Overview of

Energy Storage Technologies

For Renewable Integration

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California Energy Commission

Examples of Energy Storage Technologies

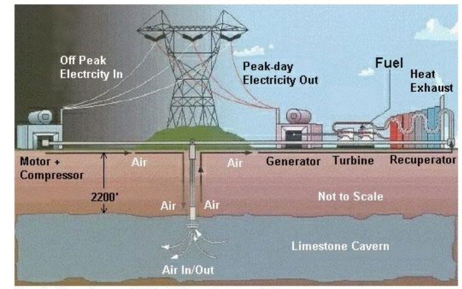


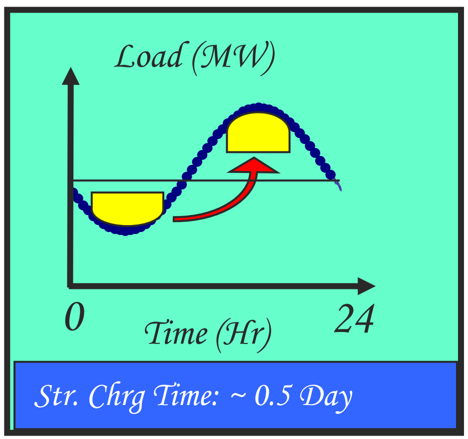
Photo Courtesy of CAES Development Company

100 kW, 15 kWh li-ion battery for UPS applications

Photo Courtesy of Saft America

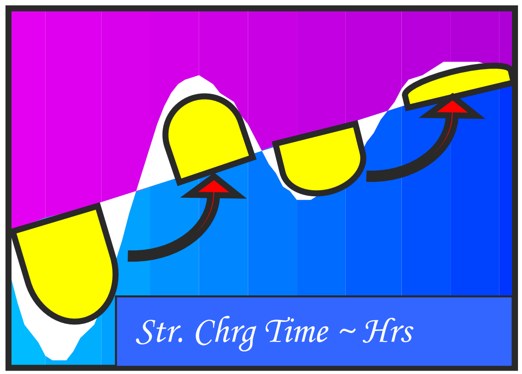
Energy Storage Efficiently Resolves Renewable Power Fluctuation, Ramping and Load Management Issues

Load Leveling



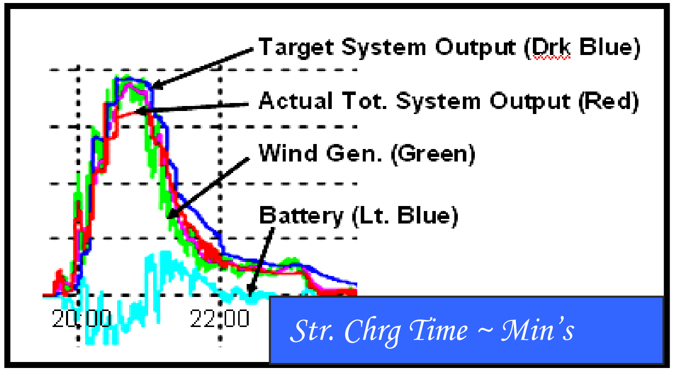
- CAES
- Pumped Hydro

Ramping:



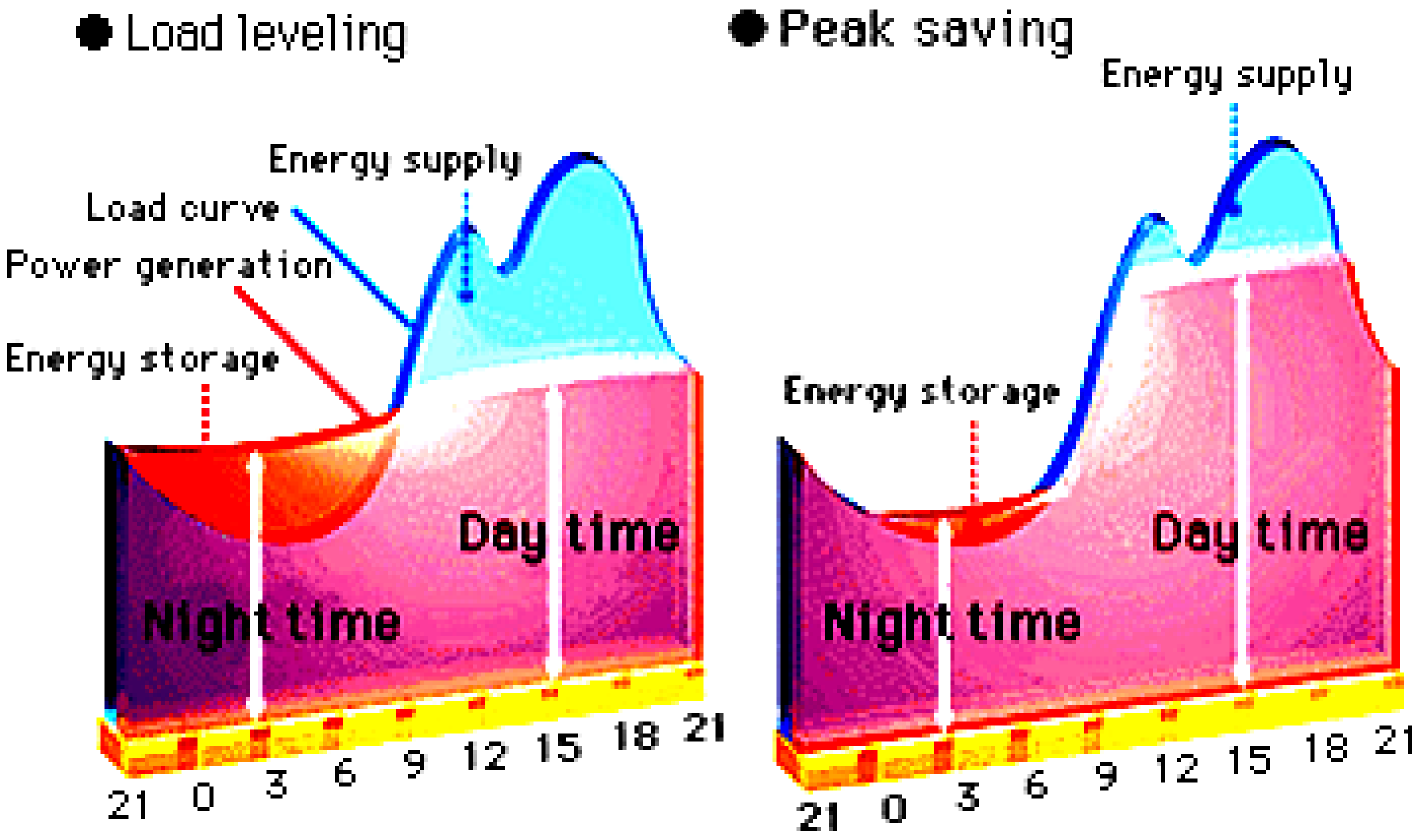
- CAES
- Pumped Hydro
- Battery, Flow type
- Note: In California ramping is a big issue

