NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Regulatory Framework of Electricity Markets in the U.S.

IEE - University of Sao Paulo

David Mooney
March 19, 2018

Outline

- Status of RE Deployments in the U.S.
- Overview of U.S. Electricity Markets
- Status of U.S. Storage Deployment
- New Markets with Cost-competitive Batteries
- Grid Services without Batteries

Outline

Status of RE Deployments in the U.S.

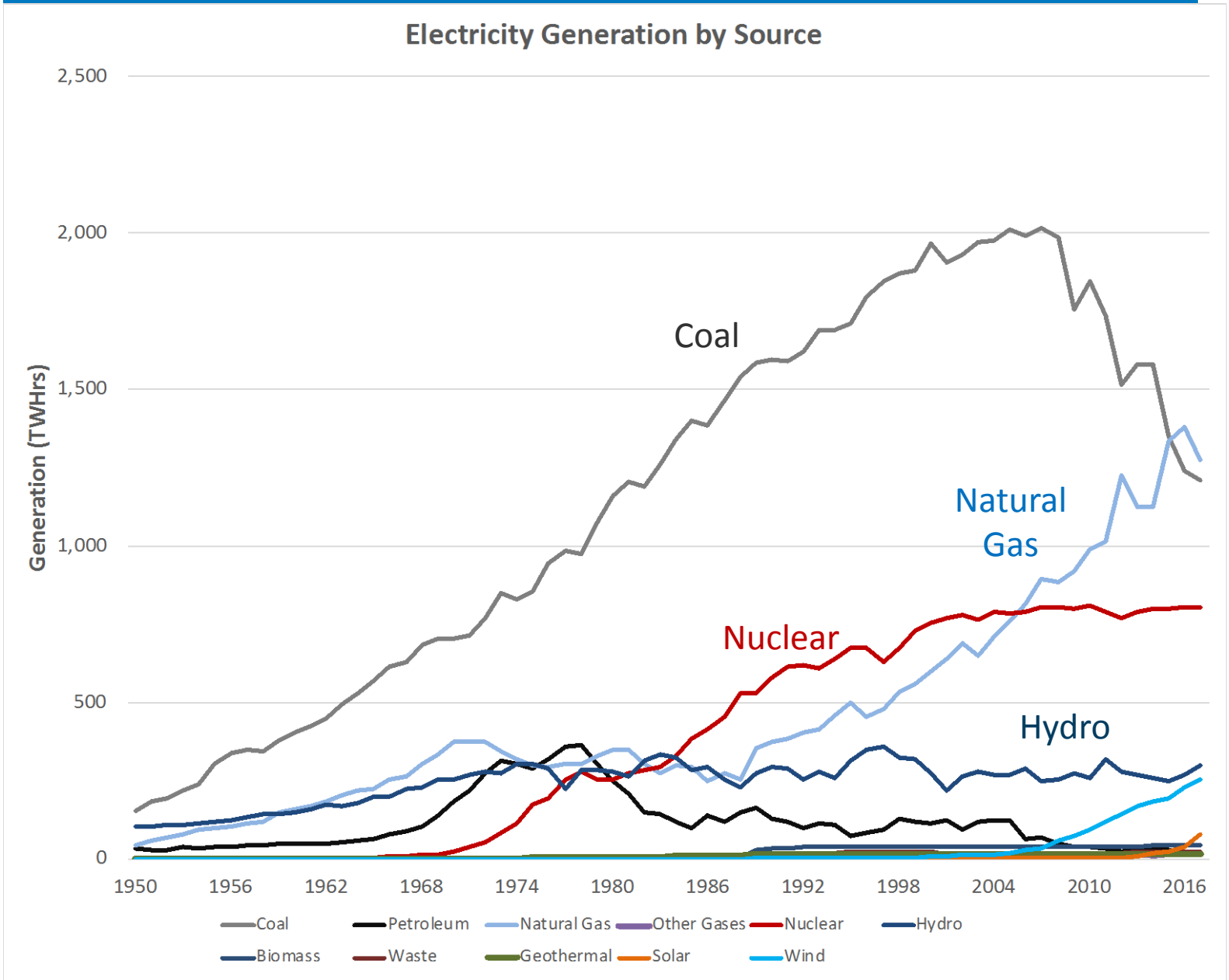
Overview of U.S. Electricity Markets

Status of U.S. Storage Deployment

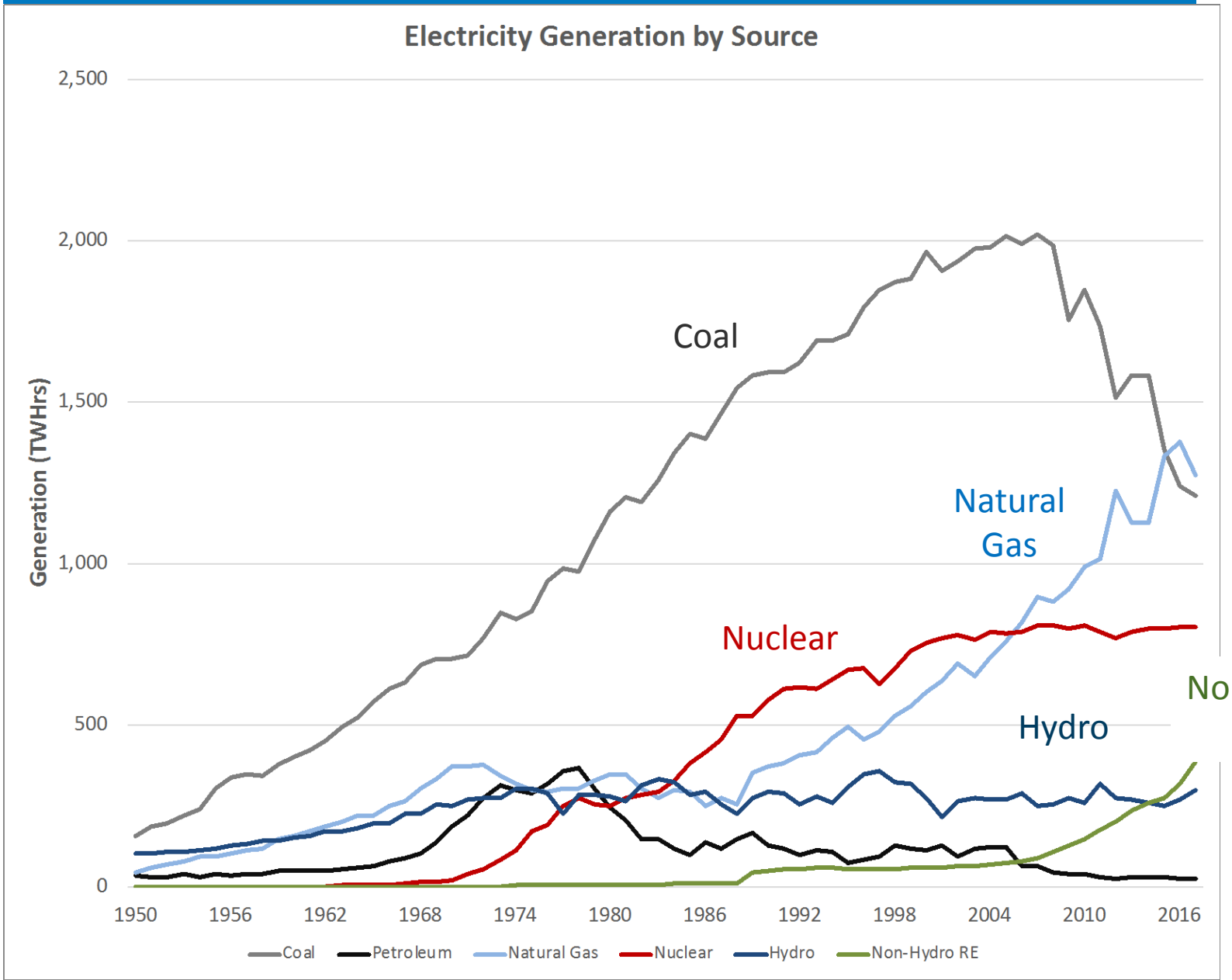
New Markets with Cost-competitive Batteries

