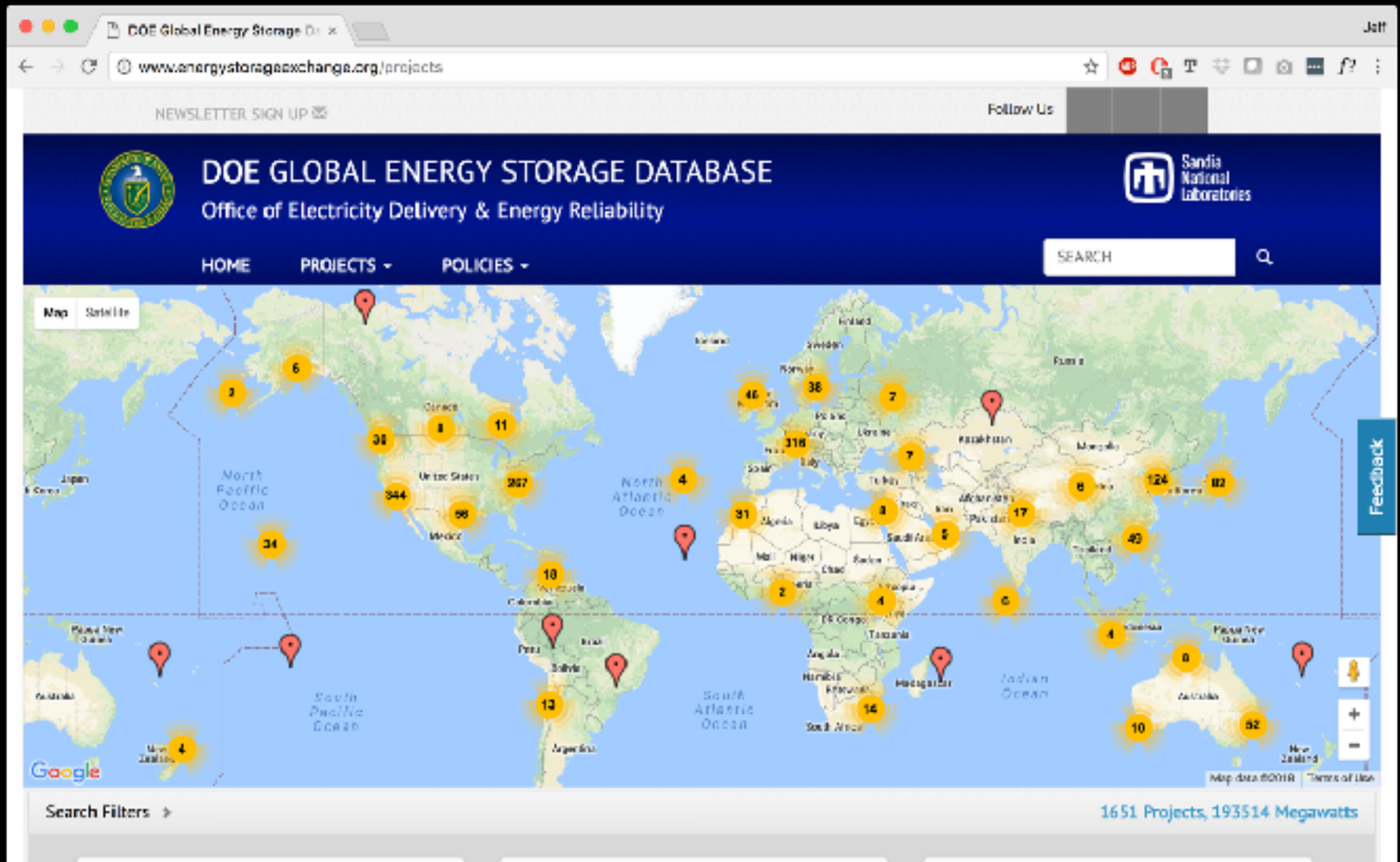


Coal storage

This was shuttered in 2017 in Jersey City

660MW

DOE Storage Database



A sustainable system by definition uses energy at or below the rate it is generally available from the environment.

