Compressed Air Energy Storage (CAES)

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Project Need

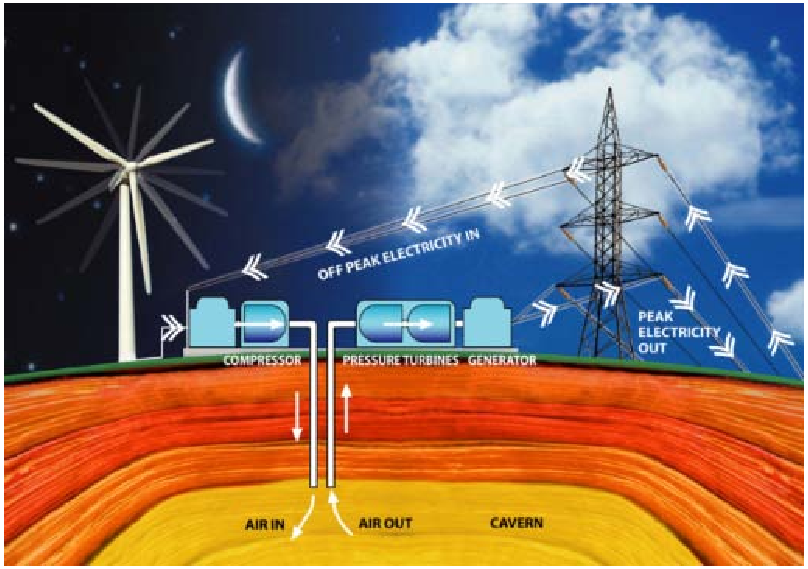
- California regulations will require that utilities procure 33% of their energy from eligible renewables
- Scenario projections show that nearly 70% of the renewable energy (23% of total energy) is likely to be provided by variable solar and wind resources.
- The CA ISO expects it will need high amounts of flexible resources, especially energy storage, to integrate renewable energy into the grid.
- Compressed Air Energy Storage has a long history of being one of the most economic forms of energy storage.
- The two existing CAES projects use salt dome reservoirs, but salt domes are not available in many parts of the U.S.
- Porous rock formations are available across much of the U.S., but there are many issues to resolve to prove that the geology will work.

Compressed Air Energy Storage Project

300 MW, up to 10 hours storage*

3 phases:

1. Permitting, reservoir testing, transmission interconnection, plant design ($25 million DOE match funding awarded 12/31/09)
2. Bid and plant construction
3. Monitoring



Partners:

ELECTRIC POWER RESEARCH INSTITUTE

California ISO Your Link to Power

Funded by:

- **Integrate intermittent renewables**
- **Store off-peak energy**
- **Provide ancillary services**
- **Manage peak demand**
- **Relieve grid congestion**
- **Use porous rock reservoir**

* Final Project size will be determined by reservoir size and definition and by testing results, subject to management and CPUC approvals.

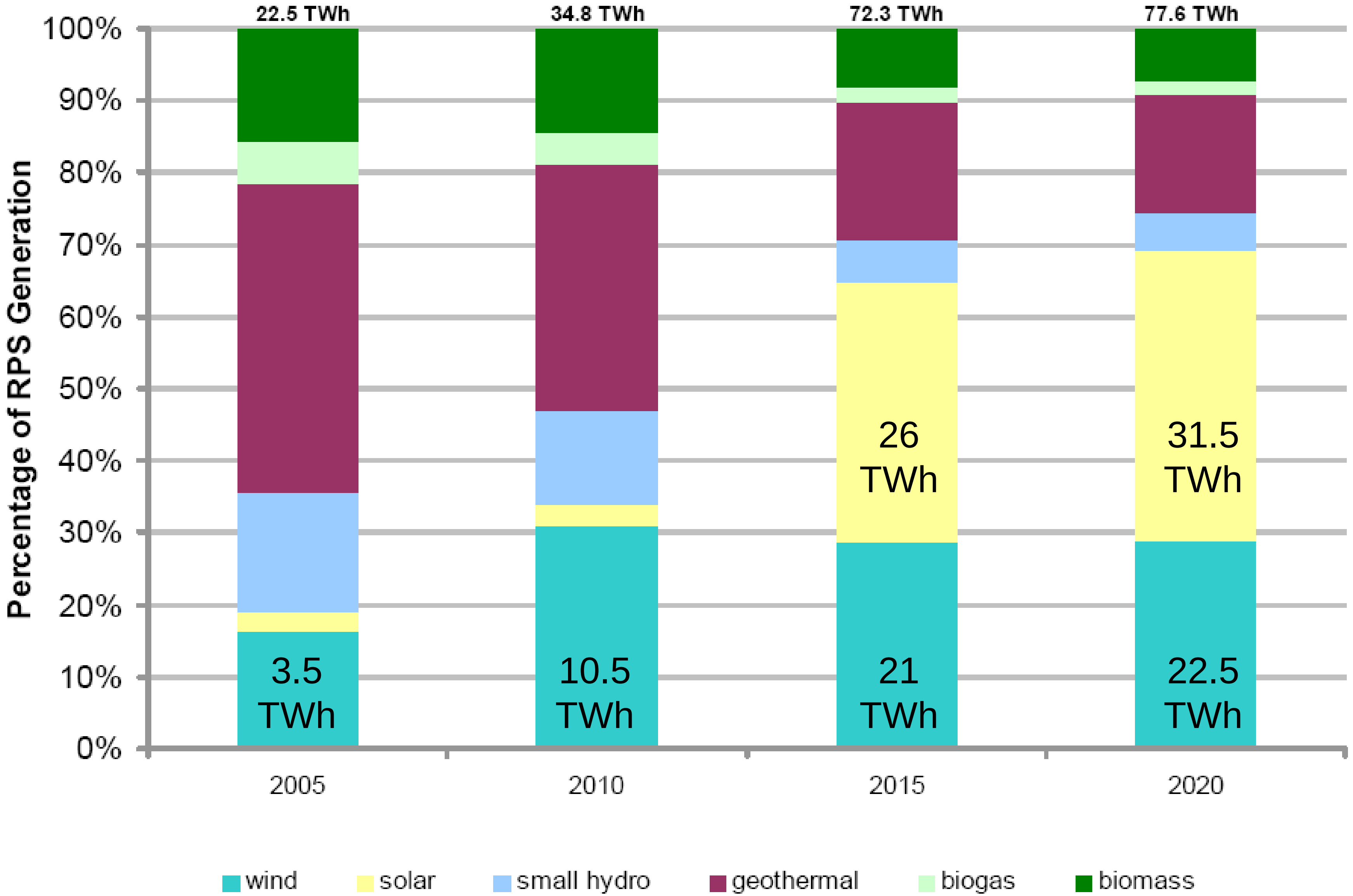
Funding

	DOE	Match
DOE Grant DE-FOA-0000036	$25 million	
California Public Utilities Commission		up to $24.9 million*
California Energy Commission		$1 million
California Energy Commission		$287,000
EPRI "Tailored Collaboration Agreement"		$153,081
Totals	$25 million	$25.05 million