Frequency Regulation:



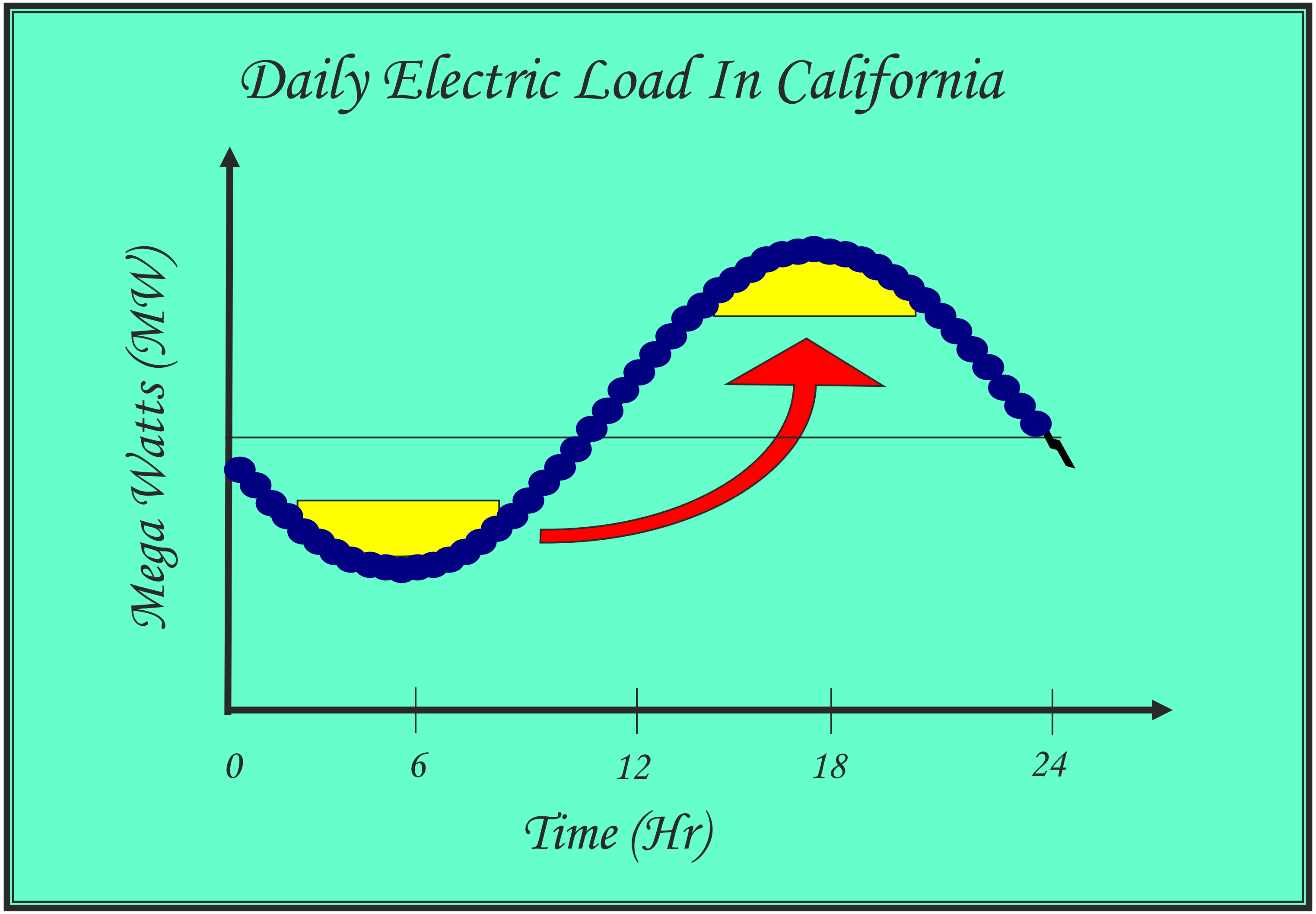
- Battery, Regular or Flow Type
- SuperCap
- Flywheel
- SMES