Grid Services without Batteries

Trends in the U.S. Power Sector - 2017



Trends in the U.S. Power Sector - 2017



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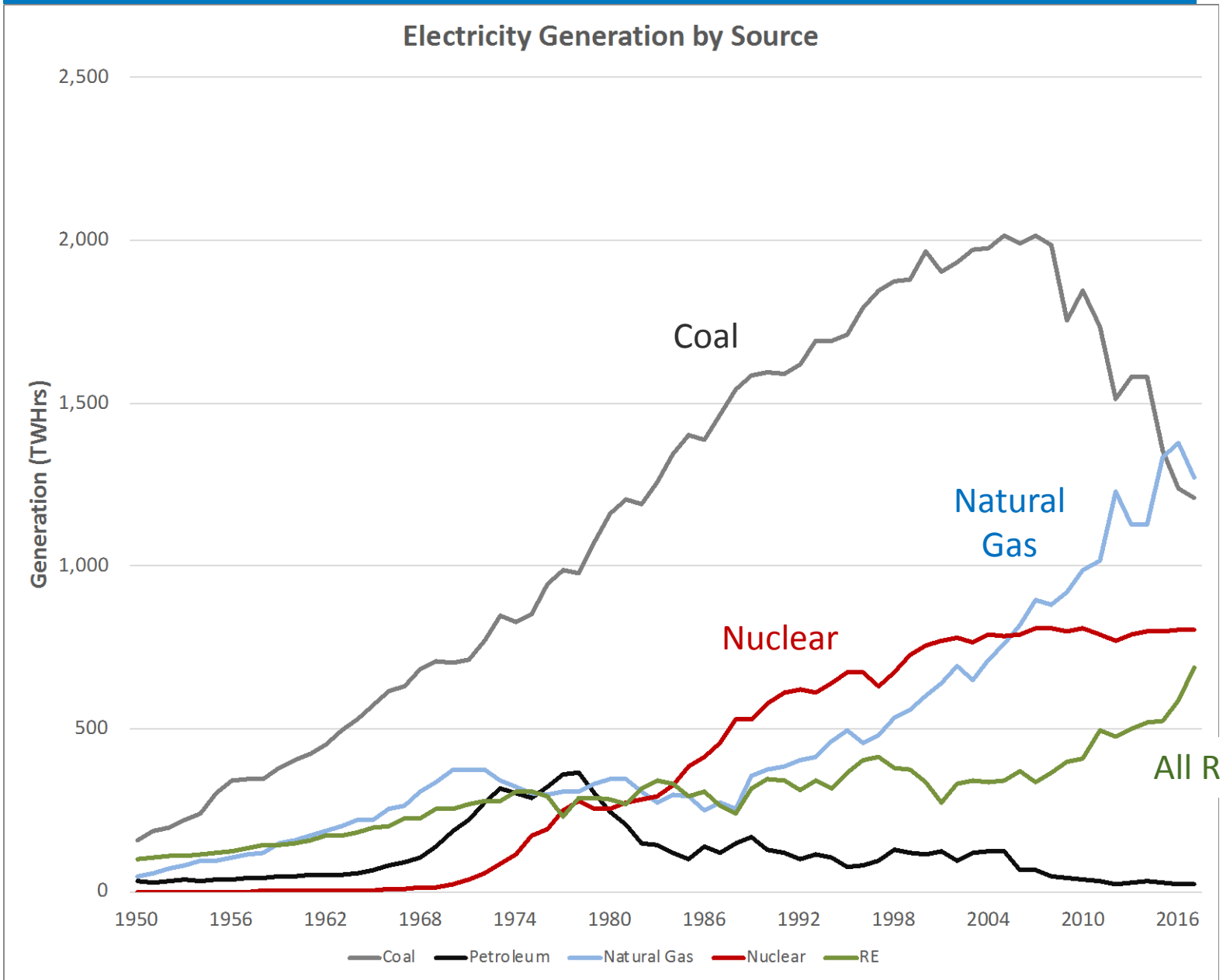
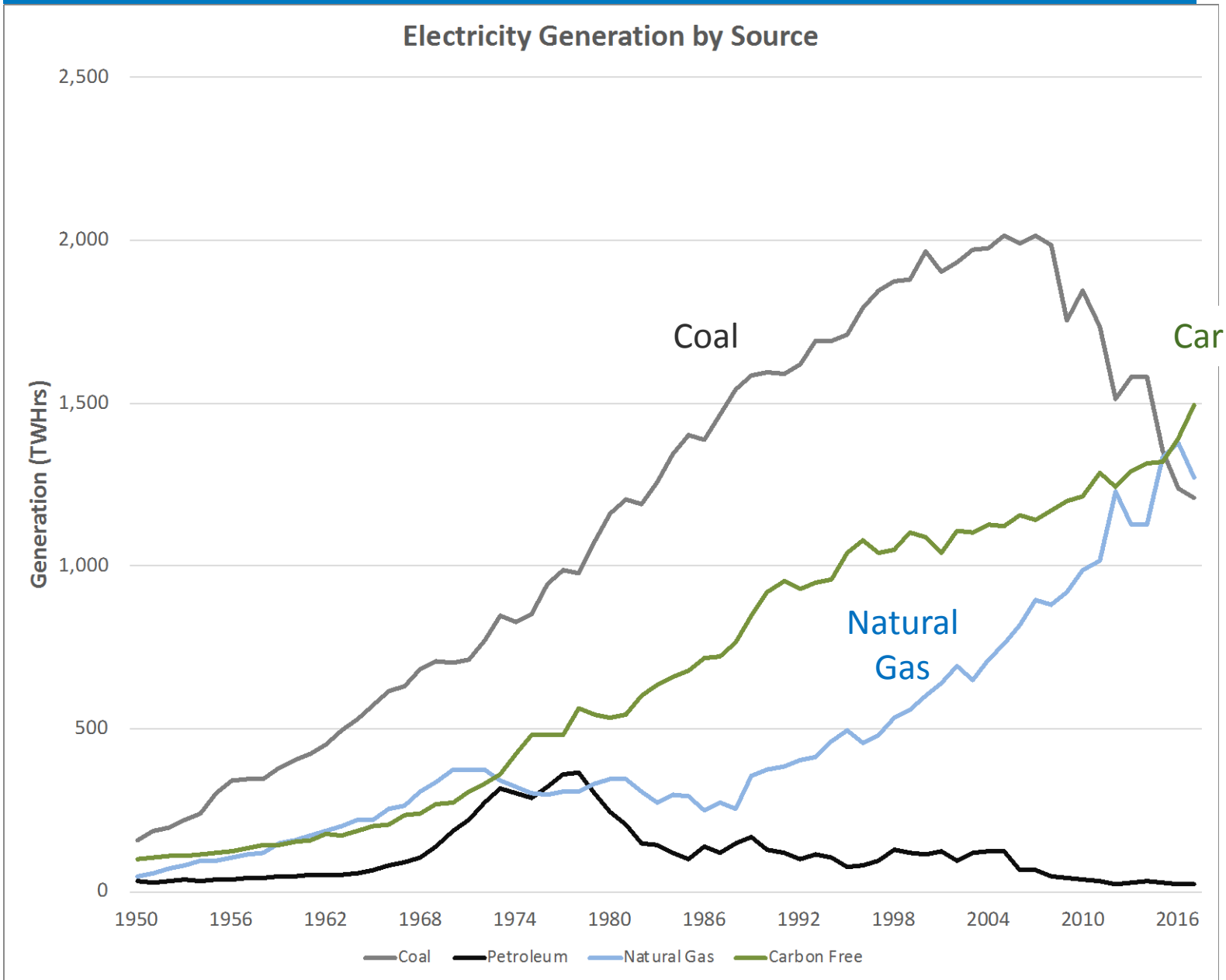
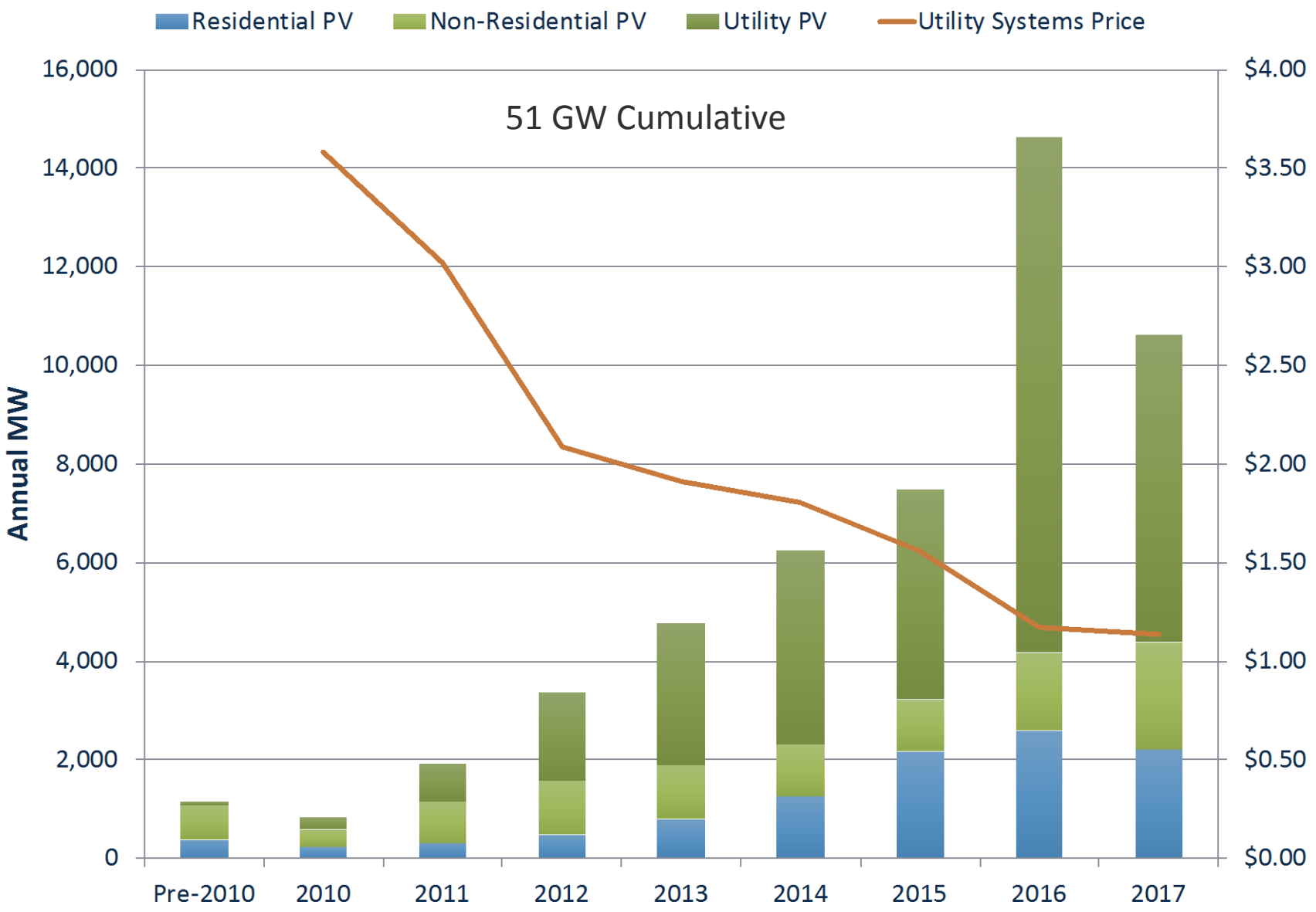


Trends in the U.S. Power Sector - 2017

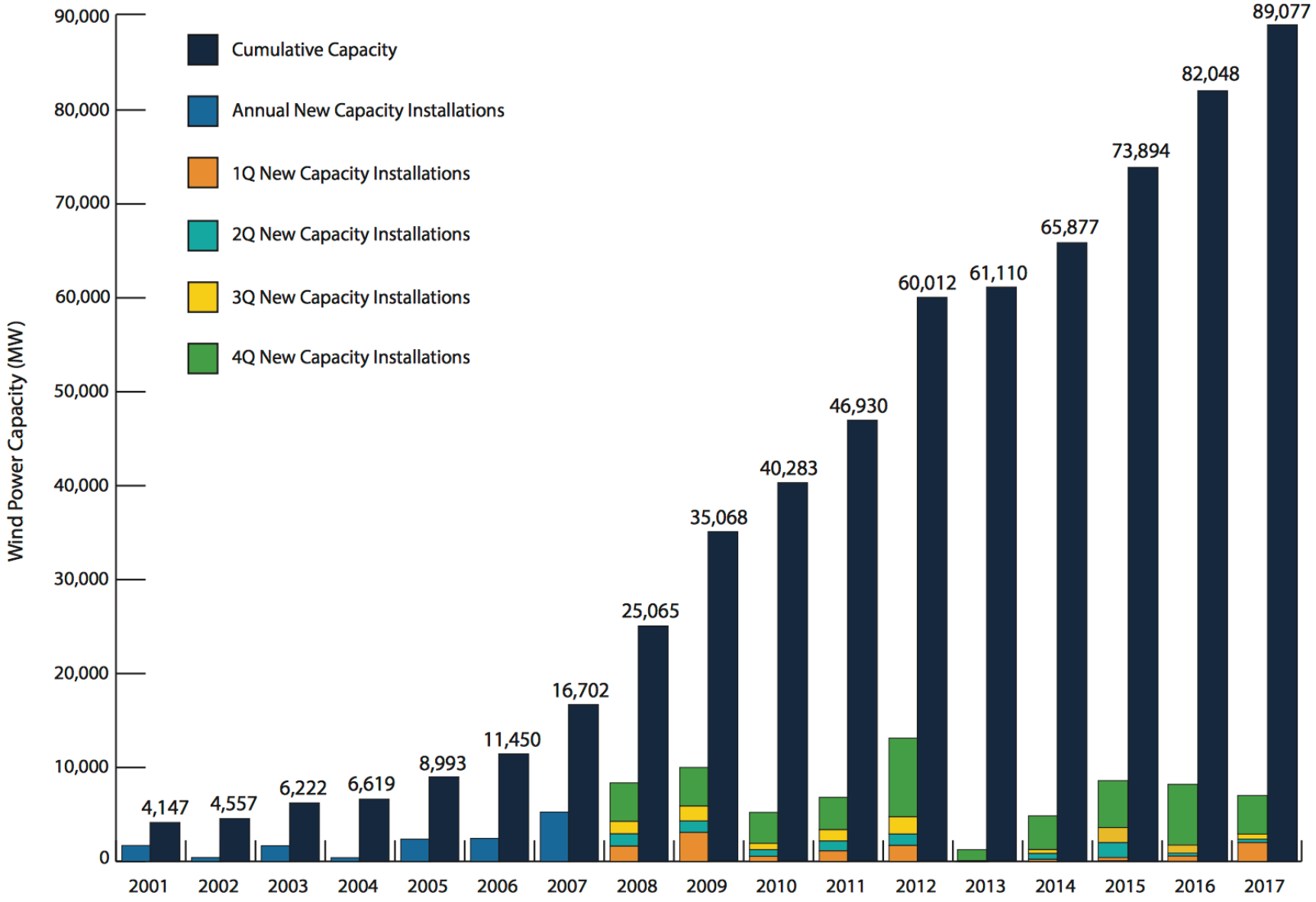


Solar Deployment in the U.S.