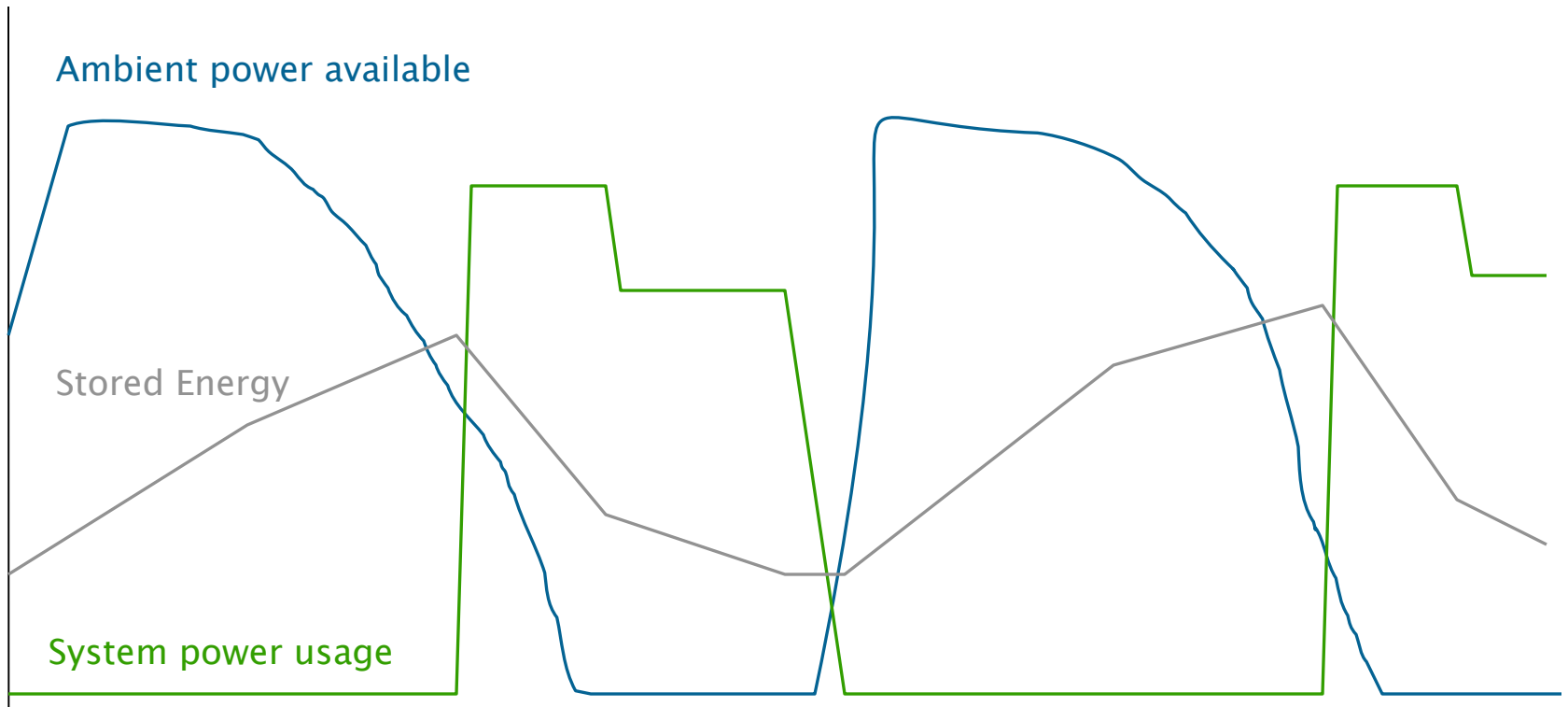
However, it may be necessary for a system to:

- **time shift** energy usage independent of fluctuating ambient availability
- **momentarily exceed** the ambient power available
- and/or handle momentary **power interruptions**

