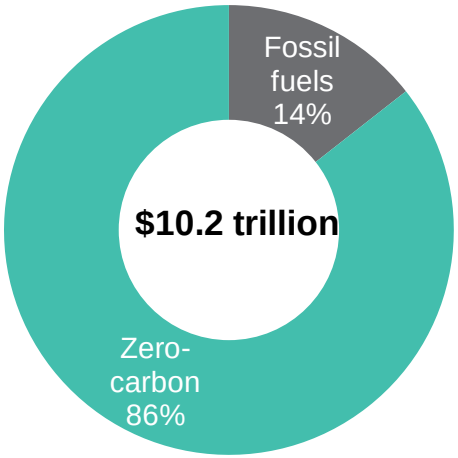
Designing the Decarbonized, Reliable and Resilient Grid of the Future

Sacramento, January 23, 2020

Angelina Galiteva
Vice Chair Board of Governors California Independent System Operator,
Founder Renewables 100 Policy Institute

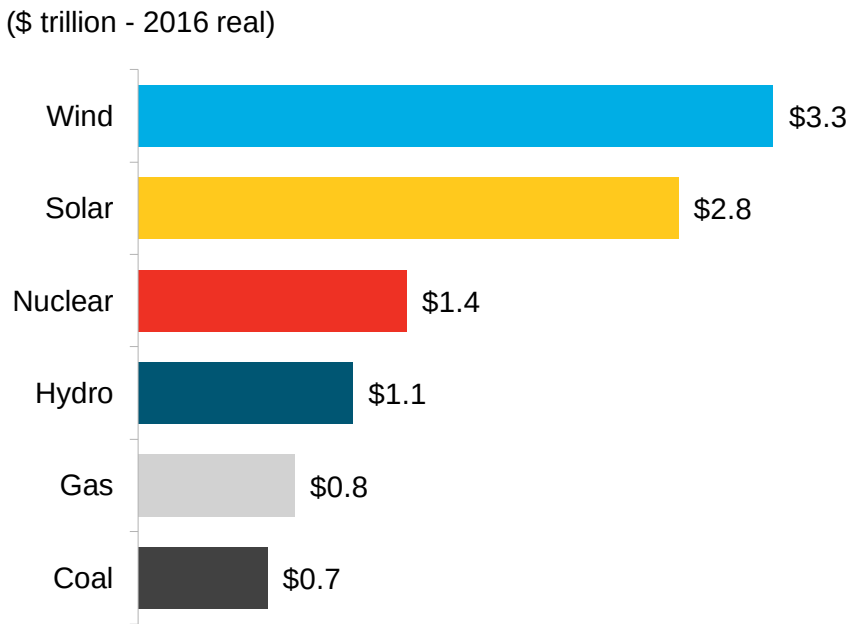
Solar and wind attract 60% of new investment in power generating capacity

Investment, by technology, 2017-2040



Source: Bloomberg New Energy Finance

Investment, by technology, 2017-2040



Source: Bloomberg New Energy Finance

Source: Bloomberg New Energy Finance

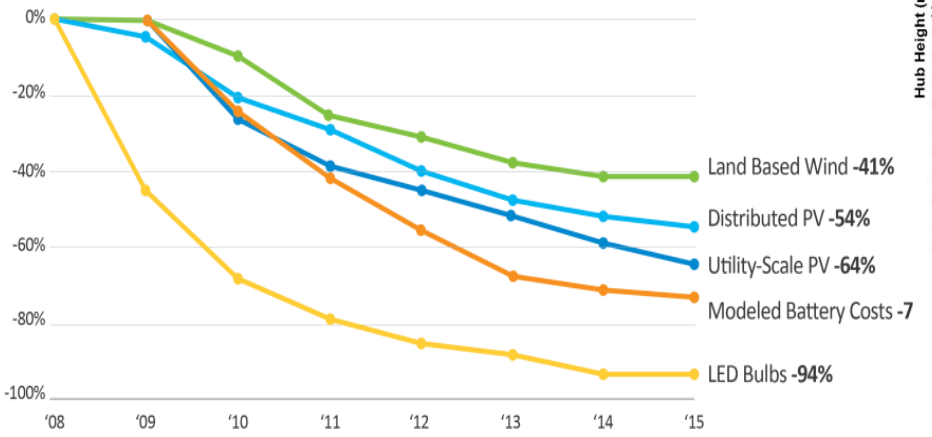
Source: Bloomberg New Energy Finance, NEO 2017