Source: GTM Research

Wind Deployment in the U.S.



Source: American Wind Energy Association

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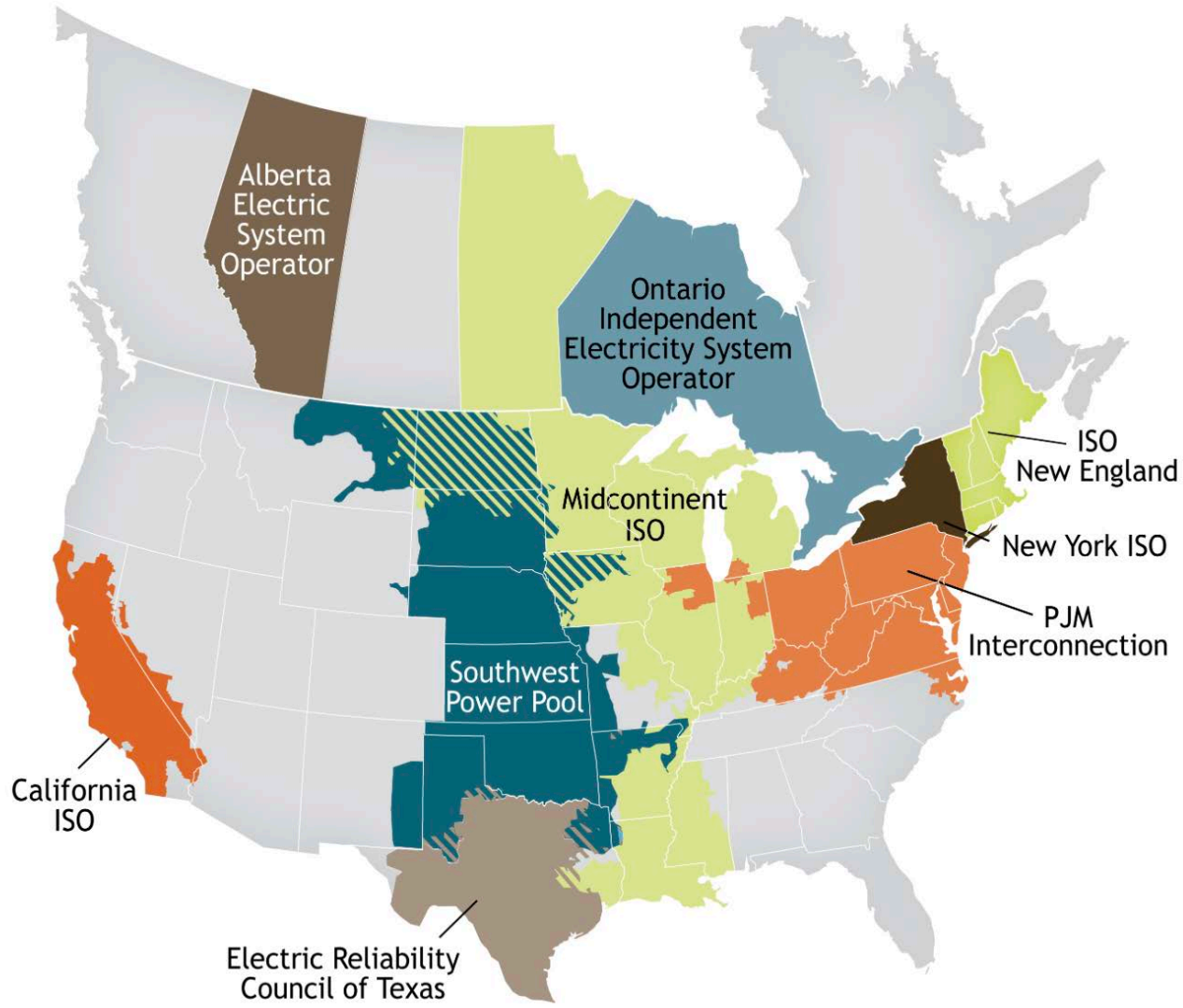
Wholesale Electricity Markets in the U.S.



Gray areas are typically served by regulated, vertically integrated utilities

IRC ISO/RTO COUNCIL

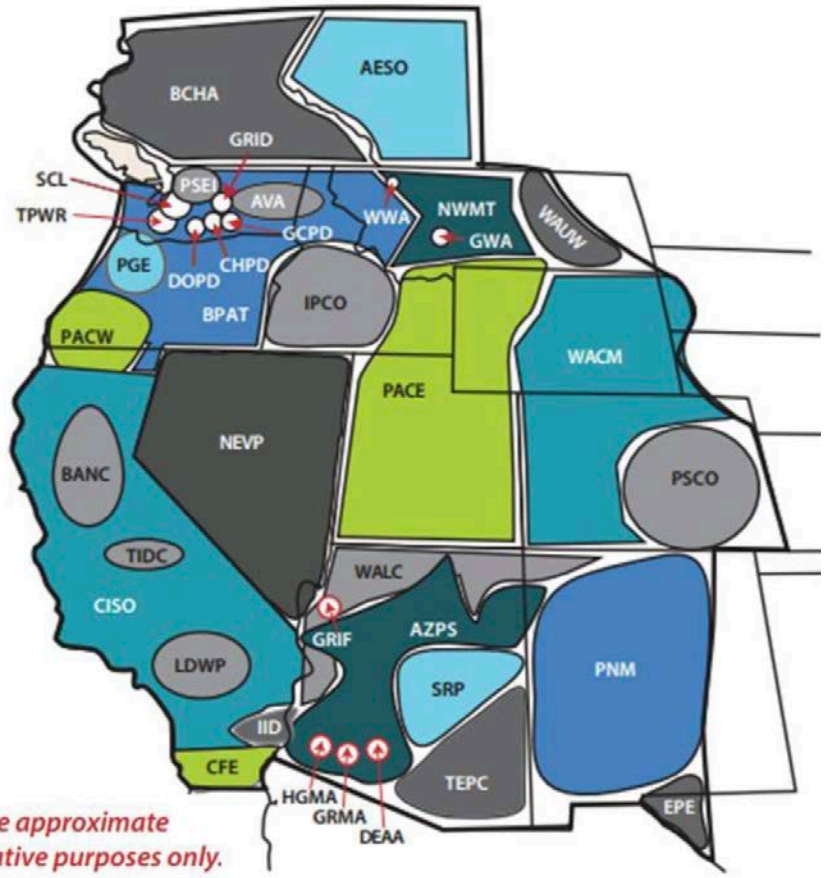
Wholesale Electricity Markets in the U.S.

	ISO-NE	NYISO	PJM	MISO	SPP	ERCOT	CAISO
Peak Load (MW)	28,000	34,000	165,000	127,000	46,000	69,000	47,000
Total Generation Capacity (MW)	31,000	39,000	184,000	180,000	83,000	77,000	60,000
Generating Units	350	400	1,400	1,400	750	550	760
Annual Energy (TWH)	120-135	160-165	780-840	600-680	225-240	340-350	230-260
Transmission (Miles)	8,000	11,000	72,000	66,000	61,000	46,000	26,000

Total Capacity ~ 655,000 MW – almost 60% of total U.S. capacity

Source: EPRI

Energy Imbalance Markets



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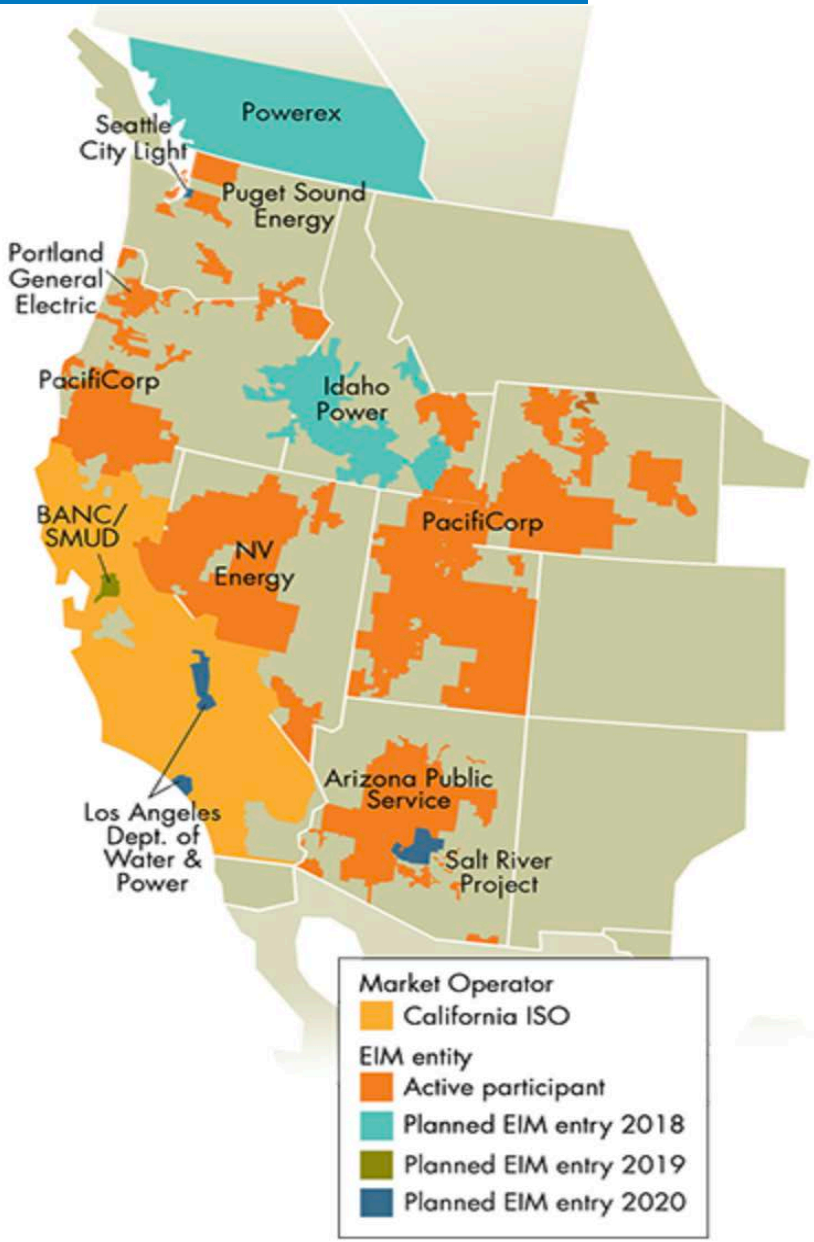