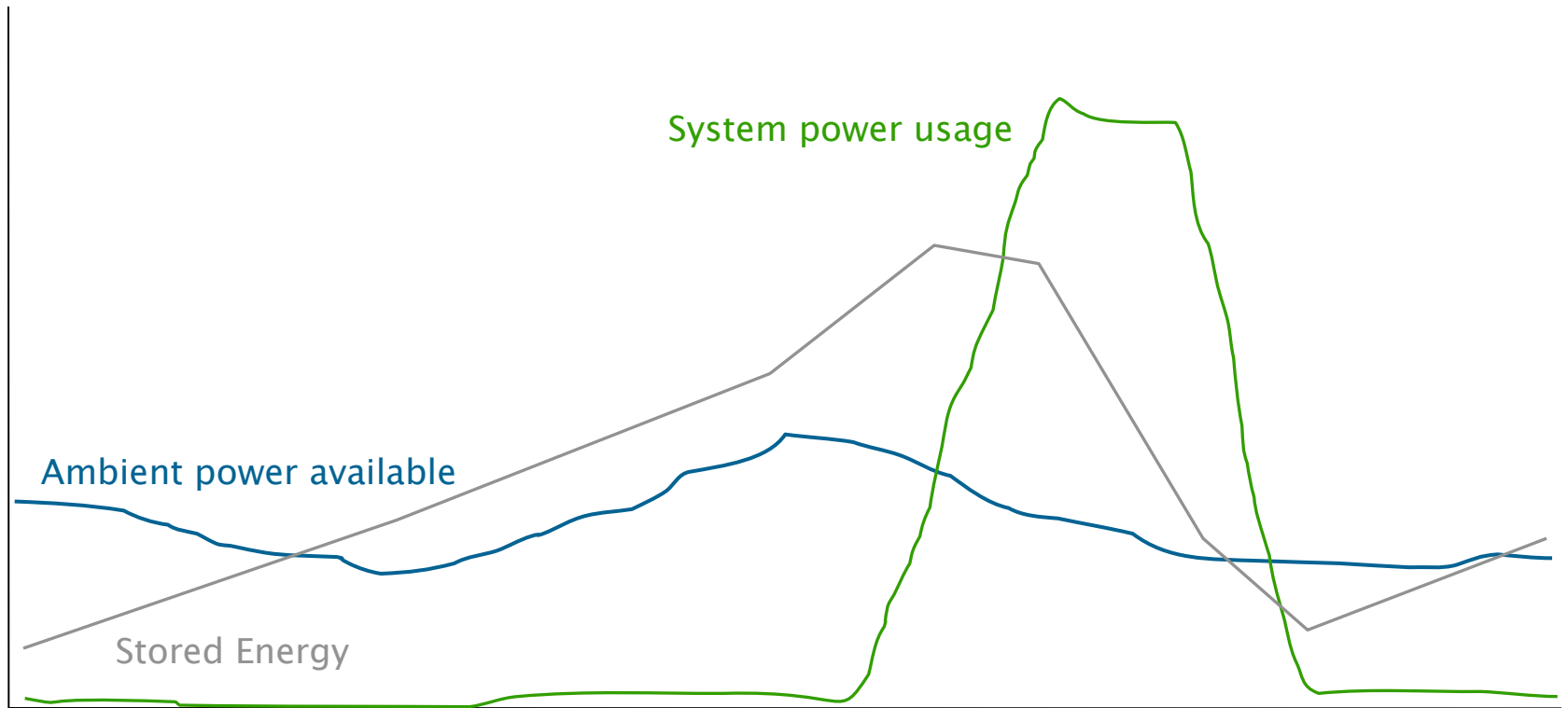
In these cases, **energy storage** will be necessary.