= contract not executed as of 10/15/10

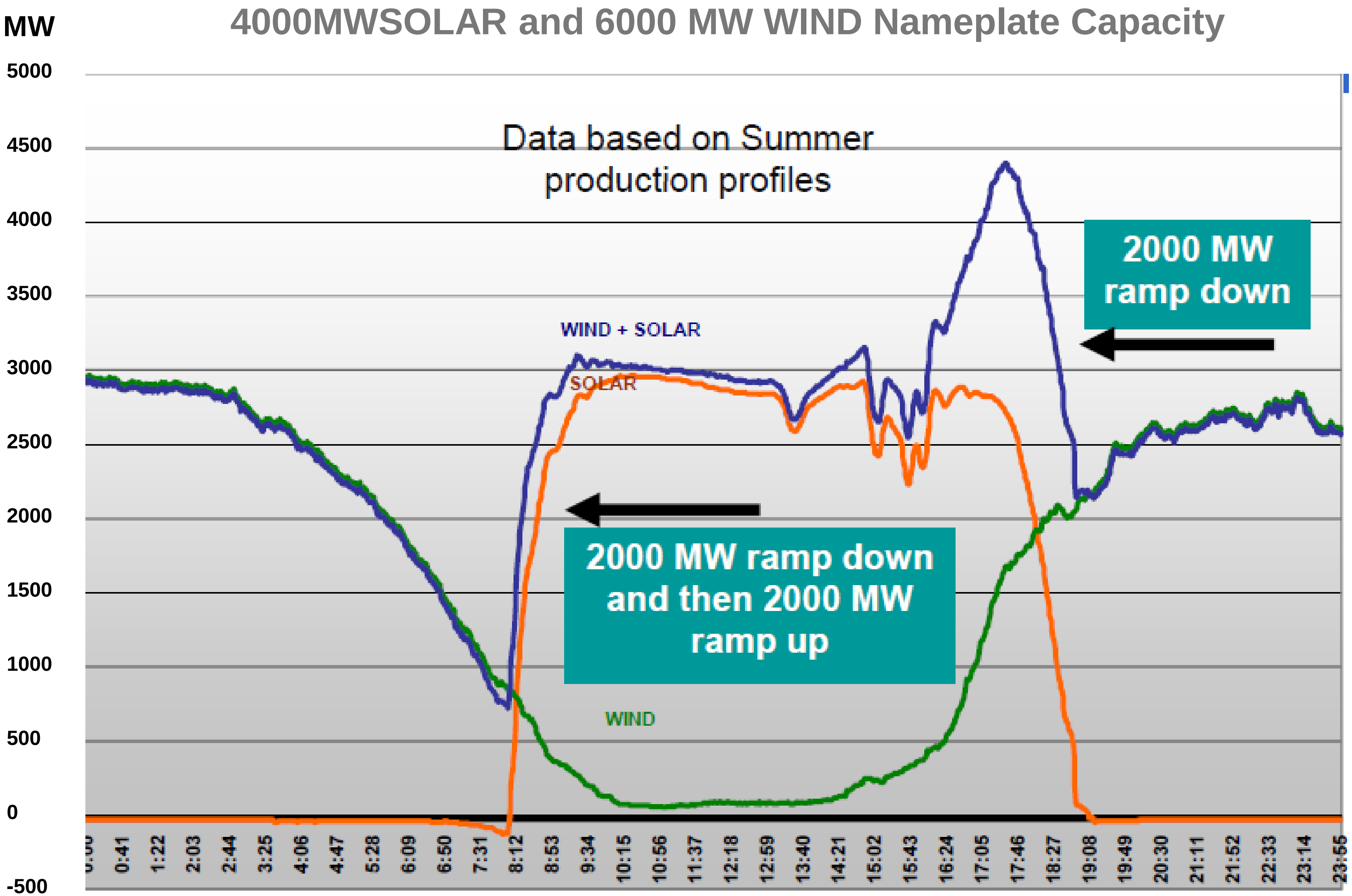
* to be reduced by any CEC funding received

Renewable Resource Mix Projections



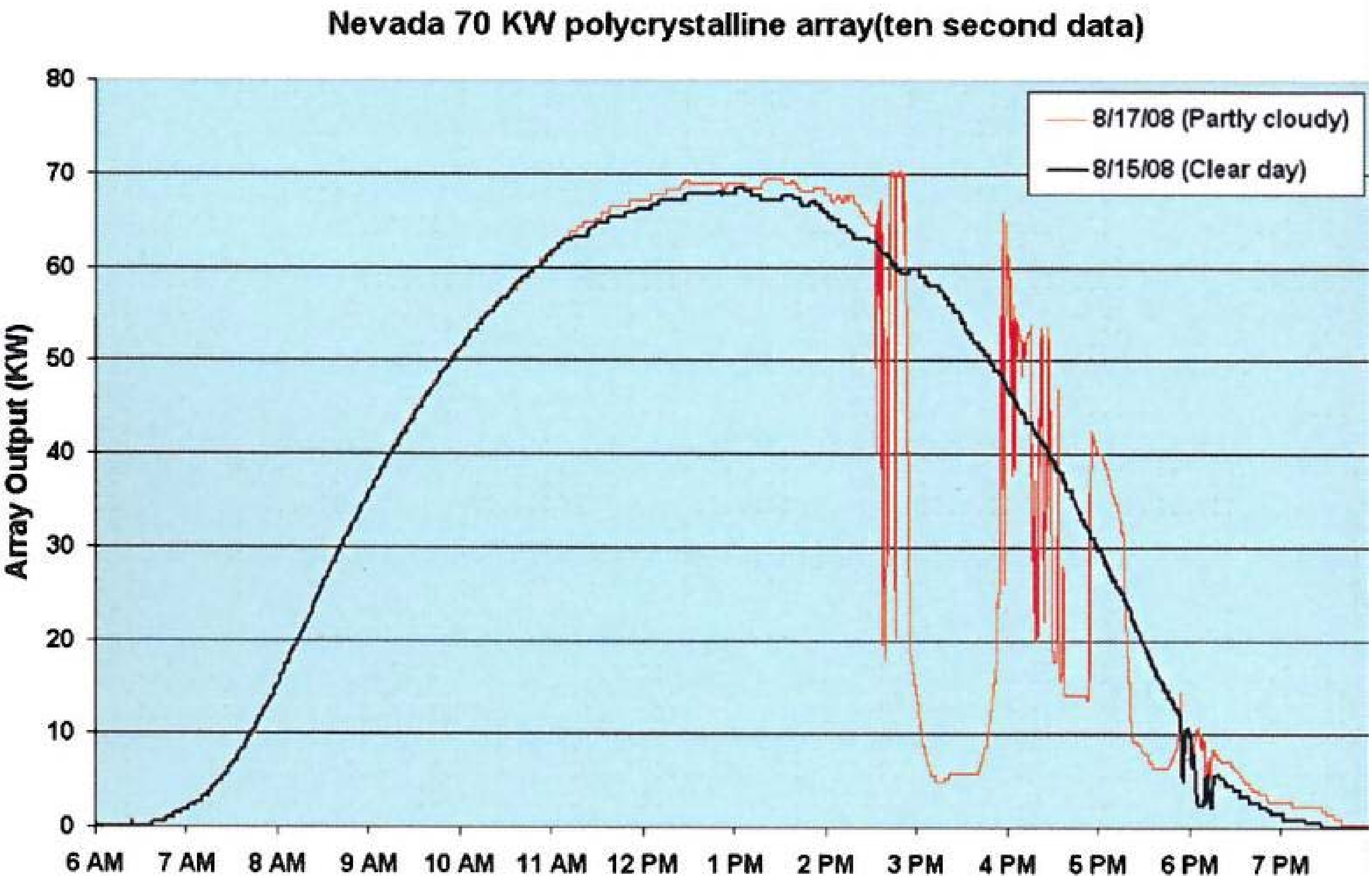
Source: California Public Utilities Commission, July 2009