Energy Storage for Load Leveling and Peak Shaving



Source Tokyo Electric Power Company

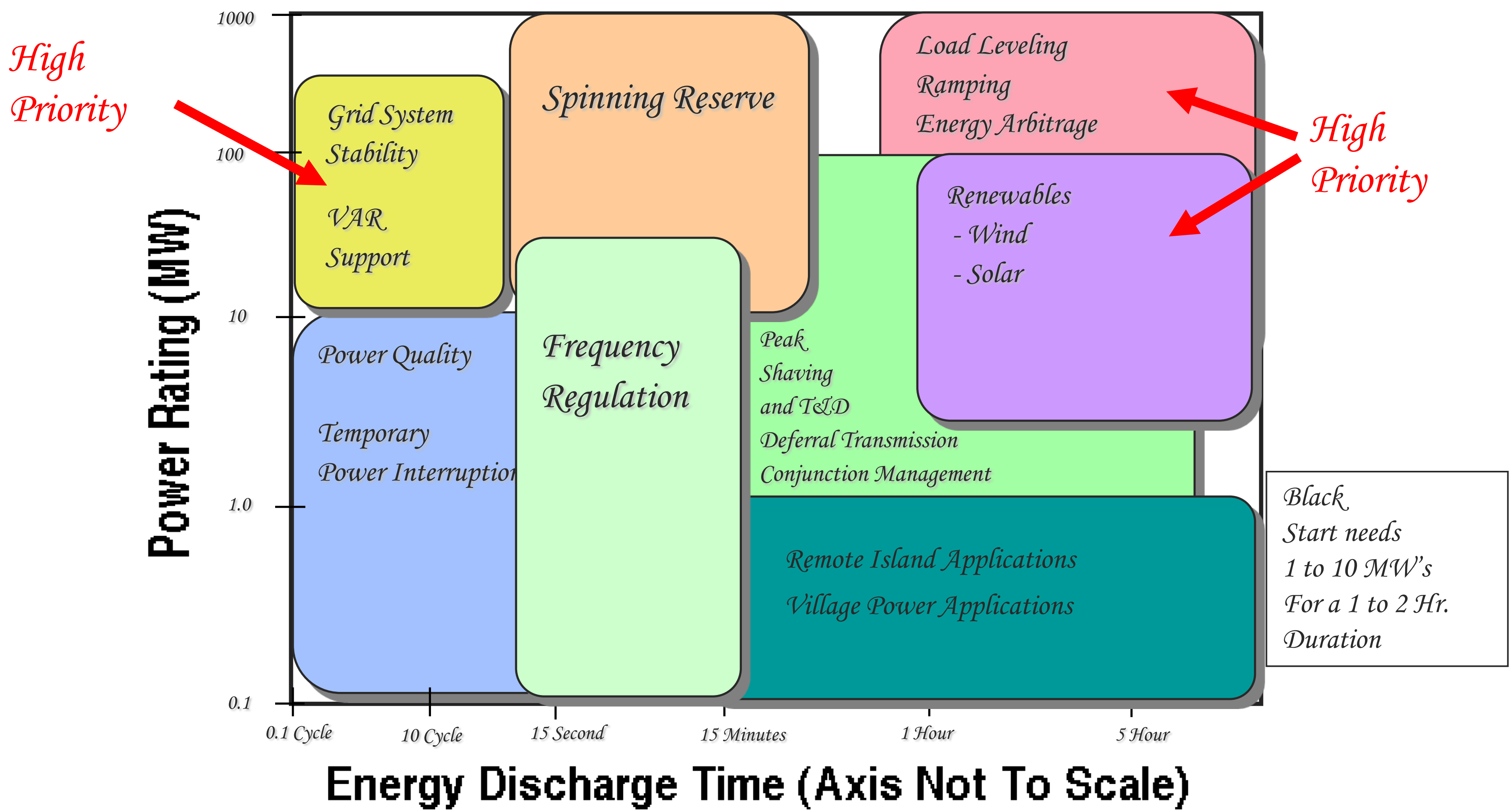
Energy Storage Efficiently Resolves Wind Power Load Management Issues