Time shift

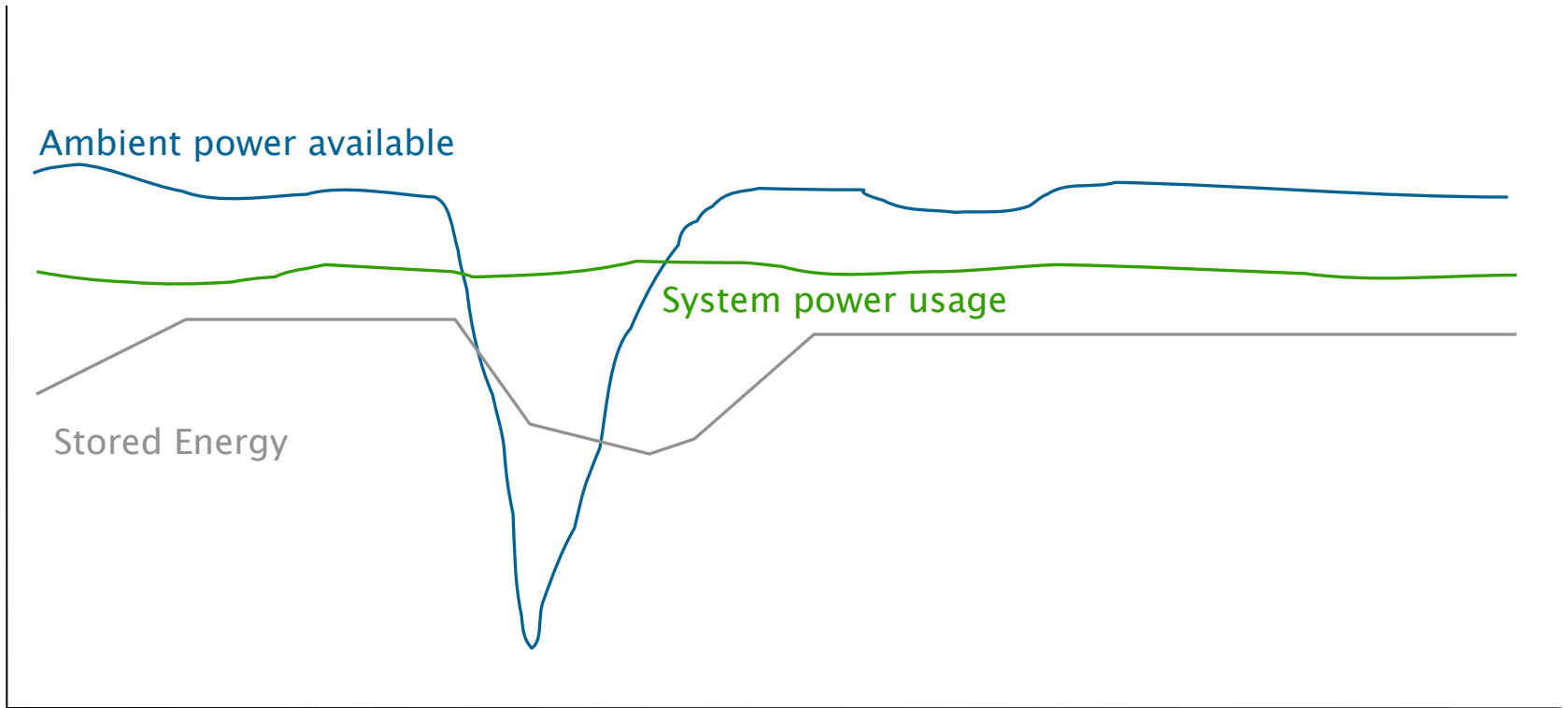
Energy usage is out of phase with ambient availability:



System requires higher momentary power than is available from the environment:



System must handle power fluctuations:



Smoothing



$$.5 * (100 \text{ microfarads}) * ((5 \text{ volts})^2) = 0.00125 \text{ joules}$$

[More about calculator.](#)



$$.5 * (3300 \text{ microfarads}) * ((5 \text{ volts})^2) = 0.04125 \text{ joules}$$

[More about calculator.](#)



$$.5 * (1 \text{ farad}) * ((5 \text{ volts})^2) = 12.5 \text{ joules}$$

[More about calculator.](#)



$$.5 * (60 \text{ farad}) * ((5 \text{ volts})^2) = 750 \text{ joules}$$

[More about calculator.](#)

Energy in a capacitor
is:

$$1/2 C * V^2$$

Storage

*

Would need 2
2.5V caps in series
to get 5V.