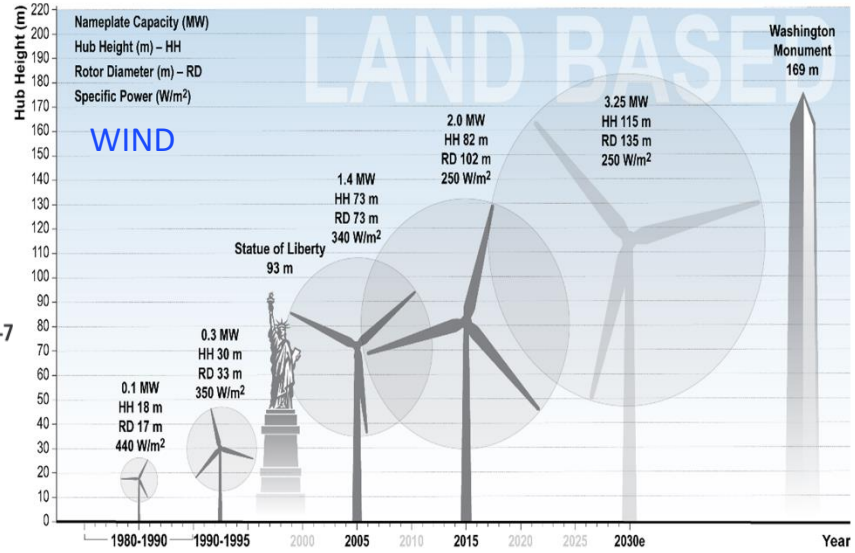
FOSSIL FUEL DECLINE: ONLY ONE OIL COMPANY REMAINS IN THE TOP TEN LIST COMPANIES

1978	1988	1998	2008	2018
General Motors $3337.5M	IBM $5258.0M	General Motors $178.17B	Exxon Mobil $466.28B	Walmart $500.34B
IBM $2719.4M	Exxon Mobil $4840.0M	Ford Motors $153.62B	Walmart $378.48B	Exxon Mobil $244.36B
Exxon Mobil $2423.0M	Ford Motors $4625.0M	Exxon Mobil $122.38B	Texaco $267.64	Berkshire Hathaway $242.14B
Ford Motors $1672.8M	Texaco $4407M	Walmart $119.30B	Conoco Phillip $246.18B	Apple $229.23B
General Electric $1088.2M	General Motors $3551.0M	General Electric $90.84B	General Electric $181.58B	UnitedHealth $201.16B
Chevron $1016.4M	General Electric $2915.0M	IBM 78.51B	General Motors $148.98B	McKesson $198.53B
Mobil $1004.7M	AT&T $2044.0M	Chrysler $61.15B	Ford Motors $145.11B	CVS Health $184.77B
Texaco $930.8M	DuPont $1786M	Mobil $59.98B	AT&T $124.03B	Amazon.com $177.87B
Gulf Oil $752.0M	Chrysler $1290M	Altria Group $56.11B	Bank of America $75.70B	AT&T $160.55B
Chrysler $163.2M	Mobil $1258M	AT&T $53.26B	Citigroup, Inc. $51.60B	General Motors $157.31B

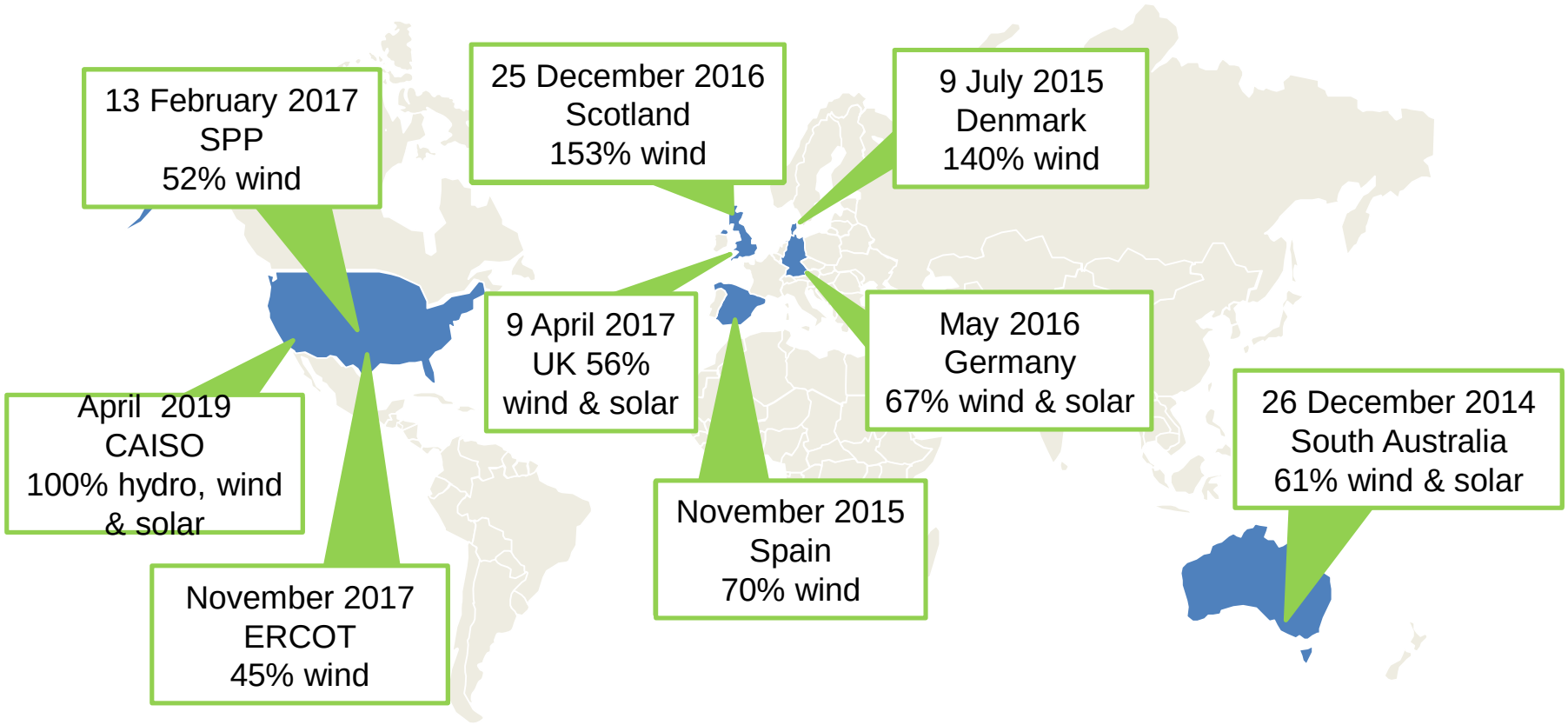
Source: Forbes Fortune 500 list, top ten companies by revenue