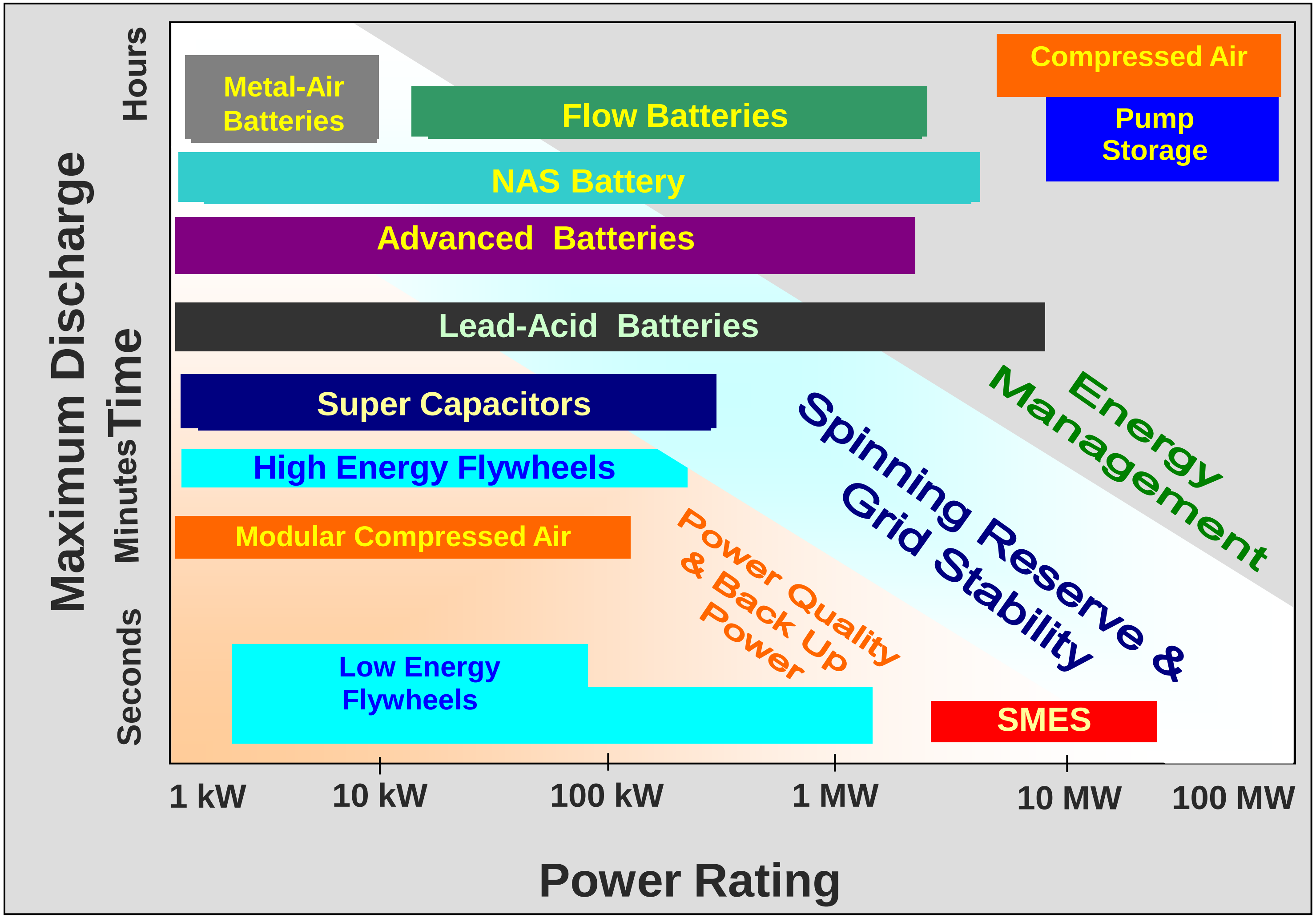
Types of Electric Energy Storage Technologies

- **Pumped Hydro**
- **Compressed Air Energy Storage (CAES)**
- **Flywheels**
- **Batteries**
- **Super-Capacitors (SuperCaps)**
- **Superconducting Magnetics**
- **Thermal Storage**
- **Fuel Cells (reversible)**
- **Hydrogen Storage**

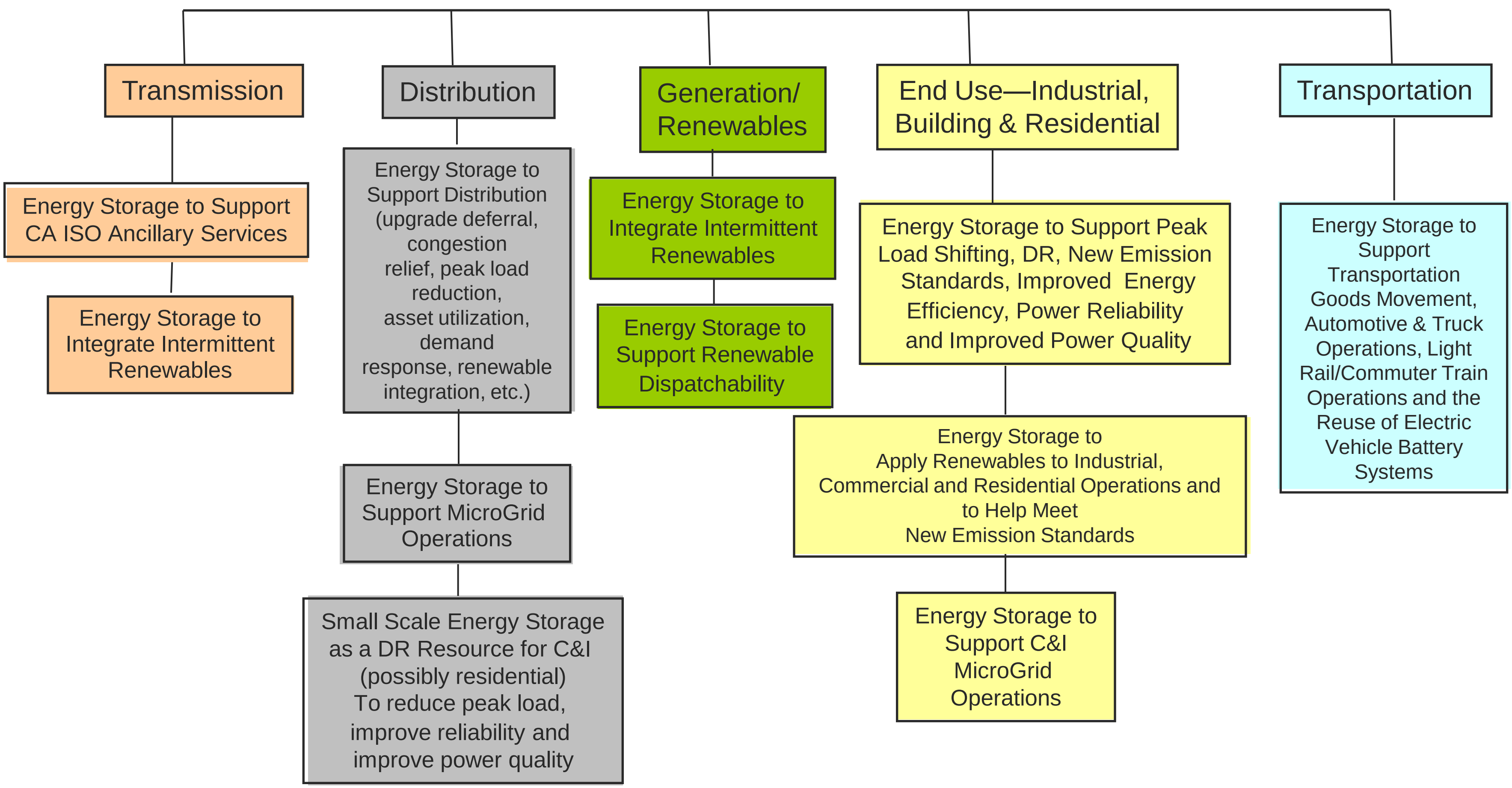
Electric Energy Storage Applications
(All Boundaries Of Regions Displayed Are Approximate)