Market Products

- **Energy Market**
  - Day-Ahead Energy Market
  - Real-Time Energy Market
- **Ancillary Services Market**
  - Reserve Market (market-based)
  - Regulation market (market-based)
  - Voltage support (cost-based)
  - Blackstart service (cost-based)
- **Financial Transmission Rights Markets**
  - Including Auction Revenue Rights
- **Capacity Markets**
  - Flexible Capacity

Source: EPRI

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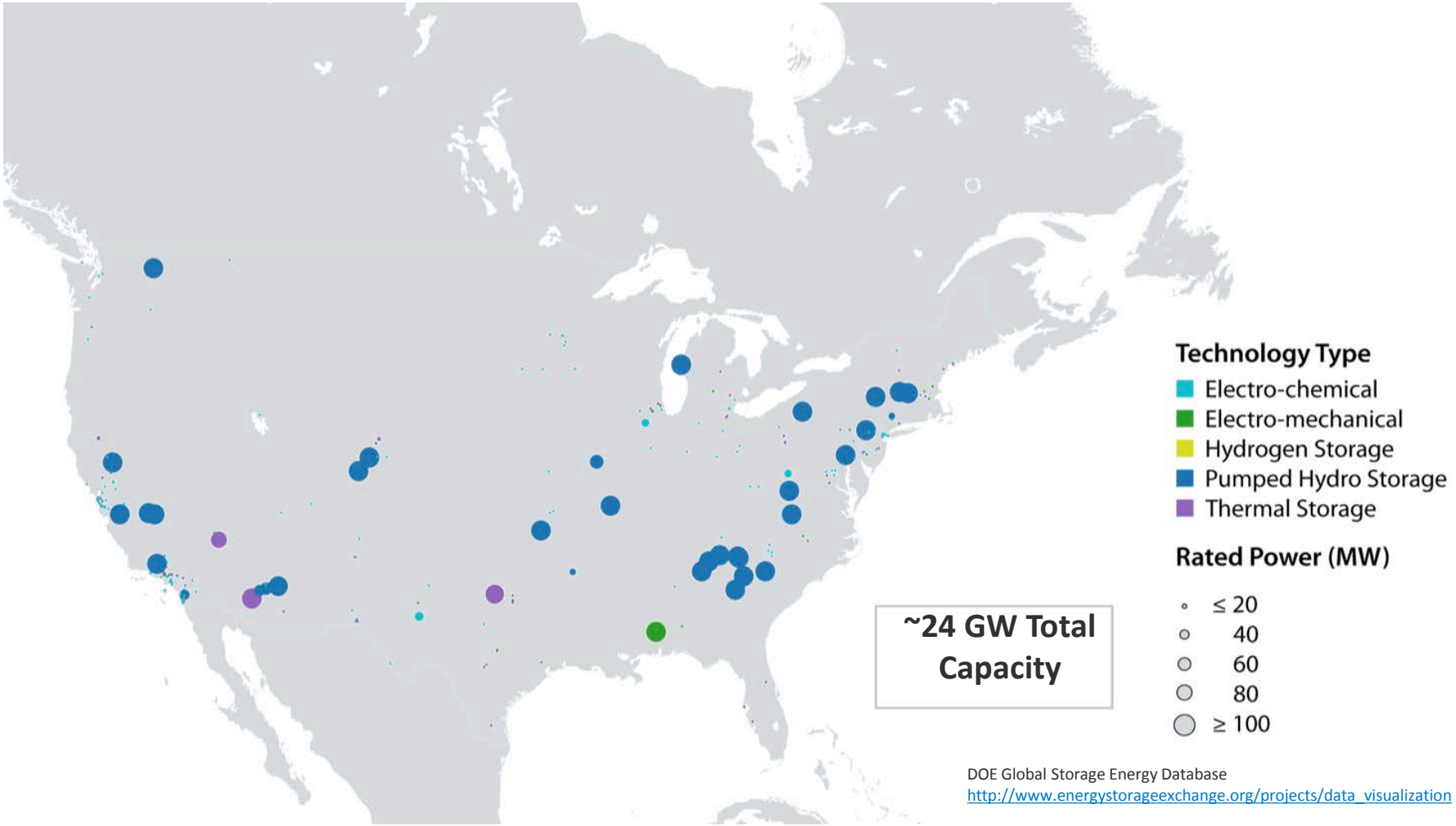
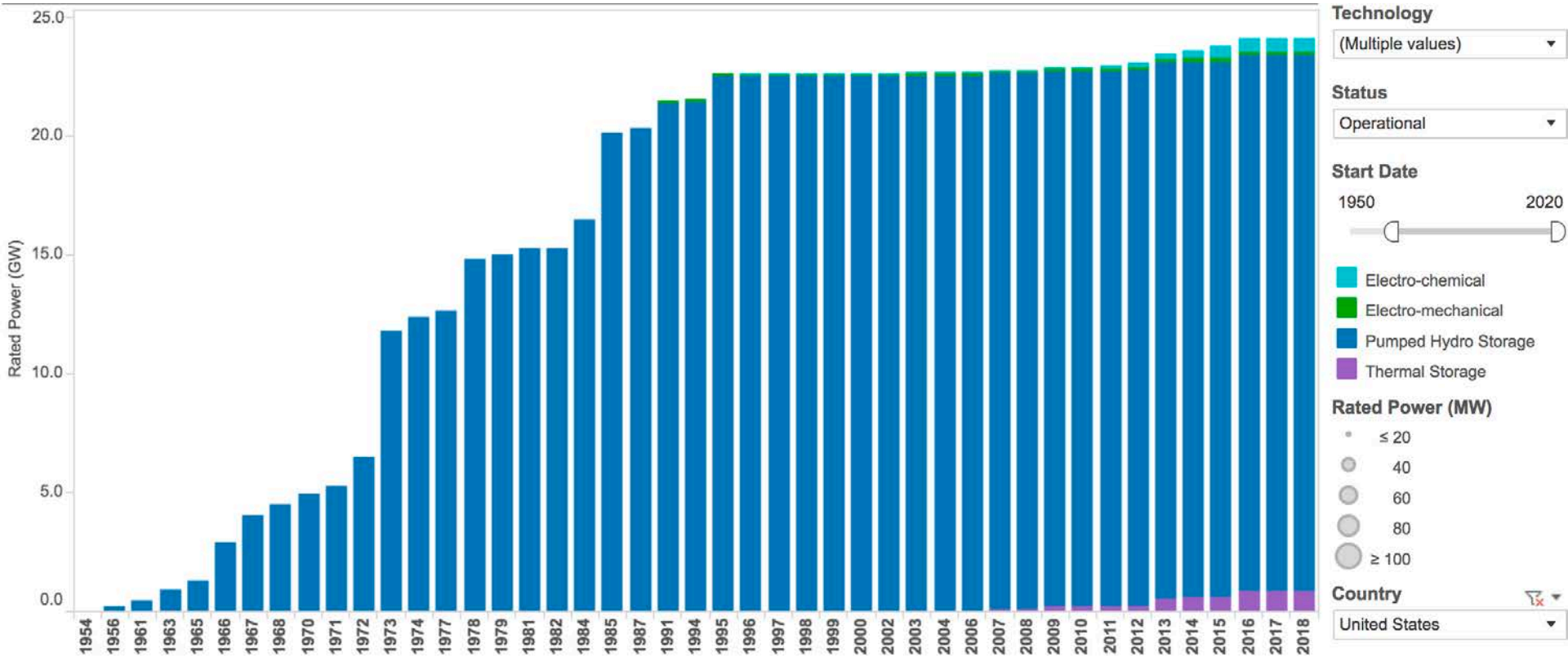
Storage in the U.S.



DOE Global Storage Energy Database
http://www.energystorageexchange.org/projects/data_visualization

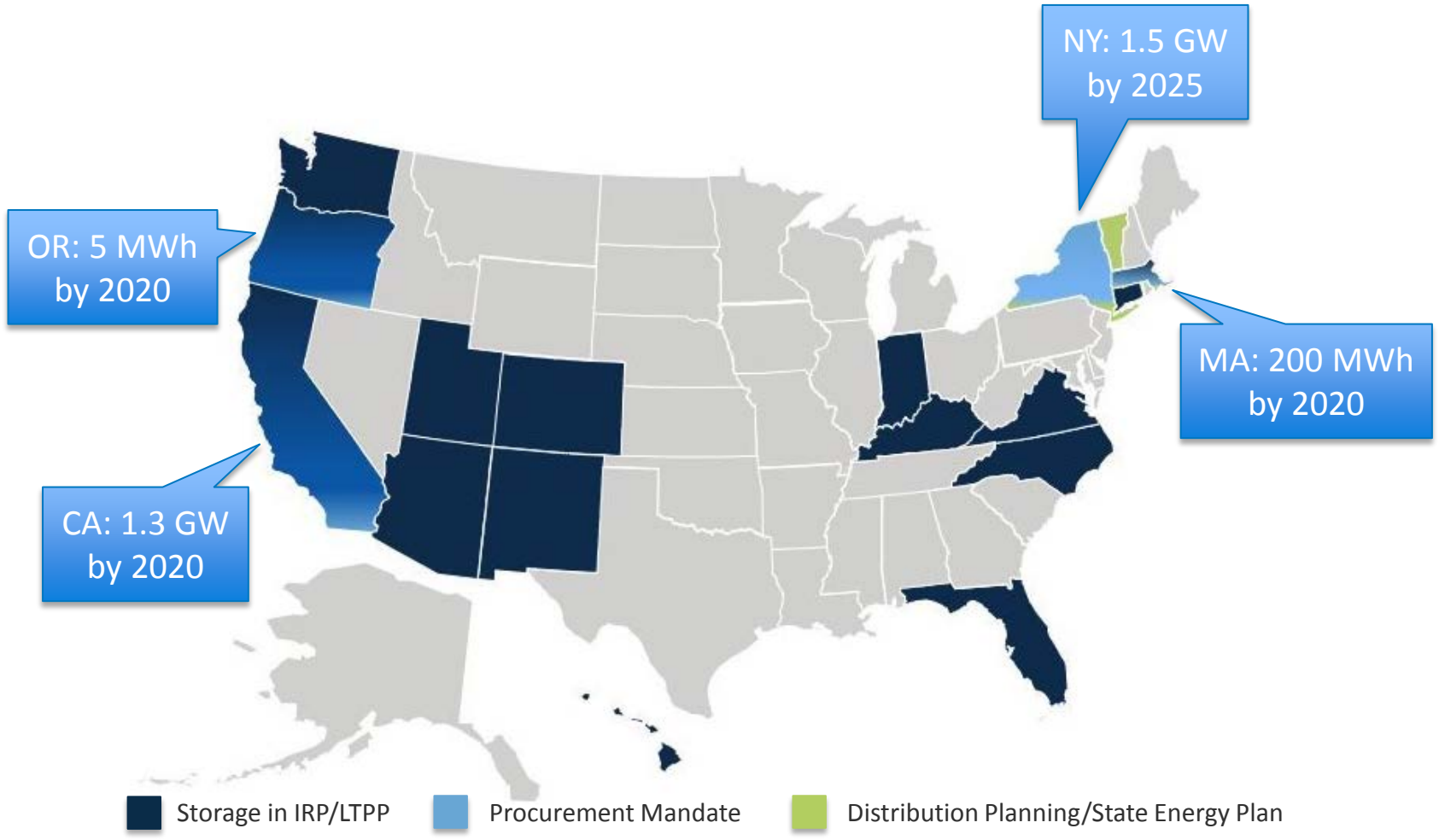
Pumped Storage Hydro is the dominant energy storage technology in the U.S.