Lots of joules



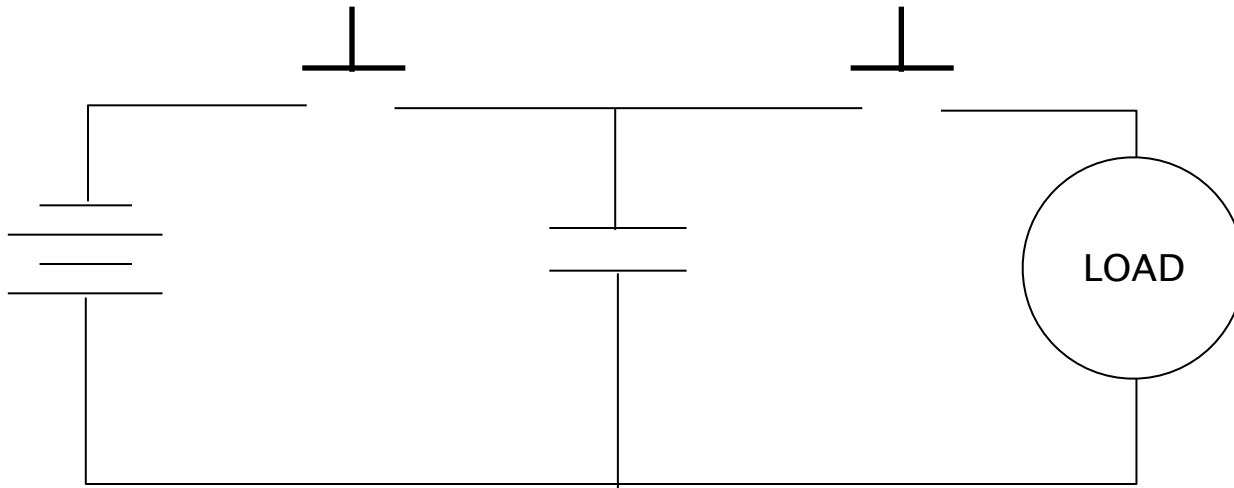
*



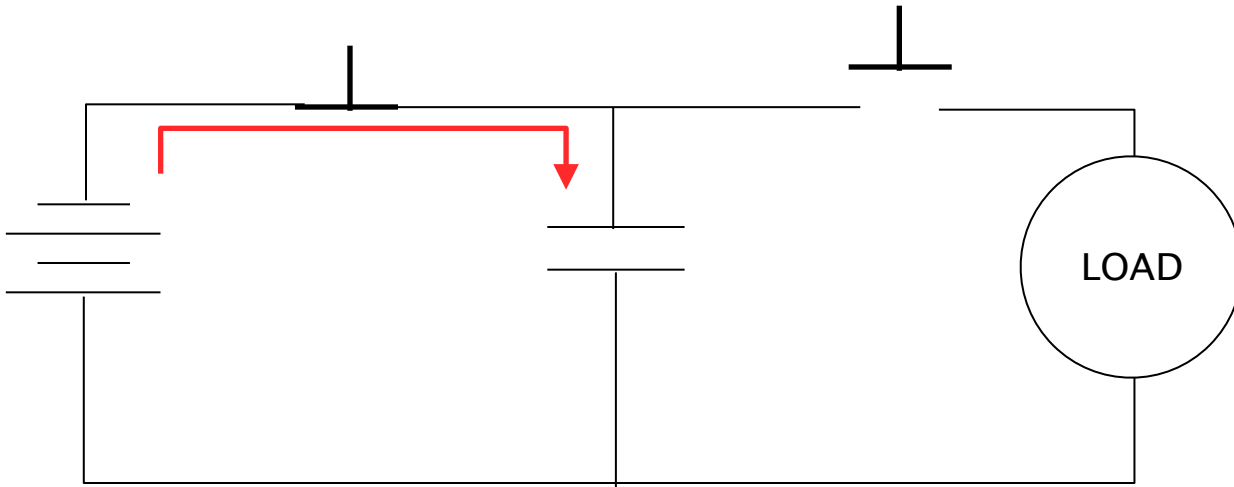
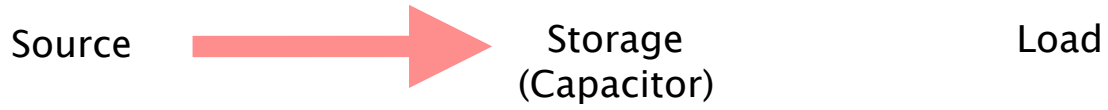
Source