Electric Energy Storage Technologies

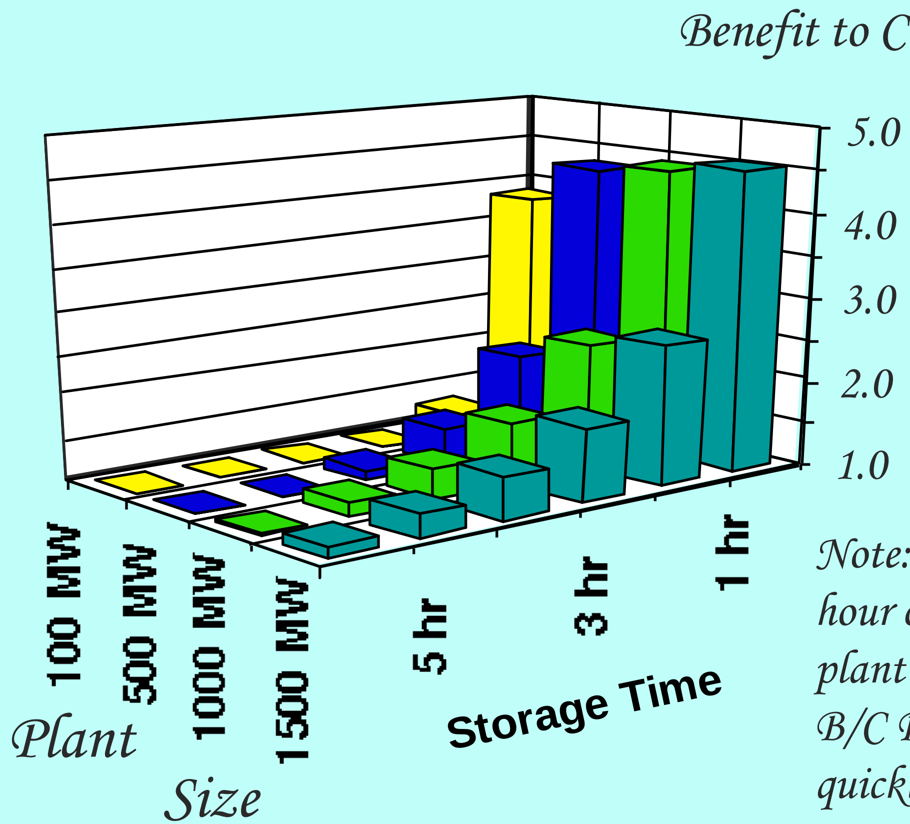


Energy Storage Applications Identified by PIER Subject Areas



Typical Transmission Benefit to Cost Ratio for Battery Plants Versus Hours of Storage and MW Size