Storage in the U.S.



Source: U.S. DOE

States with Utilities Including Storage in Resource Planning or Rate Cases



Source: https://www.greentechmedia.com/articles/read/us-energy-storage-deployments-up-46-percent-annually-in-q3-2017#gs.72ix3i4

The Dynamic Li-Ion Market

Tesla has 100 days to build a 129 MWh storage plant in South Australia

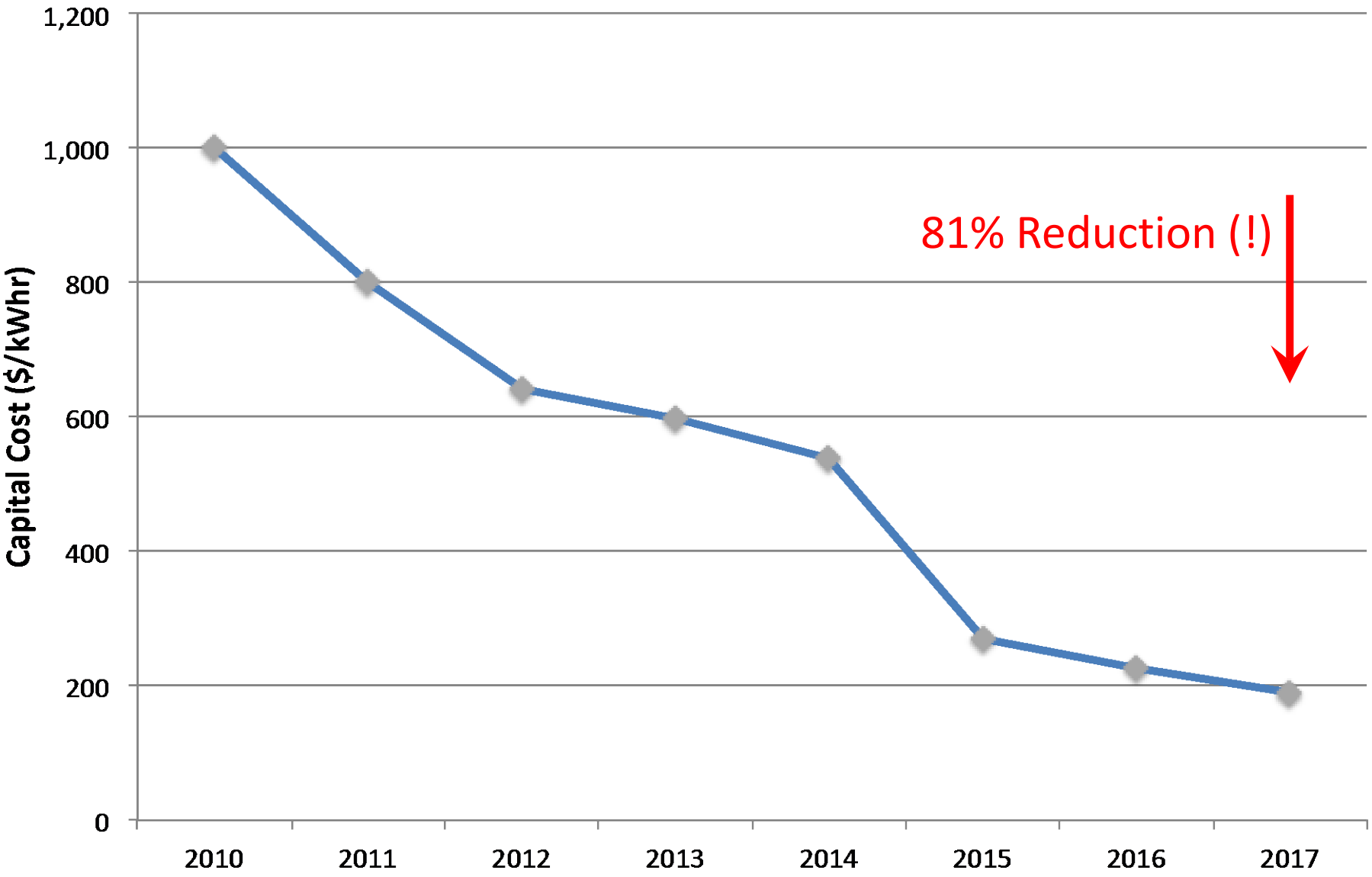
AUTHOR
Peter Maloney
@TopFloorPower

PUBLISHED
July 10, 2017

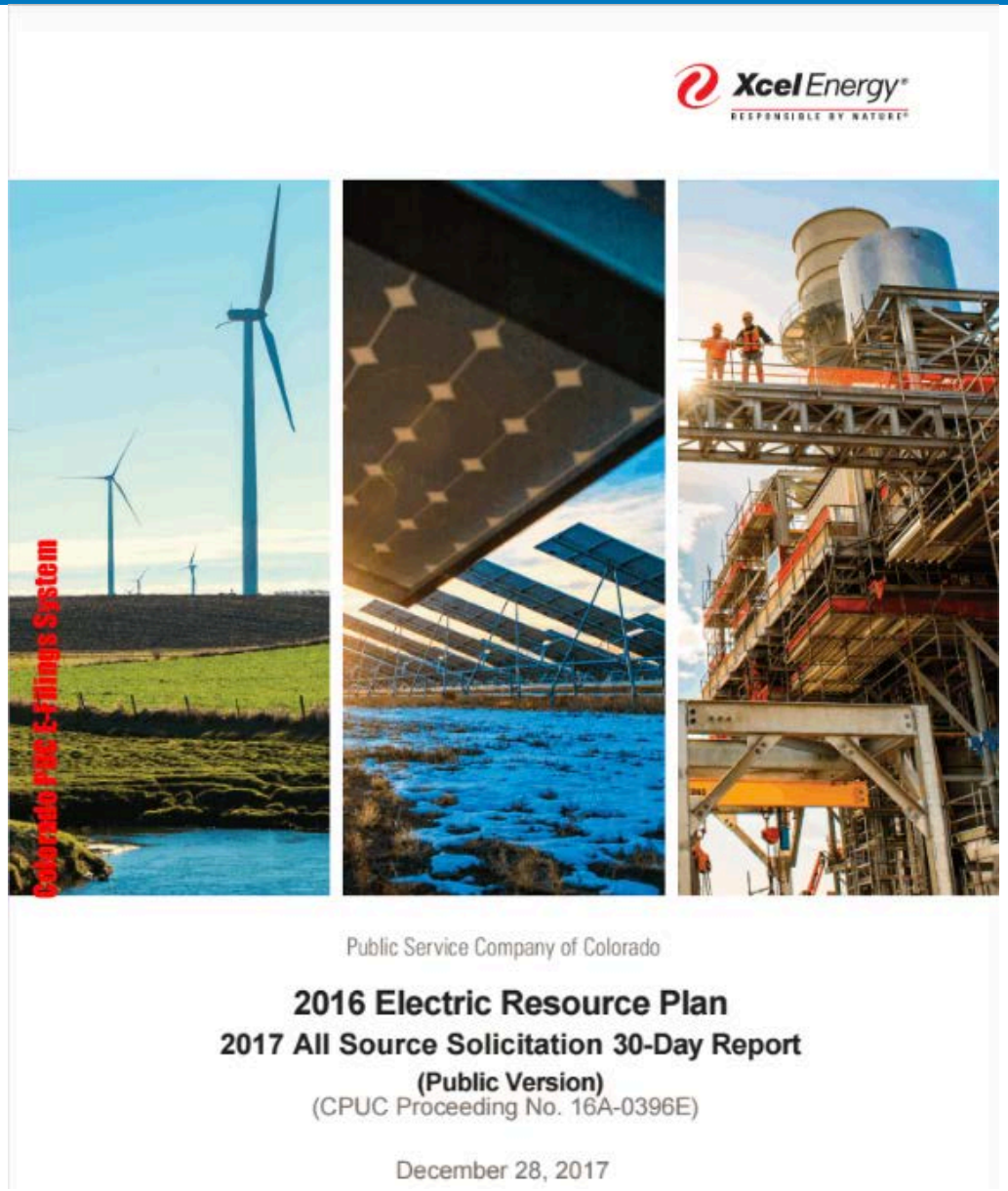
Dive Brief:

- South Australia Premier Jay Weatherill last week announced that Tesla has won a solicitation to build a 100 MW, 129 MWh energy storage project at a wind farm operated by Neoen of France.
- The storage facility will be "built and working" within 100 days of contract signature or it will be free, keeping with an offer made by Tesla CEO Elon Musk in March.
- The project will be located at Neoen's 315 MW Hornsdale wind farm that is under construction. When completed, it would be the world's largest lithium-ion battery installation.

The Dynamic Li-Ion Market



Li-Ion Market – Late Breaking News



Li-Ion Market – Late Breaking News

RFP Responses by Technology

Generation Technology	# of Bids	Bid MW	# of Projects	Project MW	Median Bid Price or Equivalent	Pricing Units
Combustion Turbine/IC Engines	30	7,141	13	2,466	$ 4.80	$/kW-mo
Combustion Turbine with Battery Storage	7	804	3	476	6.20	$/kW-mo
Gas-Fired Combined Cycles	2	451	2	451		$/kW-mo
Stand-alone Battery Storage	28	2,143	21	1,614	11.30	$/kW-mo
Compressed Air Energy Storage	1	317	1	317		$/kW-mo
Wind	96	42,278	42	17,380	$ 18.10	$/MWh
Wind and Solar	5	2,612	4	2,162	19.90	$/MWh
Wind with Battery Storage	11	5,700	8	5,097	21.00	$/MWh
Solar (PV)	152	29,710	75	13,435	29.50	$/MWh
Wind and Solar and Battery Storage	7	4,048	7	4,048	30.60	$/MWh
Solar (PV) with Battery Storage	87	16,725	59	10,813	36.00	$/MWh
IC Engine with Solar	1	5	1	5		$/MWh
Waste Heat	2	21	1	11		$/MWh
Biomass	1	9	1	9		$/MWh
Total	430	111,963	238	58,283		