Projected Wind and Solar Ramp Rates



Source: CAISO

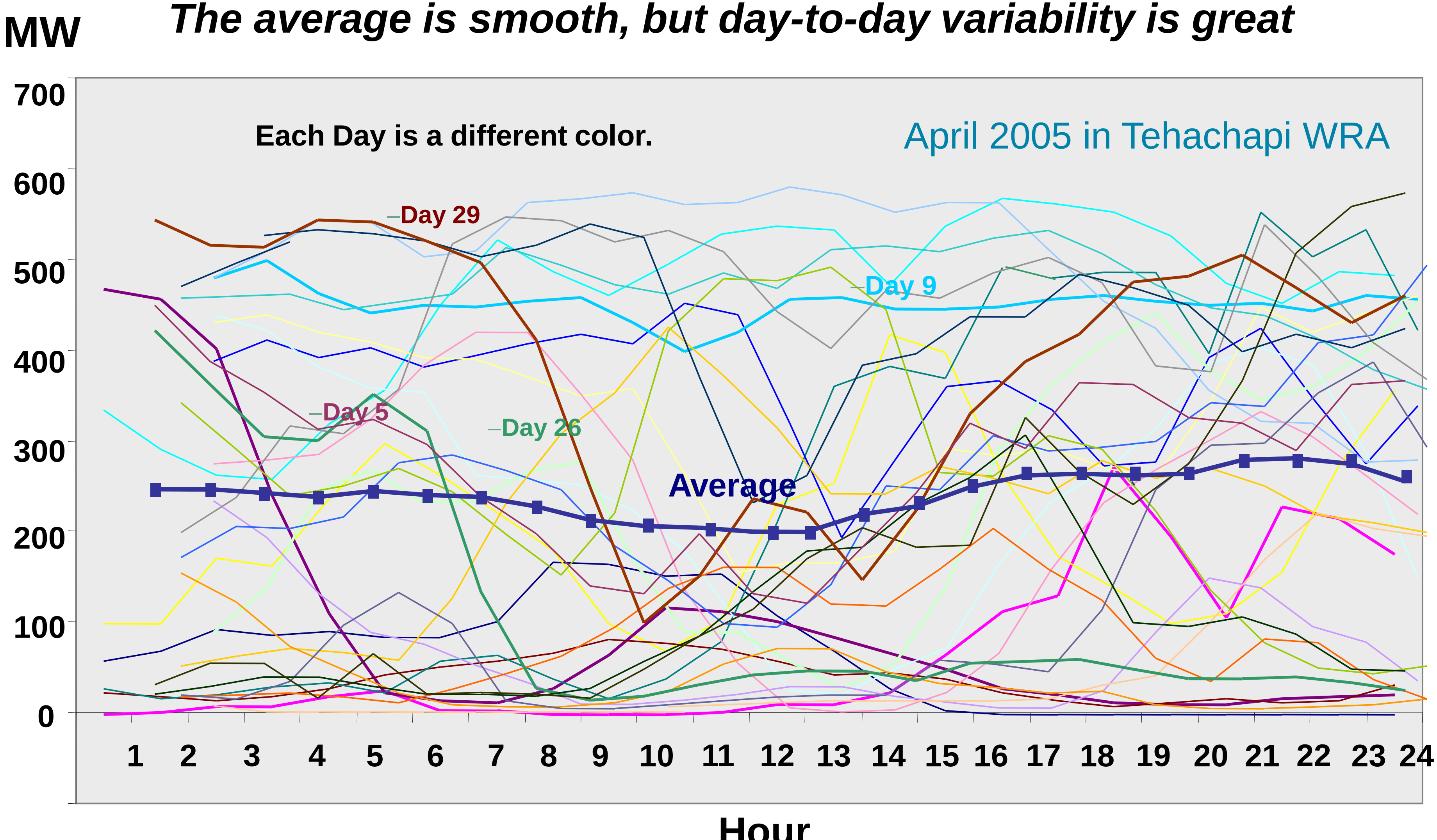
Variation of Solar PV System Output



Source: AES

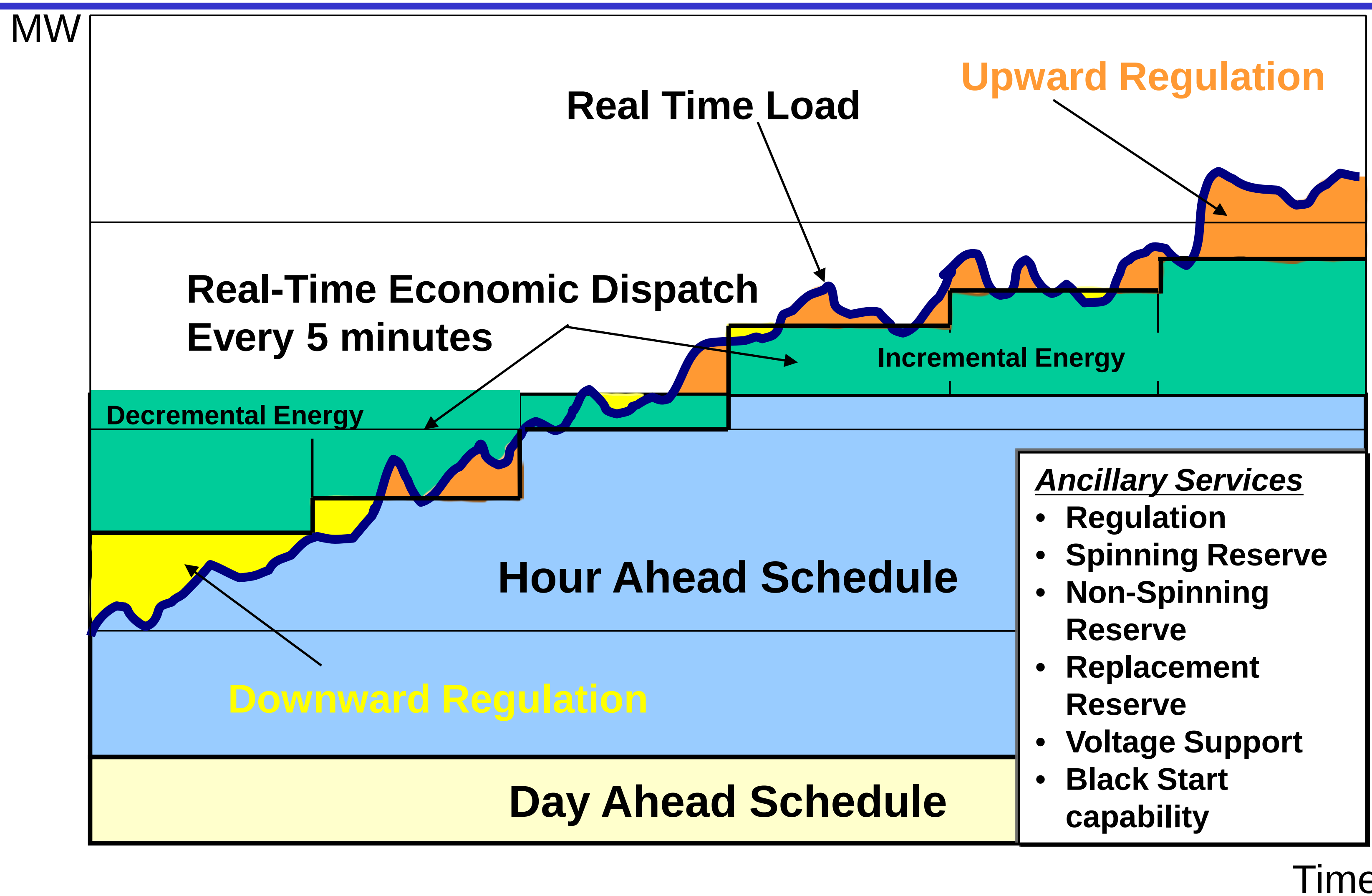
Wind Generation Varies Widely

The average is smooth, but day-to-day variability is great



Source: CAISO

Balancing Function - Area Control

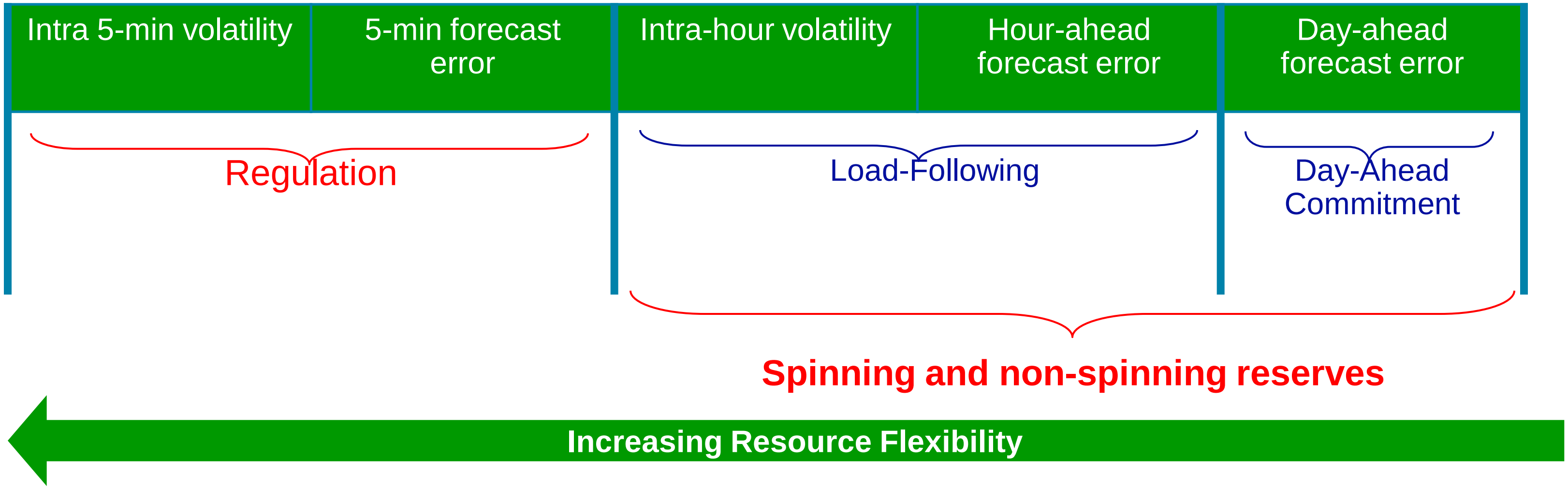


Resources Needed to Provide Ancillary Services

Ancillary services include:

- –Regulation Reserves (Reg Up/Down): resources that can increase or decrease output instantly to continuously balance generating resources and demand