Example Results Expected From EPRI Analyses

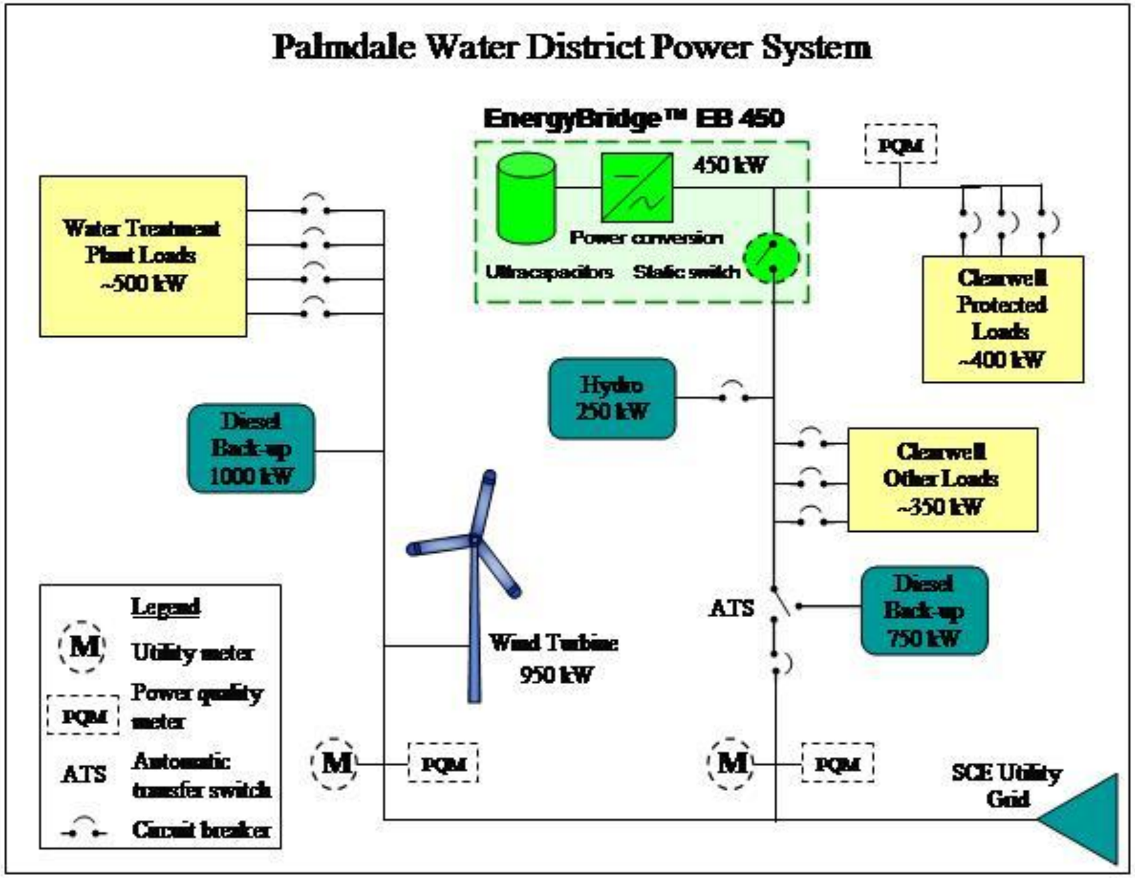


Note: The cost for an extra hour of storage for a battery plant is so expensive that the B/C Ratio goes down relatively quickly, compared to CAES.

PIER Energy Storage Research

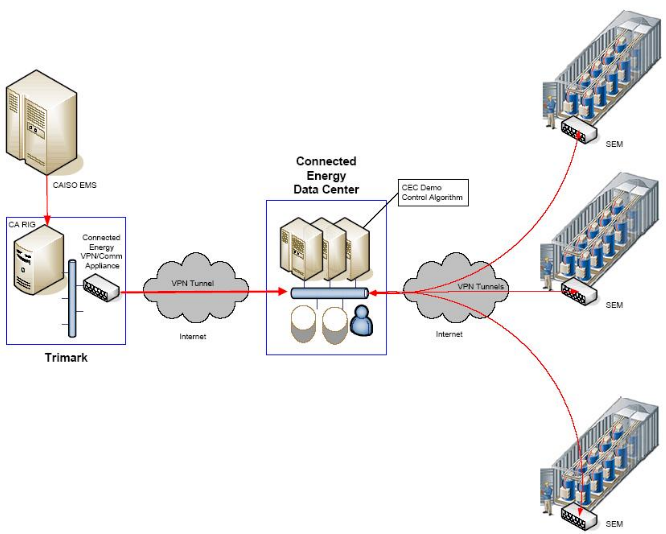
- Active Projects
  - Ultracapacitor Technology
  - Flywheel Technology
  - ZBB
  - VRB
  - CAES (underground and modular above ground)
  - NaS

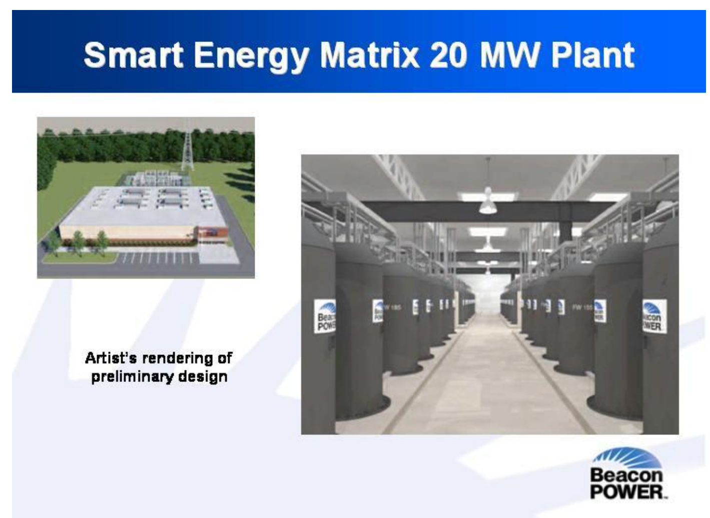
PIER Energy Storage Research
Ultra Capacitor Technology



PIER Energy Storage Research
Ultra Capacitor Technology

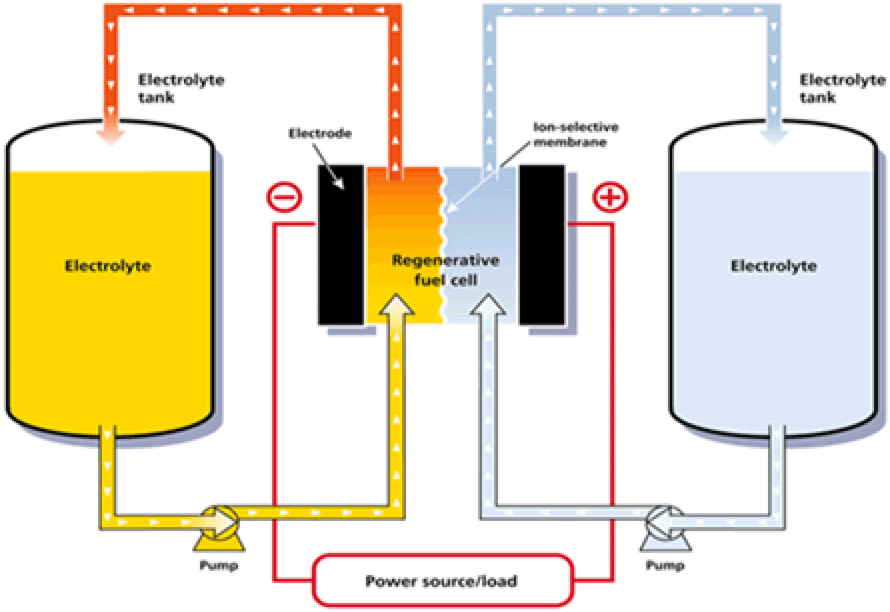
PIER Energy Storage Research
Flywheel Technology