Storage
(Capacitor)

Load



Charging



Capacitor
Voltage

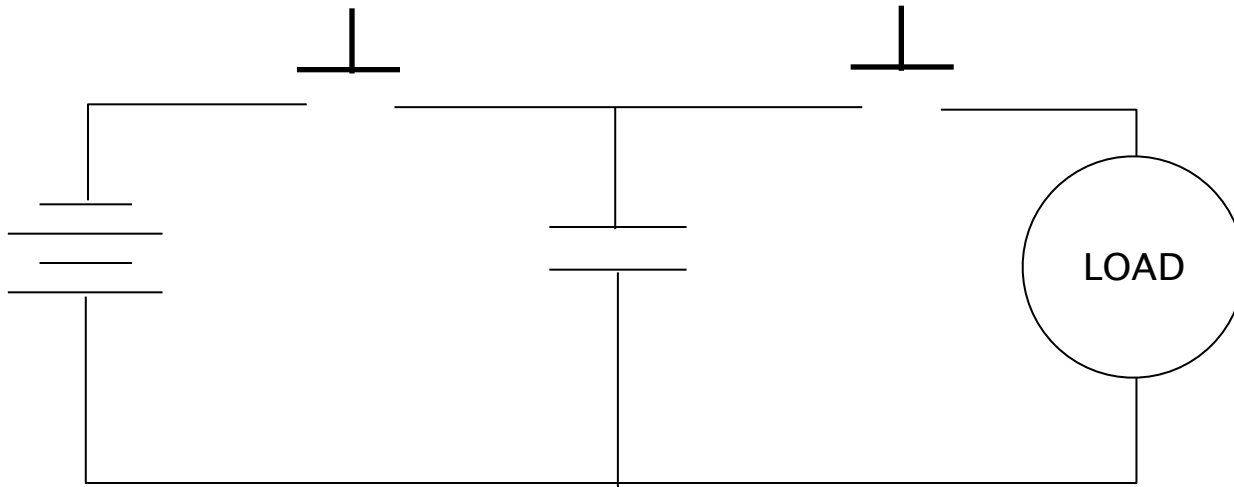


Stasis

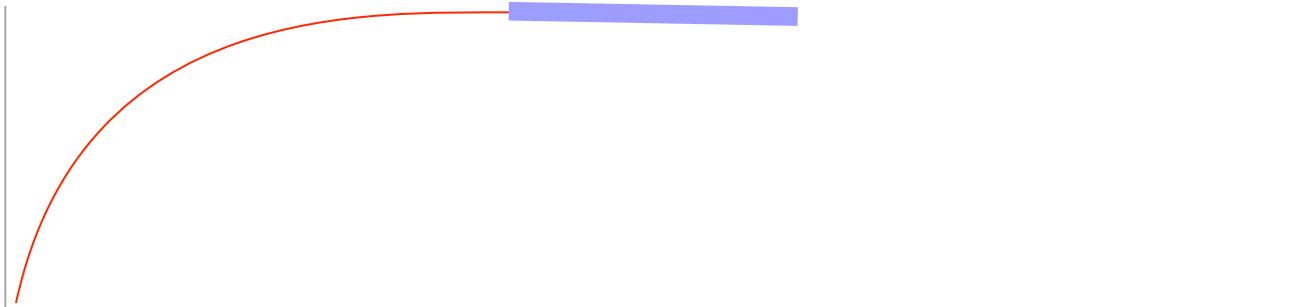
Source

Storage
(Capacitor)

Load



Capacitor
Voltage



Discharge