- –Spinning Reserves: resources that are running (i.e., "spinning") with capable of ramping within 10 minutes and running for at least two hours
- –Non-Spinning Reserves: resources that are not running, but capable of being synchronized to the grid within 10 minutes, and running for at least two hours

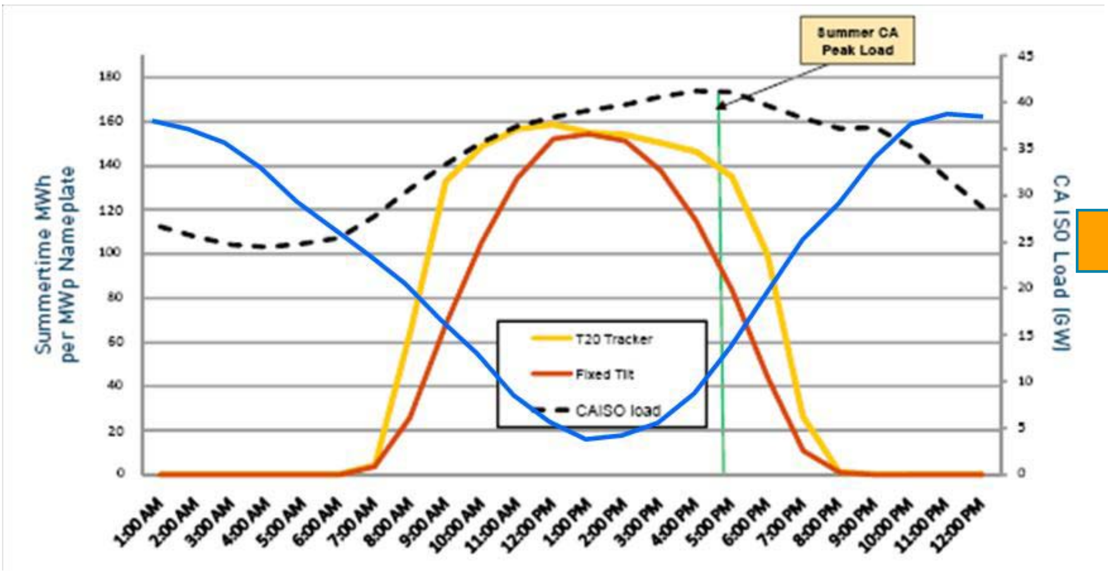
Ancillary services address load volatility and forecast errors



"Resource Adequacy" Required for Renewables Support

Renewable intermittency and mismatch with peak load contribute to the low RA values assigned to renewable generation