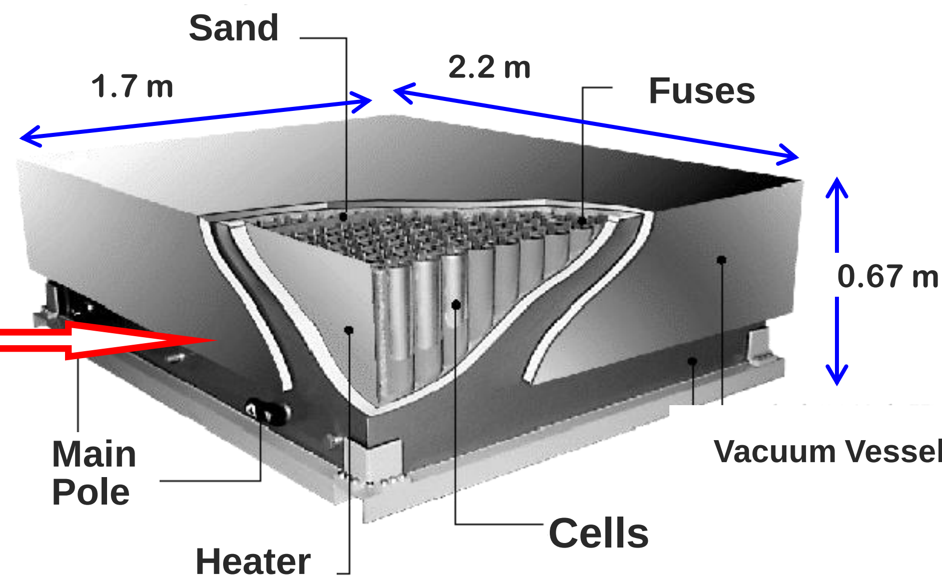
PIER Energy Storage Research
ZBB Technology

PIER Energy Storage Research
VRB Technology



PIER Energy Storage Research
NaS Technology

NAS Battery 8MW / 57.6MWh



Battery Module

PIER Energy Storage Research
NaS Technology

Capacity	2MW
Energy	14.4MWh

PIER Energy Storage Research
PG&E Proposed NaS Installation

PG&E Emerald Lake Substation

(NAS Battery Will Likely Be Installed in the Empty, Back Part of this Substation)

Source: EPRI, Schainker

Capital Cost Comparison of Energy Storage Plant Types

PUBLIC INTEREST ENERGY RESEARCH
"Research Powers the Future"