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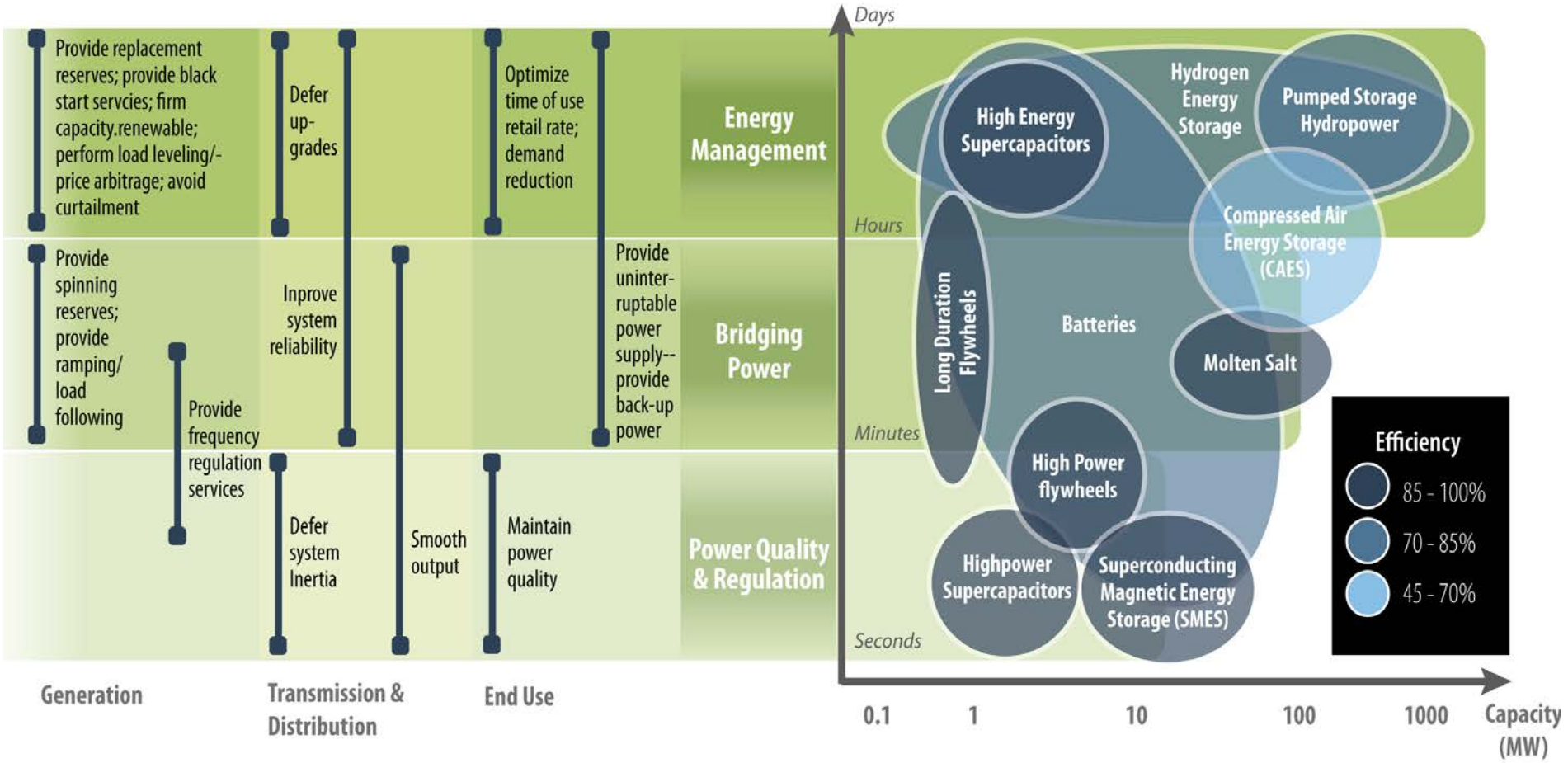
Grid Application Depends on Storage Characteristics

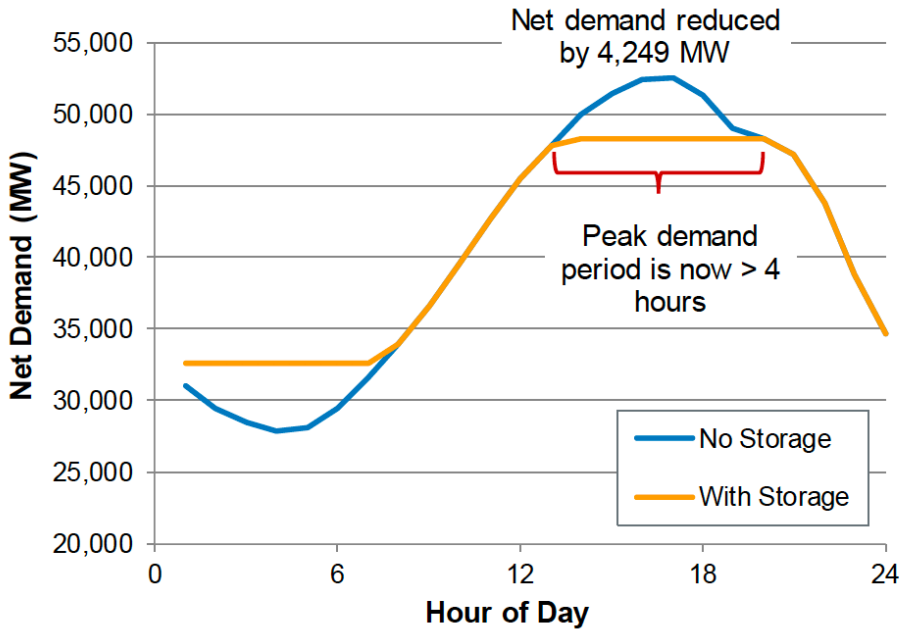


Different technologies can address different grid needs, but no single storage technology, in the near term, is likely to meet all grid applications.

Potential for Storage to Provide Peaking Capacity – Analysis for California

- To approximate capacity credit, storage is incrementally added (assuming full discharge) until adding 1 MW of storage cannot reduce net demand by 1 MW.

- Here 4,249 MW of 4-hour storage reduces peak demand by an amount equal to the power rating (4,249 MW), but more storage has a "peak demand reduction credit" less than 100%.

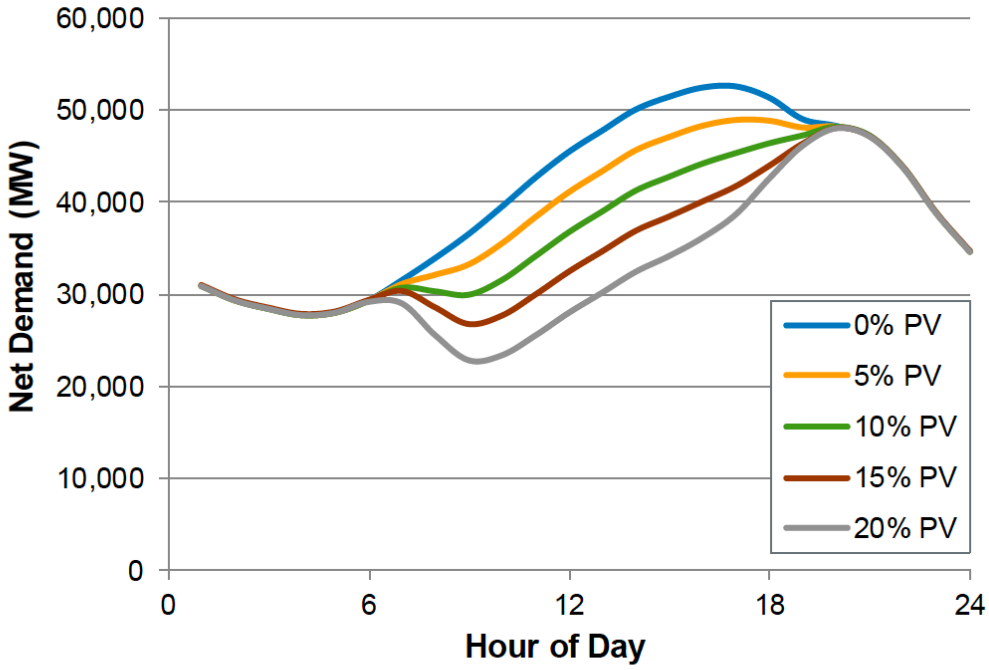


No PV Case

Impact of 4-hour storage dispatch on net demand on the peak demand day in 2011

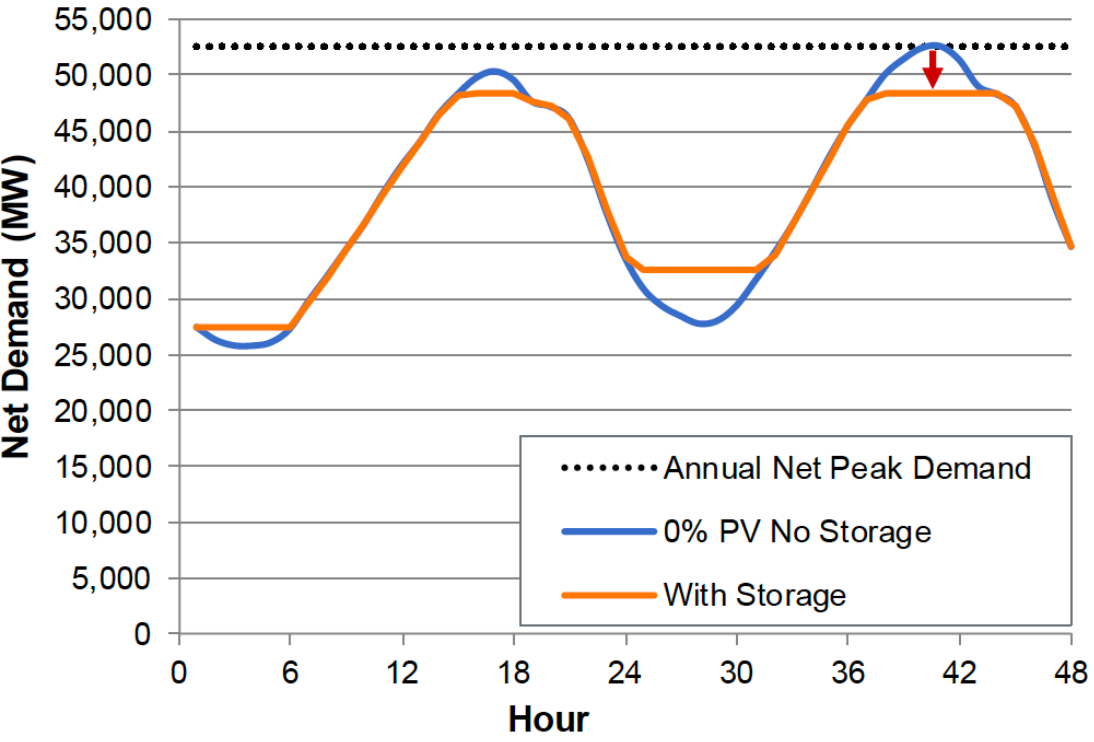
Potential for Storage to Provide Peaking Capacity – Analysis for California

- Increasing levels of PV change the net load shape: at low penetration, PV reduces and flattens the peak demand. As PV penetration increases, PV's impact on reducing peak demand diminishes, while it increases the "peakiness" (narrows the width) of the net peak demand.