Peak Load Versus Renewable Generation Profile



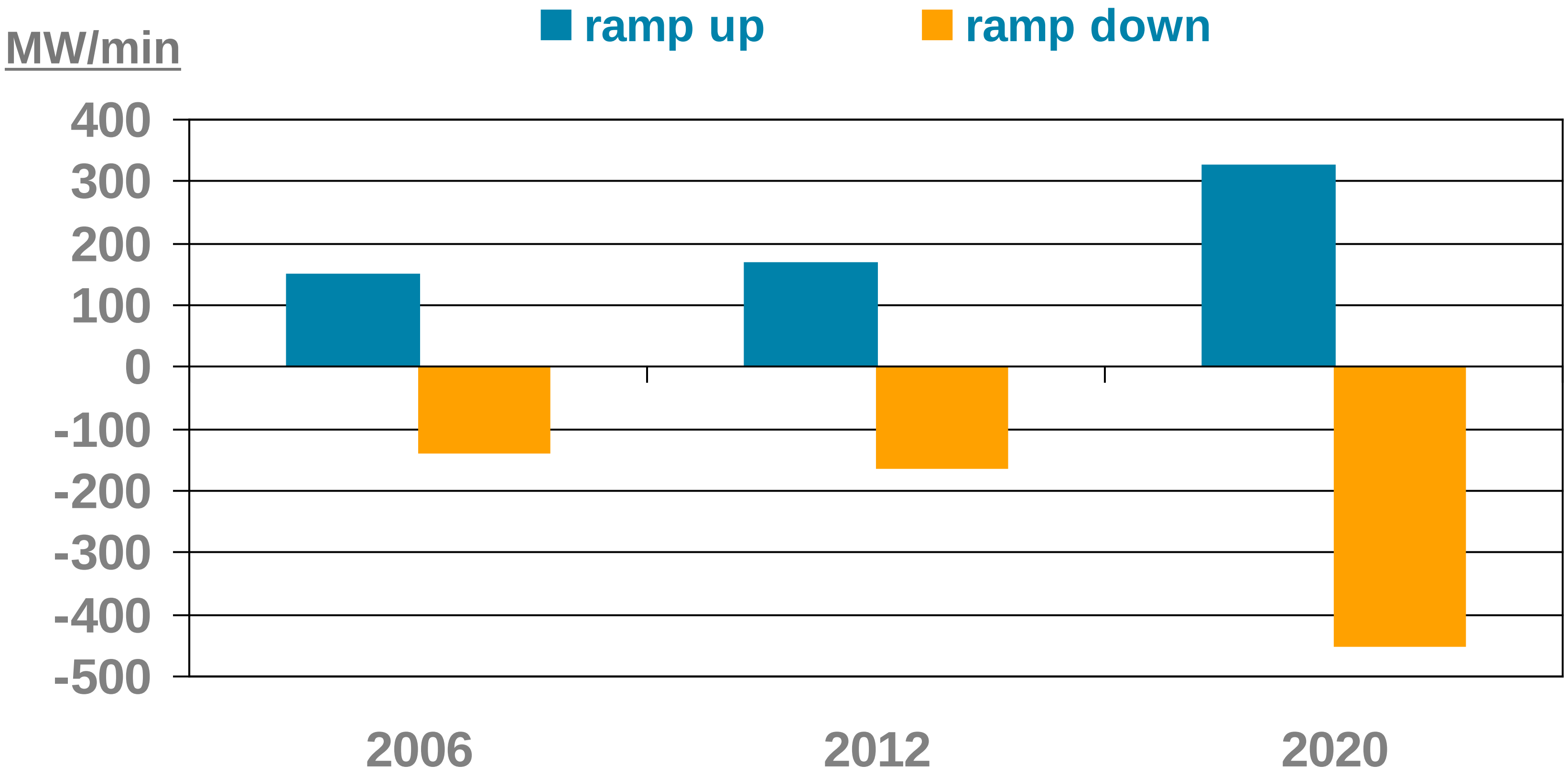
Resource	RA Value
Nuclear	1.00
Natural Gas	1.00
Geothermal	.90
Concentrating Solar Thermal	.82
Solar PV	.57
Wind	.11

RA values are CAISO assigned and may not reflect actual contribution to meeting peak load.

Higher intermittent renewable penetration requires procurement of greater total generation capacity to meet forecast peak reliability need

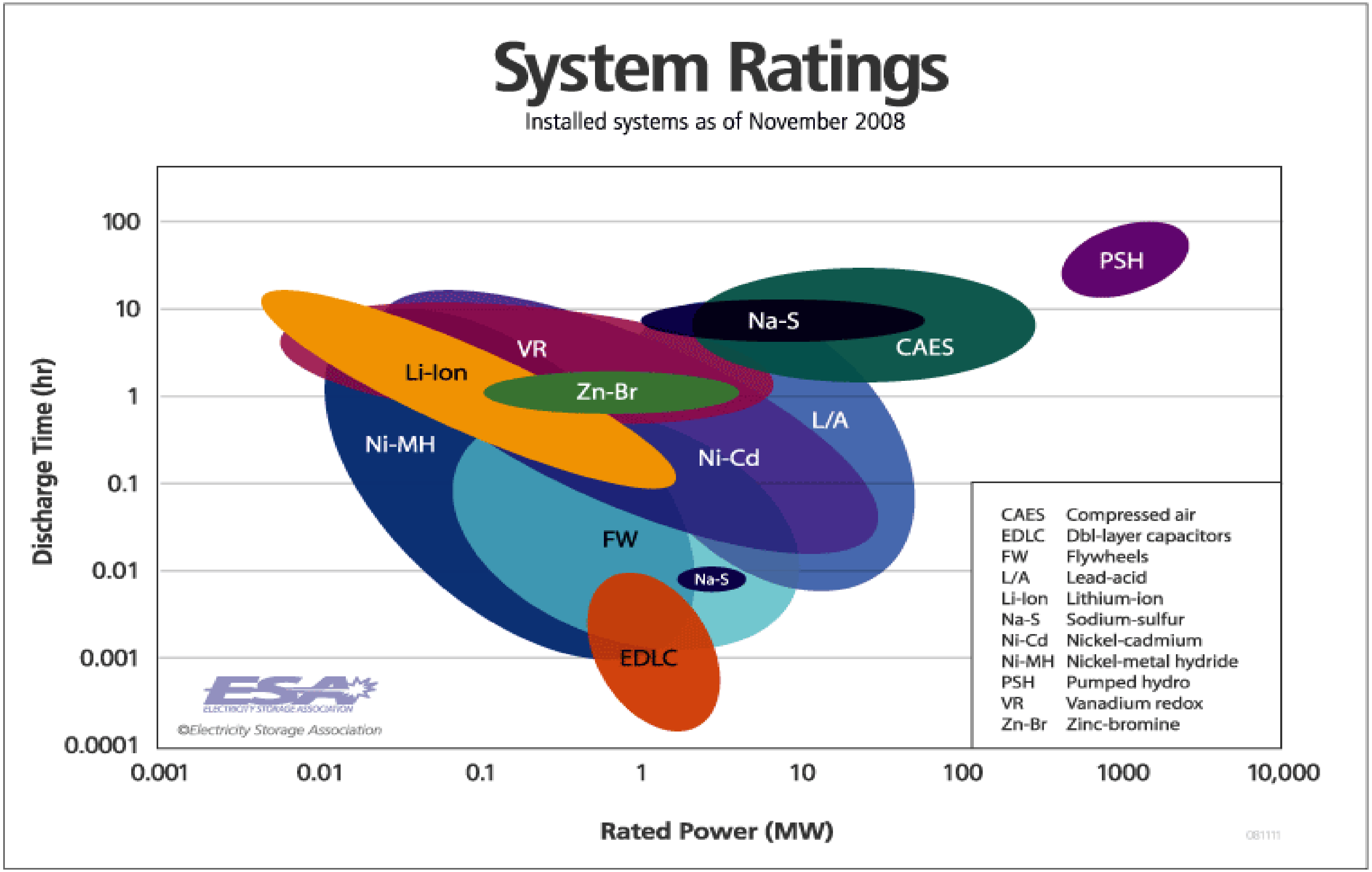
Expected increase in load following ramp rate requirement (MW per Minute)

Resources needed to provide regulation and load following will need to be able to respond to changes very quickly.