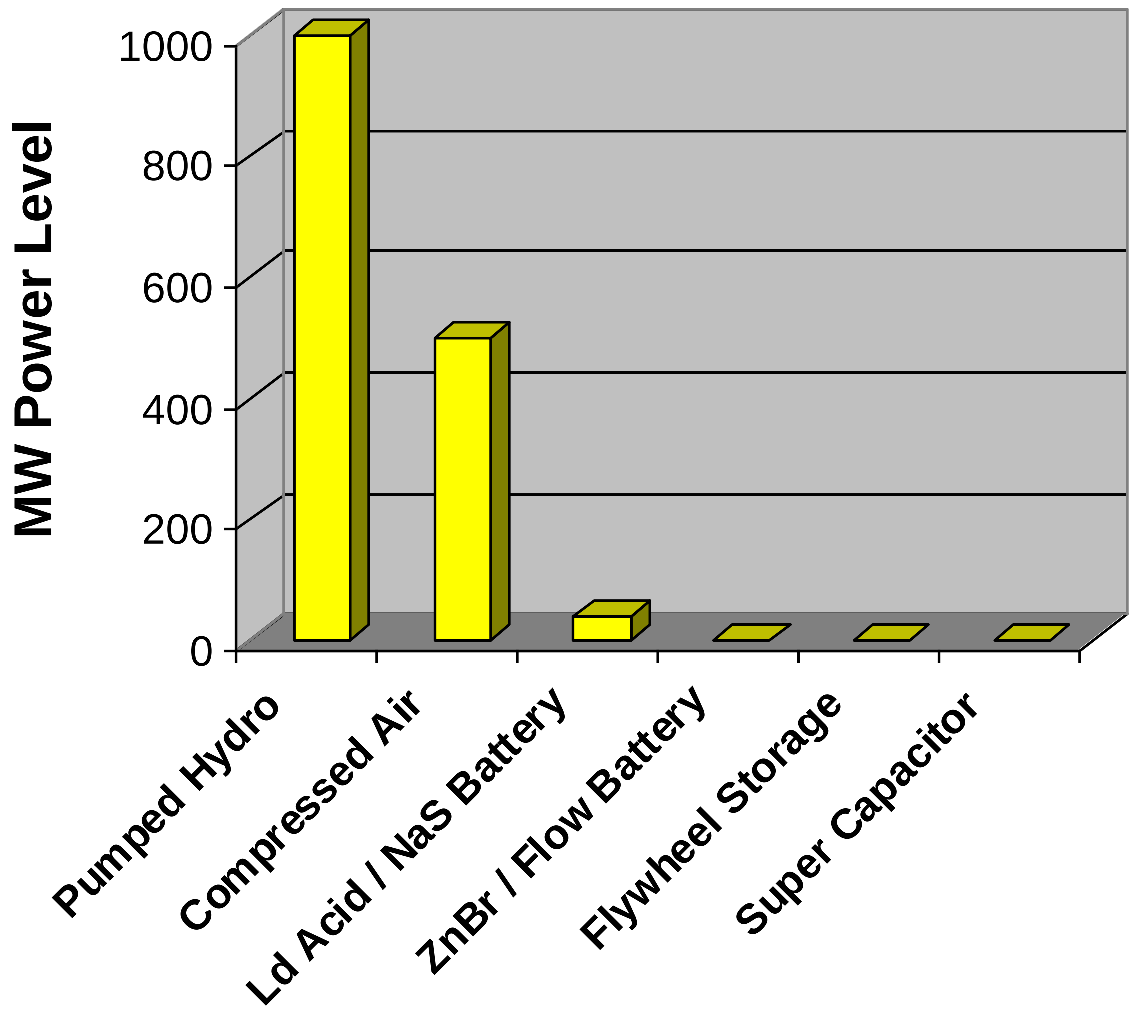
Technology	$/kW	+	$/kWH*	x	H	=	Total Capital, $/kW
Compressed Air, CAES							
- Large (100-500 MW)	440		1		10		450
- Small (10-20MW) AbvGr Str	600		80		2		760
Pumped Hydro, PH							
- Conventional PH (1000MW)	1300		40		10		1700
Battery, BES (target) (10MW)							
- Lead Acid, commercial	250		300		2		1150
- Advanced (NaS/Flow)	250		500		2		1250
Flywheel (target) (100kW)	250		700		2		1650
Superconducting (1MW) Magnetic Storage, SMES (target)	200		1000		2		2200
Super-Capacitors (best today)	250		12000		1/60		450
(target)	250		1200		1/60		270

* This capital cost is for the storage "reservoir", expressed in $/kW for each hour of storage. For battery plants, costs do not include expected cell replacements. EPRI updates these plant costs as technology improvements occur.

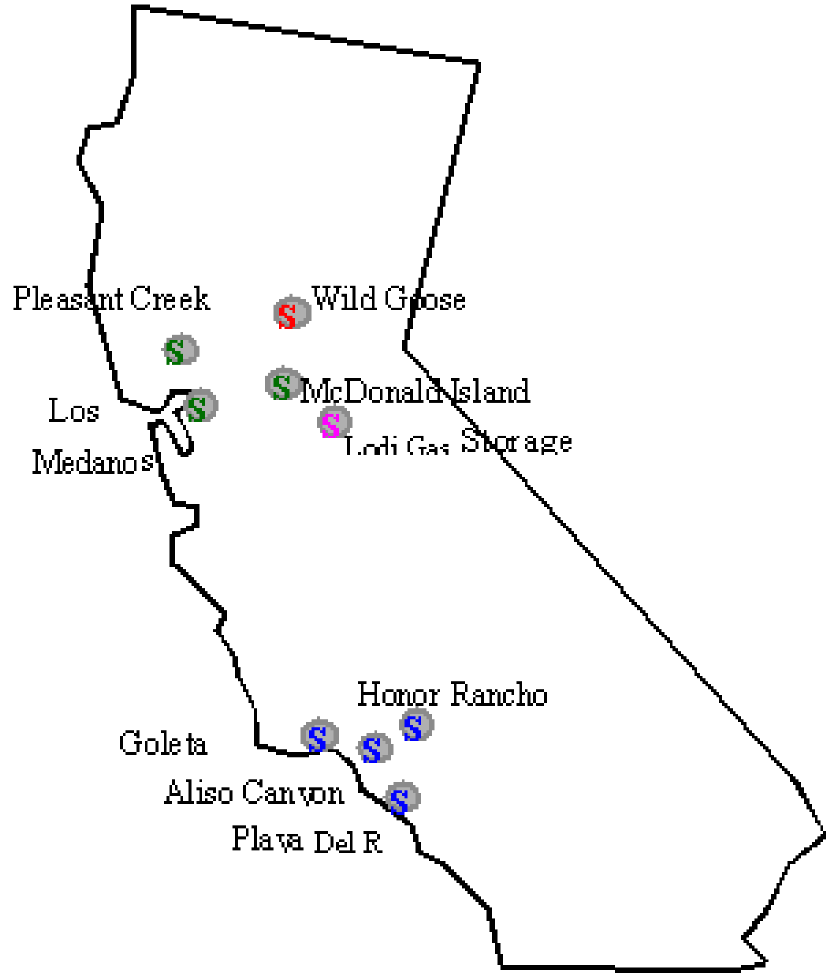
EPRI ELECTRIC POWER RESEARCH INSTITUTE

MW Capability Of Energy Storage Plants (In Next Five Years)

MW Power Scale Per "Module" For Energy Storage Plant Types



CAES Geologic Siting Opportunities In CA



Map not to scale
Source: California Energy Commission

Underground Natural Gas Storage Facilities in the Lower 48 States

This chart shows the successful siting and operation of natural gas storage in U.S.