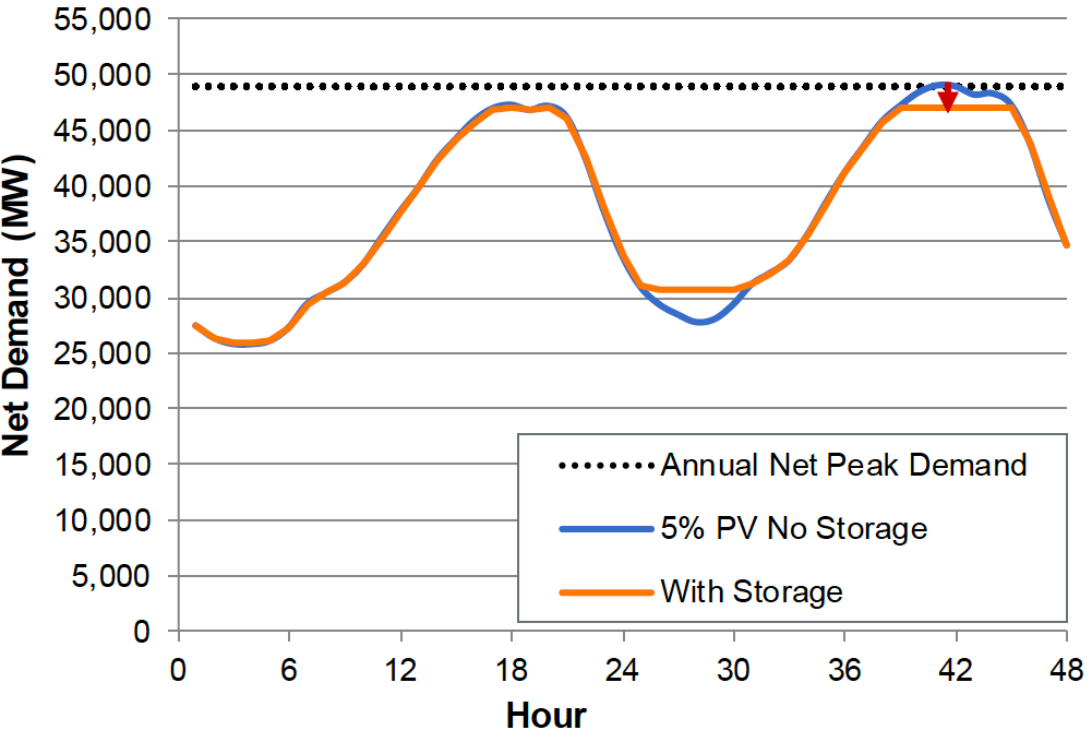
Simulated change in California net load shape due to PV on a peak demand day in September 2011

Potential for Storage to Provide Peaking Capacity – Analysis for California



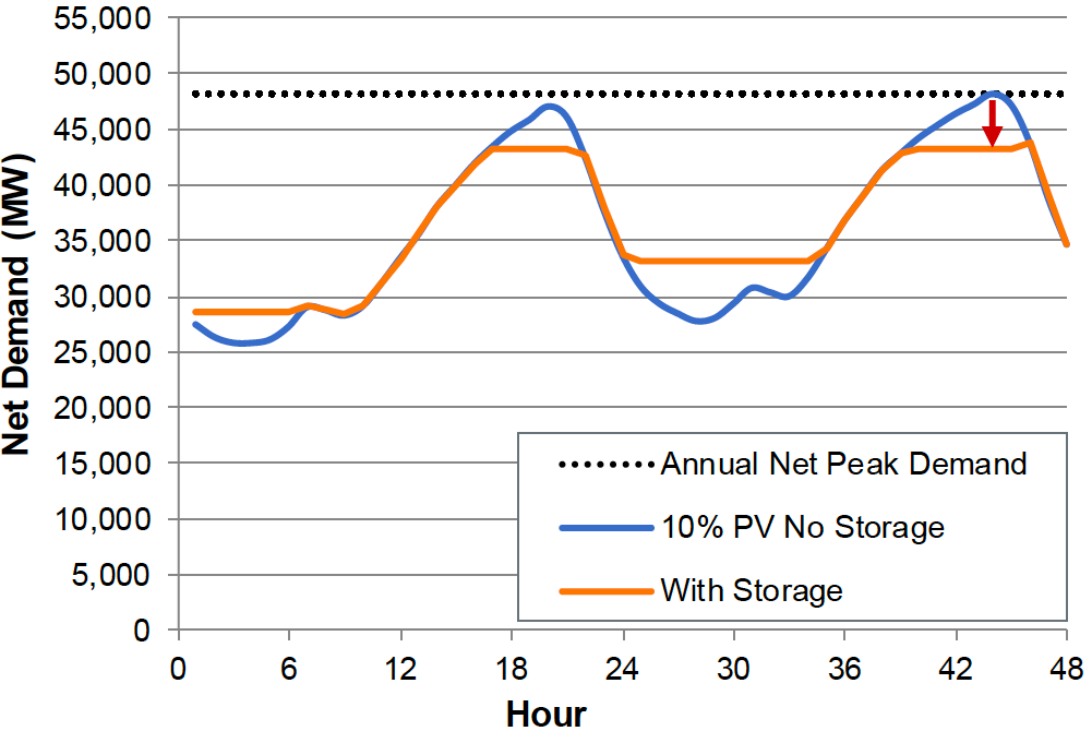
Zero PV. Peak demand occurs on September 6 (day 2) and is 52,540 MW. Peak demand reduction with 4-hr storage at 100% credit is 4,249 MW. Annual net peak demand is reduced to 48,292 MW. Storage is not completely utilized on day one so could have had additional charge/discharge for greater price arbitrage.

Potential for Storage to Provide Peaking Capacity – Analysis for California



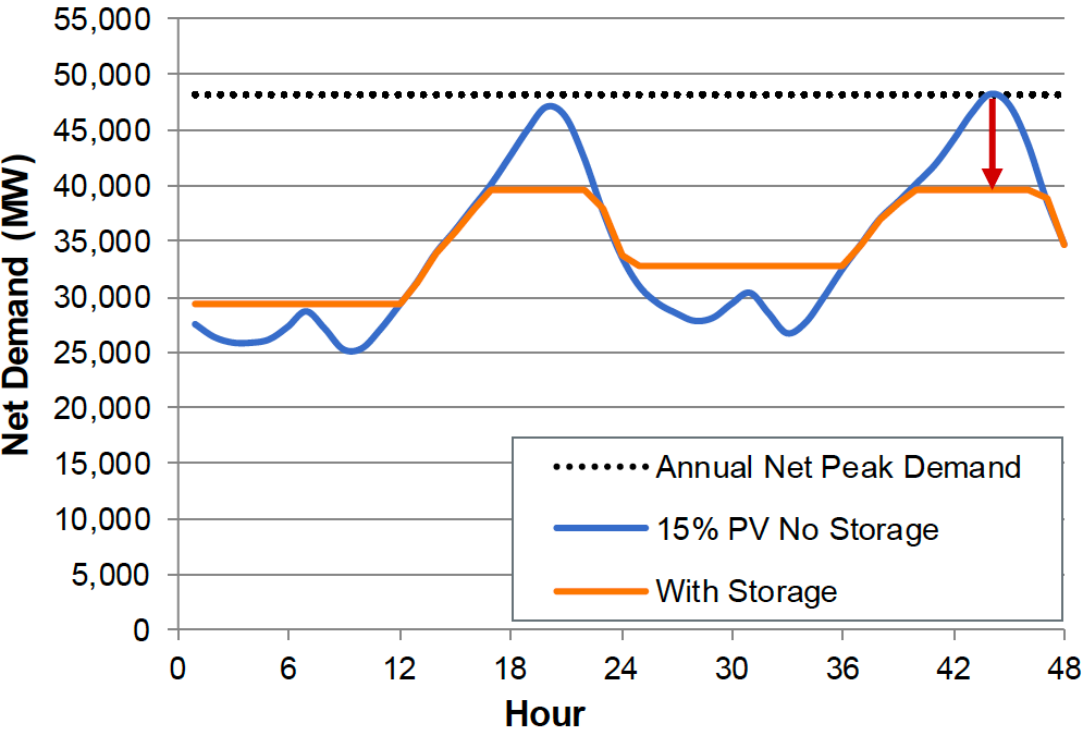
5% PV. PV generation has reduced net peak demand has been reduced to 48,940 MW. The peak shape is clipped (flattened) compared to zero PV case. Peak demand reduction of 4-hr storage at 100% credit is 1,937 MW (less than with zero PV).

Potential for Storage to Provide Peaking Capacity – Analysis for California



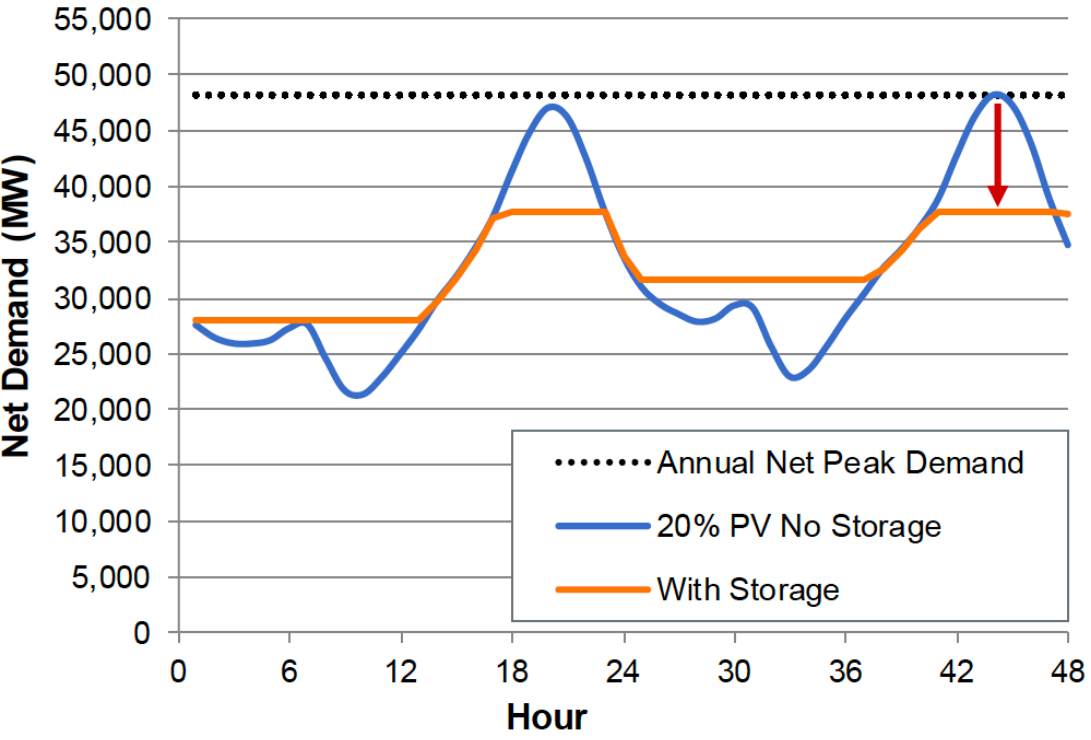
10% PV. PV generation has reduced net peak demand has been reduced to 48,172 MW. Peak demand shape has been narrowed relative to previous cases. Peak demand reduction with 4-hr storage at 100% credit has increased to 4,935 MW, a small increase relative to the zero PV case.