Source: Renewable Issues Forum 2010: Product and Market Review, CAISO, July 16, 2010

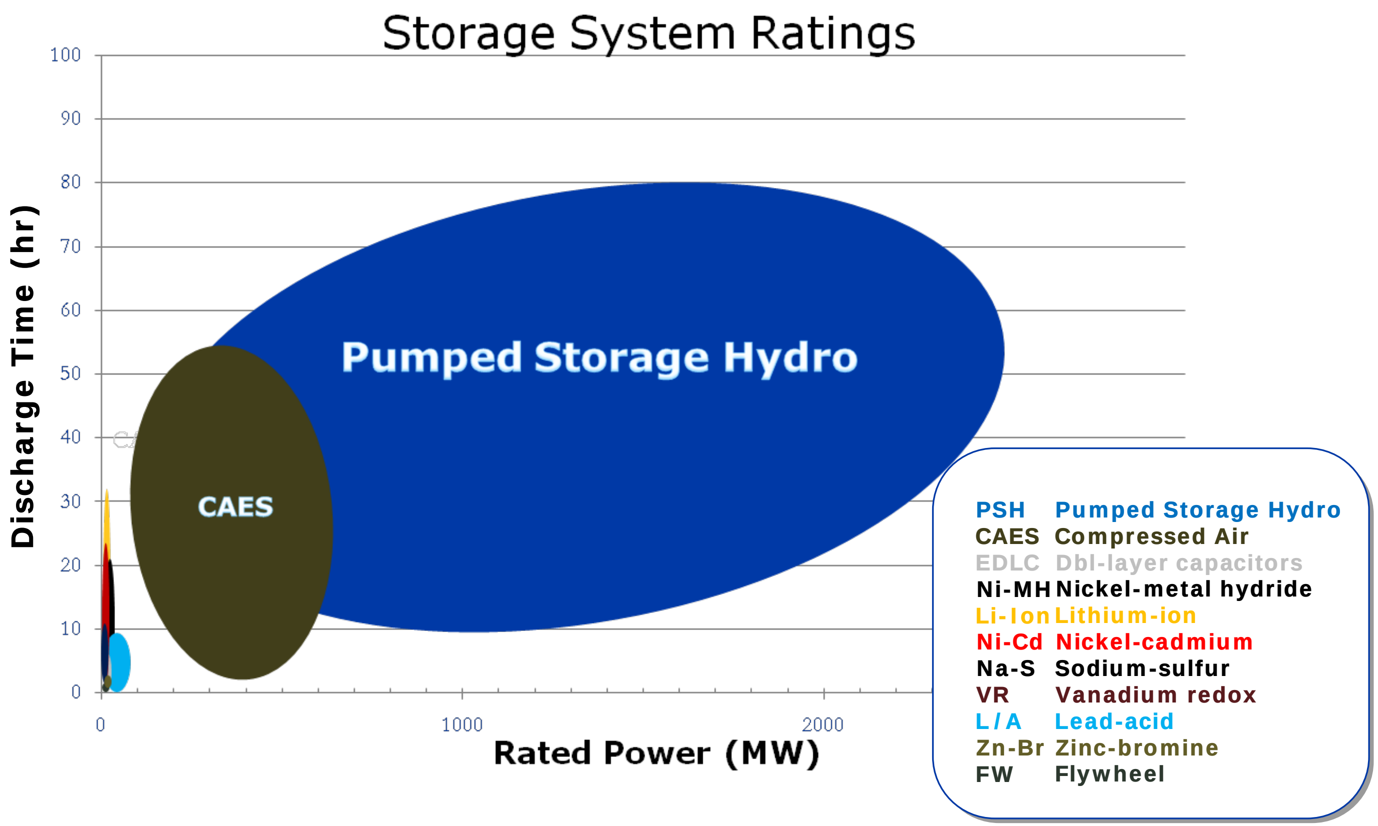
Storage Technologies: Size and Capabilities



Source: Electricity Storage Association

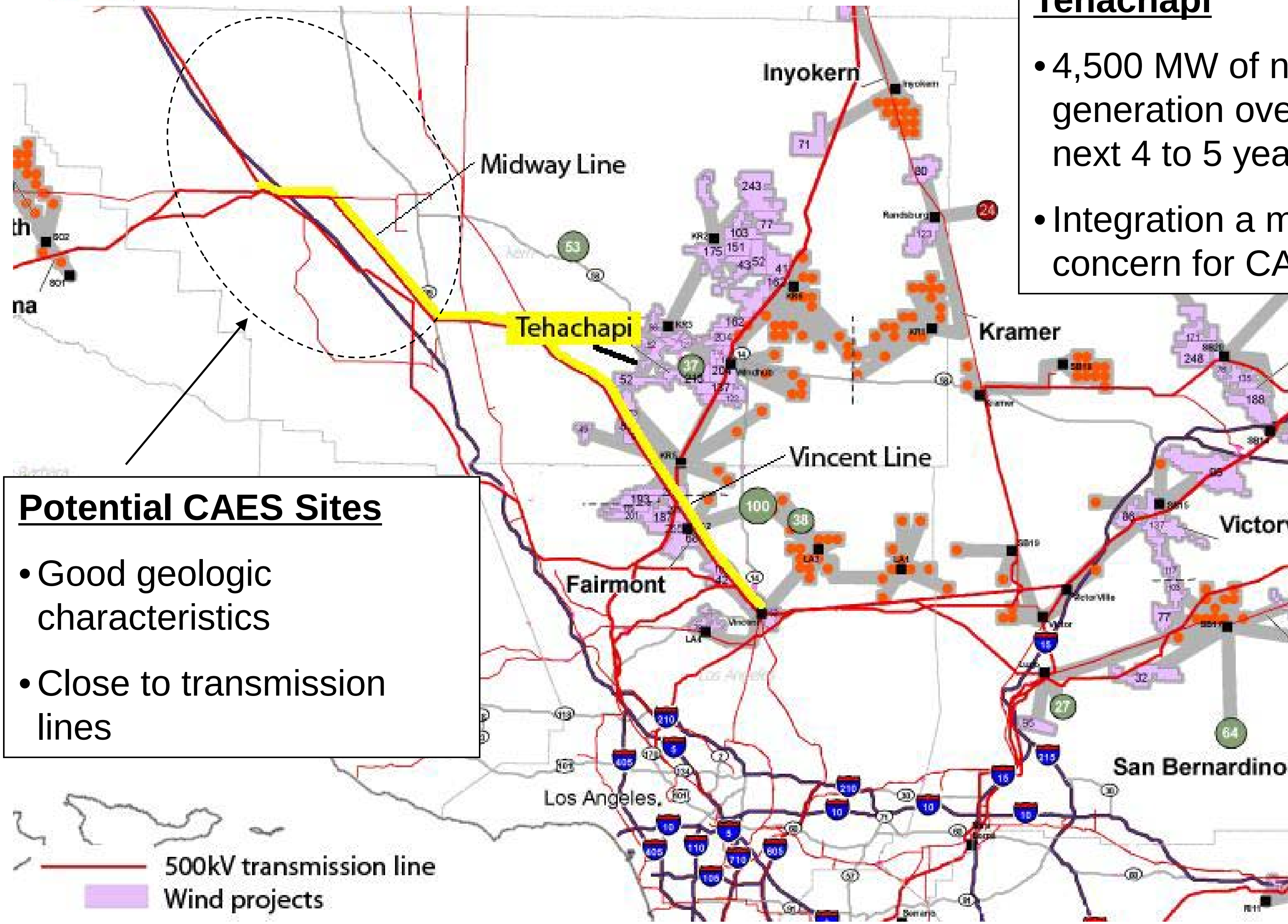
Why CAES? - Meeting Utility-Scale Needs

Energy Storage Technologies



Source: Same as prior graph by Electricity Storage Association (converted to normal scale by Rick Miller, HDR | DTA)

CAES Plant Site To Be Near Wind Resources



Tehachapi

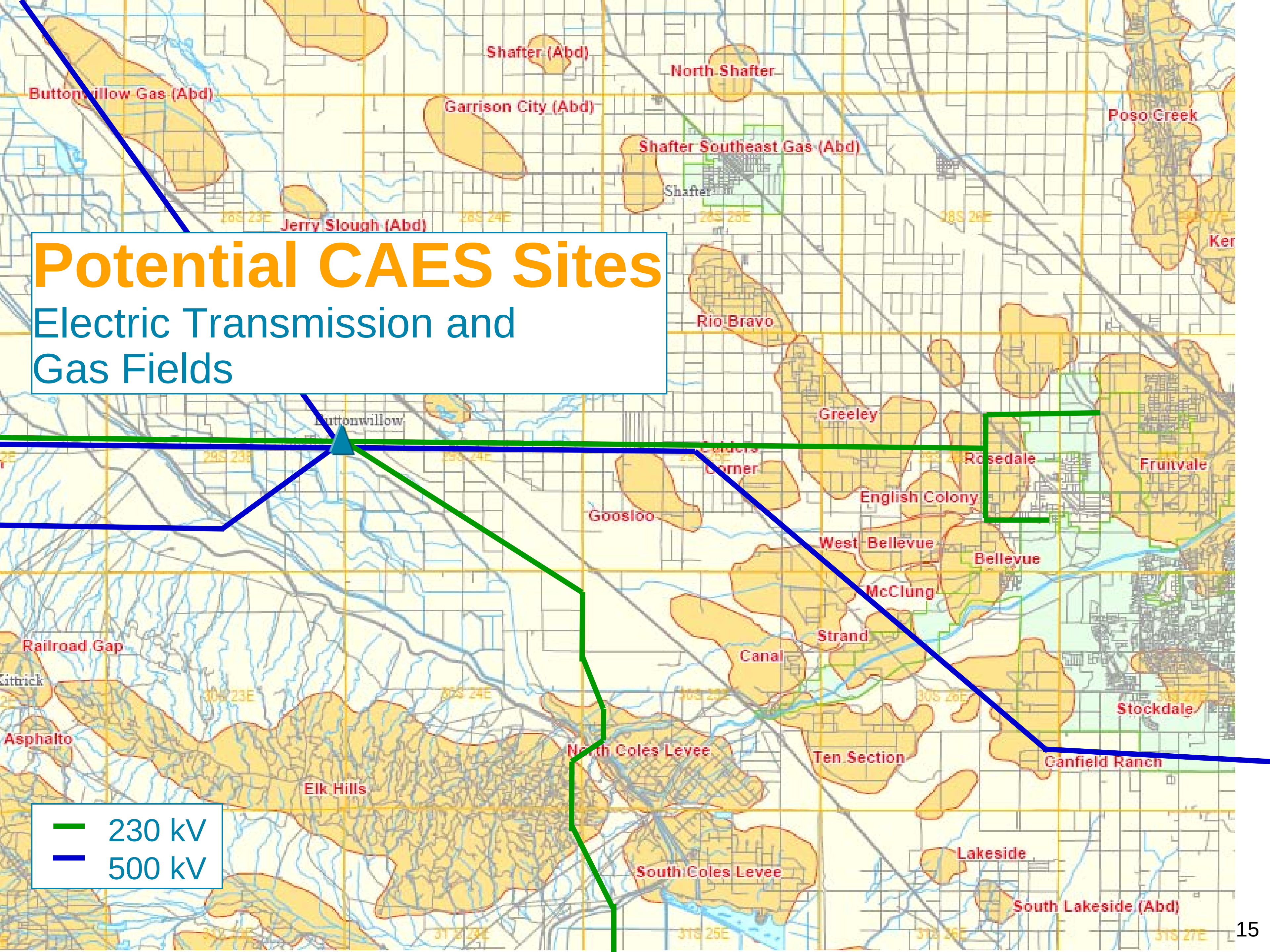
- 4,500 MW of new wind generation over the next 4 to 5 years
- Integration a major concern for CAISO

Potential CAES Sites

- Good geologic characteristics
- Close to transmission lines

Potential CAES Sites

Electric Transmission and Gas Fields



Geology Screening

	Unusable	Marginal	OK	Good	Excellent
Permeability (md)	< 100	100-200	200-300	300-500	> 500
Porosity (%)	< 7	7-10	10-13	13-16	> 16
Total Reservoir Volume (V_R/V_S)	< 0.5		0.5 – 0.8 or > 3.0	0.8 – 1.0 or 1.2 – 3.0	1.0 – 1.2
Total Closure Rating (h/H)	< 0.5		0.5-0.75	0.75-0.95	0.95-1.0
Depth to top of reservoir (m)	< 137 or >760	140 – 170	170 – 260 or 670-760	260-430 or 550-570	430-550
Reservoir Pressure (bars)	< 13 or > 69	13-15	15-23 or 61-69	23-29 or 50-61	39-50 (565-725 psi)
Type of Reservoir	Highly discontinuous	Moderately vuggy limestone & dolomite	Highly vuggy limestone & dolomite	Channel sandstones	Blanket sandstones
Residual Hydrocarbons (%)	> 5%		1-5%		< 1%
Caprock leakage	Evident		No leakage revealed by pumping tests		
Caprock Permeability (md)			> 10^{-3}		< 10^{-3}
Caprock Threshold Pressure			21-55		> 55
Caprock Thickness (m)			< 6		> 6 (>19.7 ft.)