Potential for Storage to Provide Peaking Capacity – Analysis for California



15% PV. PV generation has reduced net peak demand has been reduced to 48,123 MW. Net demand peak now occurs during period of low solar output and incremental capacity credit of PV is approaching zero. Peak shape has been significantly narrowed. Peak demand reduction with 4-hr storage at 100% credit is 8,462 MW, or about double the zero PV case.

Potential for Storage to Provide Peaking Capacity – Analysis for California



20% PV. PV generation has reduced net peak demand to 48,117 MW. Essentially zero incremental capacity credit of PV. The peak continues to narrow. Peak demand reduction with 4-hr storage at 100% credit is 10,372 MW.

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Grid Services without Batteries

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Demonstration of Essential Reliability Services by a 300-MW Solar PV Power Plant

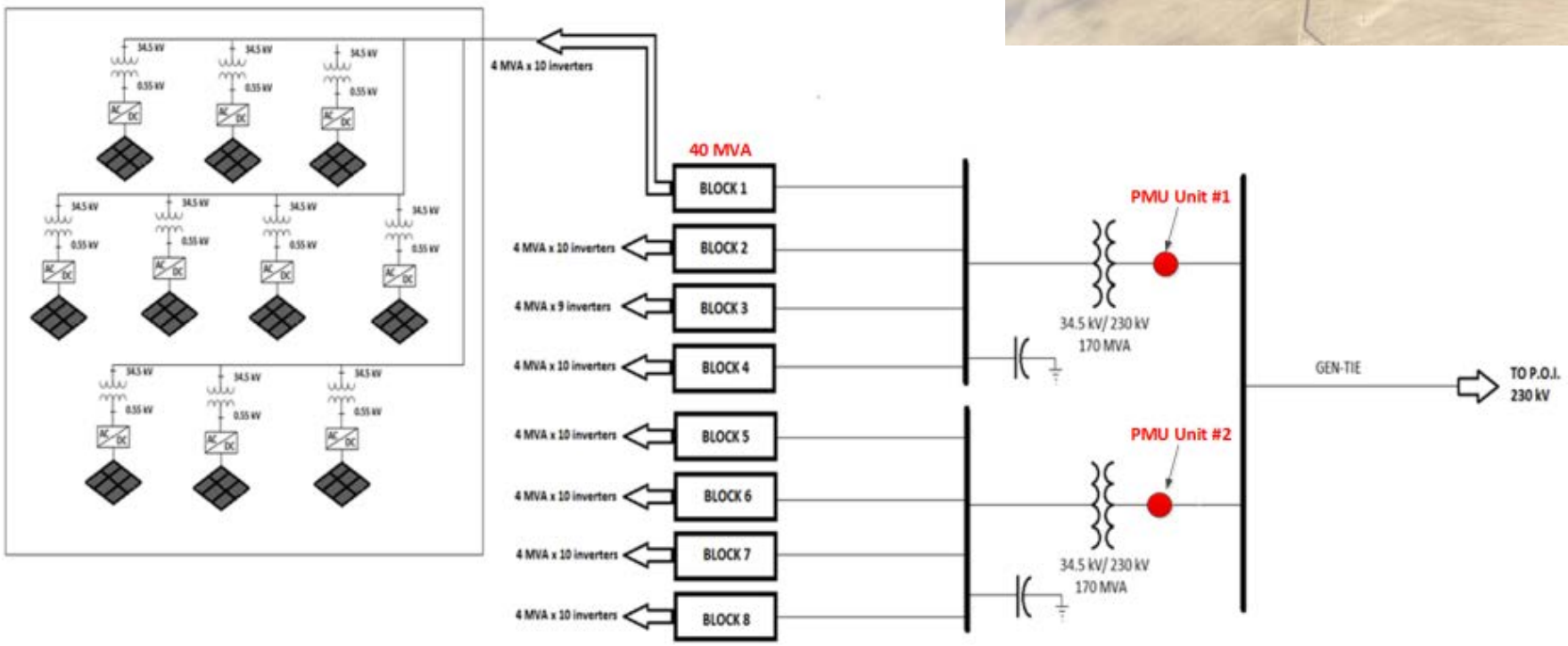
Presenter: V. Gevorgian, NREL

January 25, 2017

Publication No.

Grid Services without Batteries

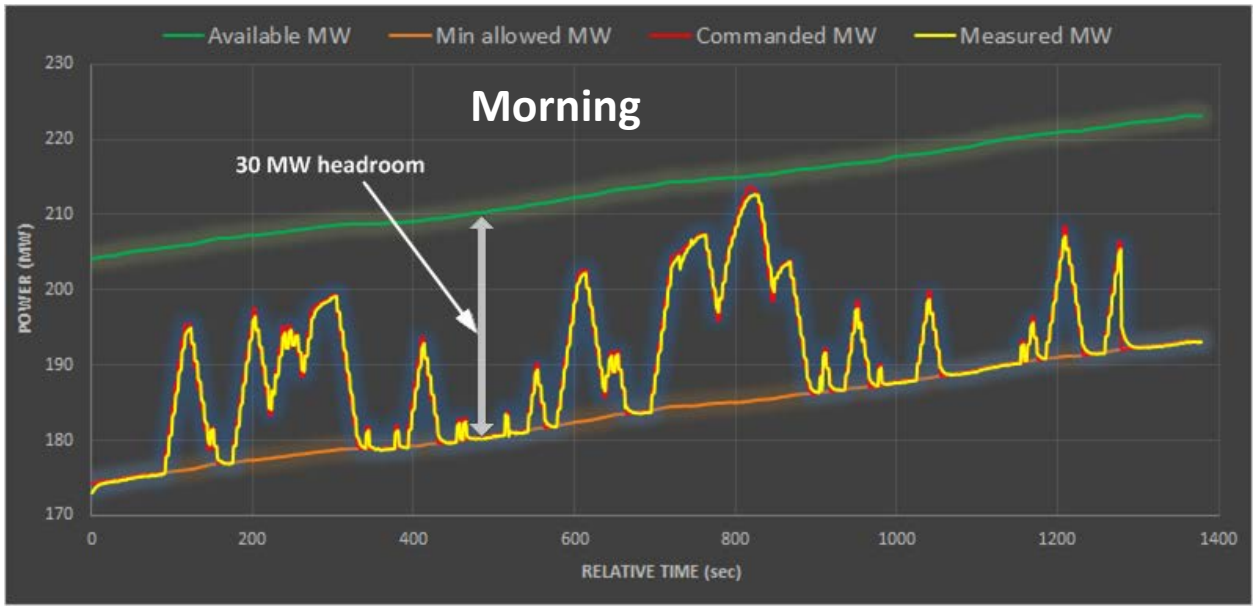
- Thin-film Cd-Te PV modules
- 4 MVA PV inverters
- 9 x 40 MVA blocks
- 34.5 kV collector system
- Two 170 MVA transformers
- Tie with 230 kV transmission line
- PMUs collecting data on 230 kV side

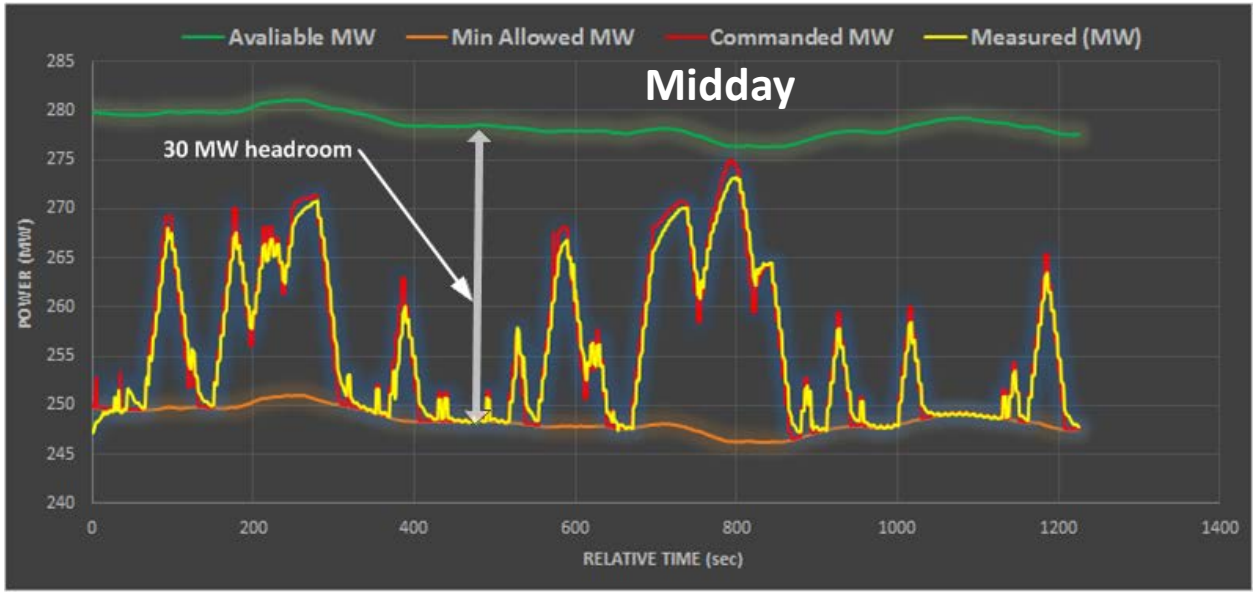


Summary of Tests

- **CAISO-NREL-First Solar custom-developed test scenarios:**
  - *Regulation-up and regulation-down*, or AGC tests during sunrise, middle of the day, and sunset
  - *Frequency response* tests with 3% and 5% droop settings for over- frequency and under- frequency conditions
  - *Curtailment and APC* tests to verify plant performance to decrease or increase its output while maintaining specific ramp rates
  - *Voltage and reactive power* control tests
  - *Voltage control* at near zero active power levels (nighttime control).
- **More standardized First Solar's power plant controller (PPC) system commissioning tests:**
  - Automatic manual control of inverters (individual, blocks of inverters, whole plant)
  - Active power curtailment control, generation failure and restoration control, frequency control validation
  - Automatic voltage regulation at high and low power generation
  - Power factor control
  - Voltage limit control
  - Volt-ampere reactive (VAR) control.

Grid Services without Batteries





- 4-sec AGC signal provided to PPC
- 30 MW headroom
- Tests were conducted at three resource intensity conditions (20 minutes at each condition):
  - Sunrise
  - Middle of the day
  - Sunset
- 1-sec data collected by plant PPC

Test Summary and Comparison

Measured Regulation Accuracy by 300 MW PV Plant

Time Frame	Solar PV Plant Test Results
Sunrise	93.7%
Middle of the day	87.1%
Sunset	87.4%

Typical Regulation-Up Accuracy of CAISO Conventional Generation

	Combined Cycle	Gas Turbine	Hydro	Limited Energy Battery Resource	Pump Storage Turbine	Steam Turbine
Regulation-Up Accuracy	46.88%	63.08%	46.67%	61.35%	45.31%	40%

Thank You

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