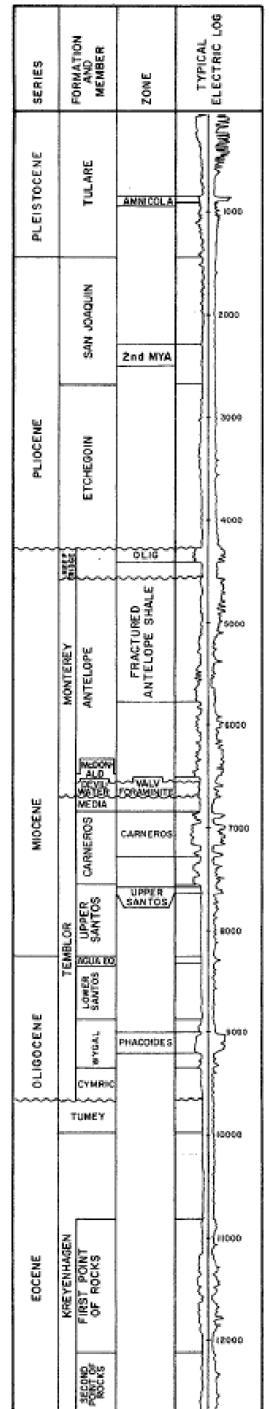
Source: Final Report on CAES Sitting in Northeastern Colorado, University of Colorado - Boulder, October 2008

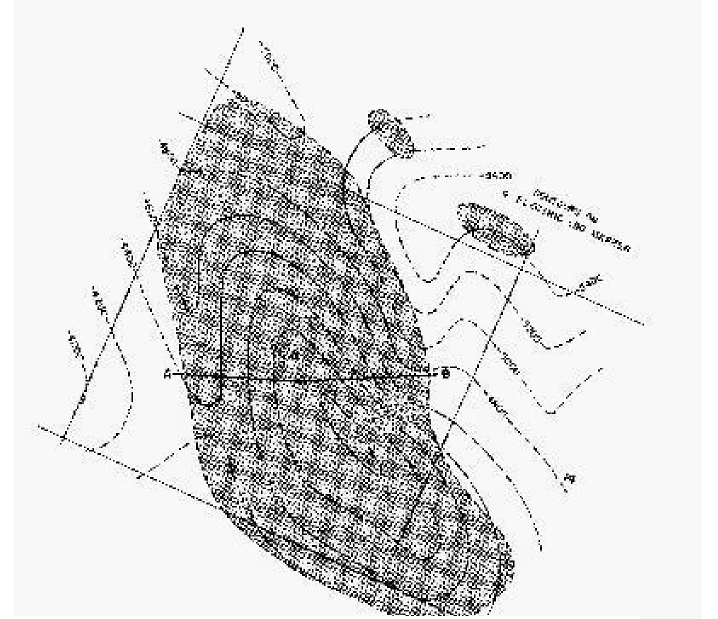
Porous Rock: Saline Aquifer or Depleted Gas Field?

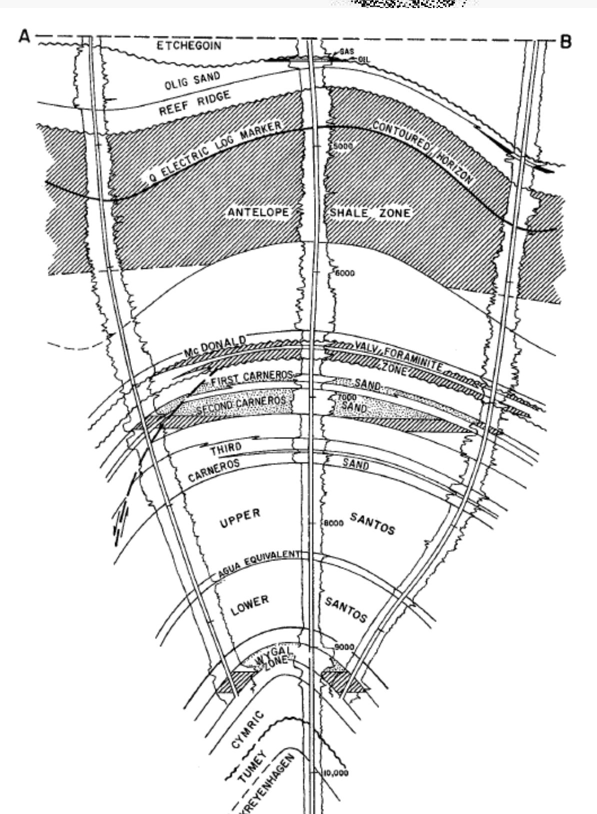
- Gas fields still contain some methane
  - –Combustion risk?
  - –Need to address methane emissions during testing
- Air in an aquifer could change key parameters
- Aquifers generally not well characterized
  - –Deep aquifers part of CO_2 sequestration study
  - –Uncharacterized aquifers less certain with greater development costs and risks
- Gas fields have well-documented history and characteristics

Sample Well Log

- **Depleted gas field documentation:**
  - Porosity: 35%
  - Permeability: 1600 md
  - Initial Pressure: 1,000 psi
  - Depth: 2,300 ft.
- **Reservoir size**
- **Dome structure**
- **Caprock**







Other Siting Considerations

- Connected to Midway Substation
  - 500 kV most direct, but expensive
  - 230 kV considerably cheaper
- Access to high-pressure gas line
- Environmentally-suitable site
  - Species
  - Noise
- Near distribution voltage for construction power ideal

Progress to Date

1. Addressed tax liability issue.
2. NEPA categorical exclusion obtained 5/19/10.
3. Completed all DOE/NETL requirements and submitted contract to DOE/NETL May 24, 2010.
4. Participated in DOE webinars for reporting requirements and Metrics and Benefits training for Principal Investigators.
5. Held meetings with 10 Geology Services companies to identify services and experience of these entities and identify potential project roles & responsibilities.
6. Performed initial engineering analysis to identify key technical plant parameters (i.e. flowrate, inlet/outlet pressures, storage volume, etc.)
7. Revised existing vendor contracts to make them DOE-compliant.
8. Developed, revised, and finalized EPRI Tailored Collaboration Agreement to meet project needs.
9. Ongoing work with existing contractor to identify required activities, costs, and scheduling to obtain required CEC permit.
10. Economic benefit studies by EPRI and PG&E.
11. Mixed gas studies review by EPRI is underway.
12. Scheduled McIntosh (Alabama) CAES plant visit for November 2010.
13. Attended CAES 2010 workshop at Columbia University, featuring : a) “CAES Studies at the National Renewable Energy Laboratory” b) “Potential Risks Associated with Underground CAES” (by Sandia National Laboratory) c) “On the Use of Large-scale Multi-physics Modeling to Address Potential Vulnerabilities Associated with Air/Gas Mixtures in CAES” (by Brookhaven National Laboratory) d) “Use of Carbon Dioxide as a Cushion Gas for CAES” (by Lawrence Berkeley National Laboratory)

Summary/Conclusions

Summary

- CAES using porous rock has the potential to allow wider integration of variable renewables

Conclusions

- All pre-contract requirements complete
- Some project progress since award, but limited without DOE contract
- Key aspect of the project is geology
- Selection of depleted gas field or aquifer will be major determinant of future work

Future Tasks

First Deliverables:

1. Project Management Plan Update
2. Interoperability and Cyber Security Plan (EPRI)
3. Metrics and Benefits Reporting (EPRI)

Other Tasks:

1. Owner's Engineer contract
2. Desktop Study contract and resultant site selections
3. Land option contracts
4. Geology Services contracts
5. Environmental Permit Review
6. Request for Temporary Construction Power (3 Sites)
7. Air Permit Exemption Applications (3 sites)
8. Well Air Injection Testing (Site 1)
9. Drilling Permits (3 sites)
10. Drill Test Wells (Site 1)
11. Evaluate Test Wells (Site 1)
12. Preliminary and Optimized Facility Design
13. Transmission Studies
14. CEC Application

Questions?