Price of renewables continue to decrease





High Levels of Renewable Penetration Globally



Source: Bloomberg New Energy Finance, various

U.S. Renewable Resources

Achieving 100% Renewables include:

- *Grid modernization*
- *Storage options*
- *Transmission*
- *Behaviors/education*
- *Resources*
- *Cooperation*

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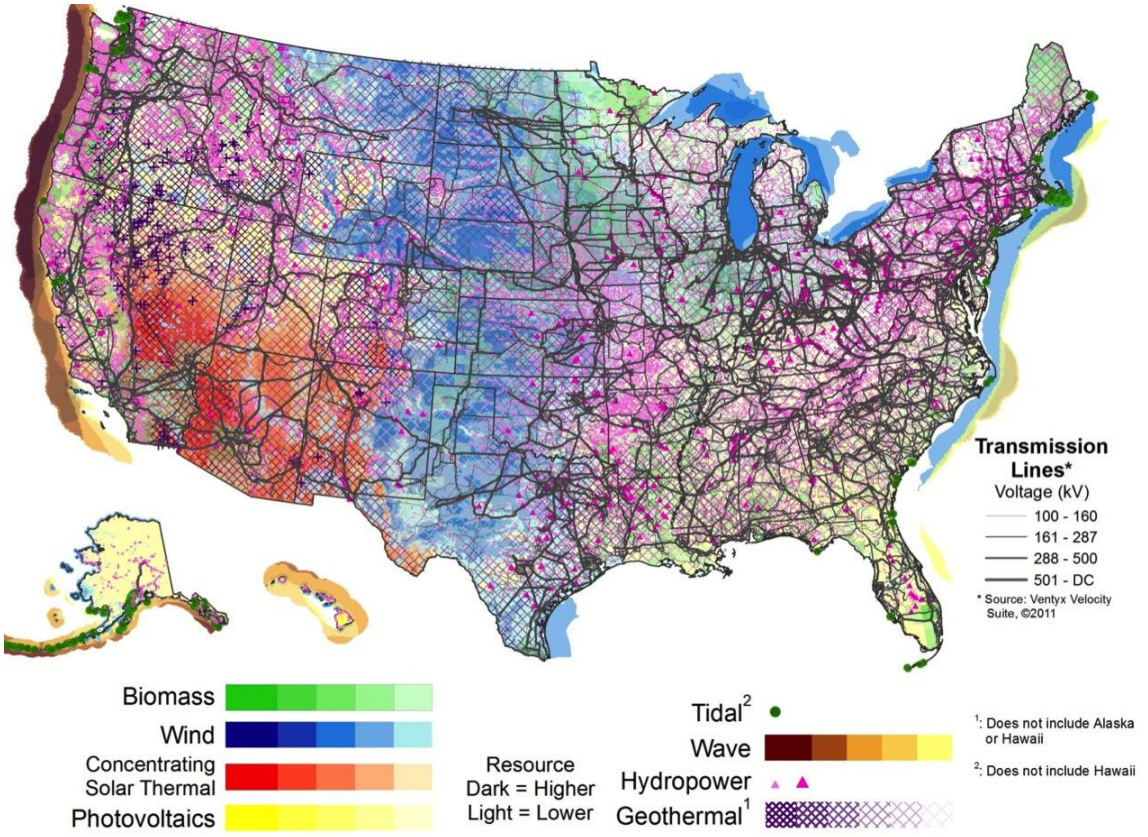
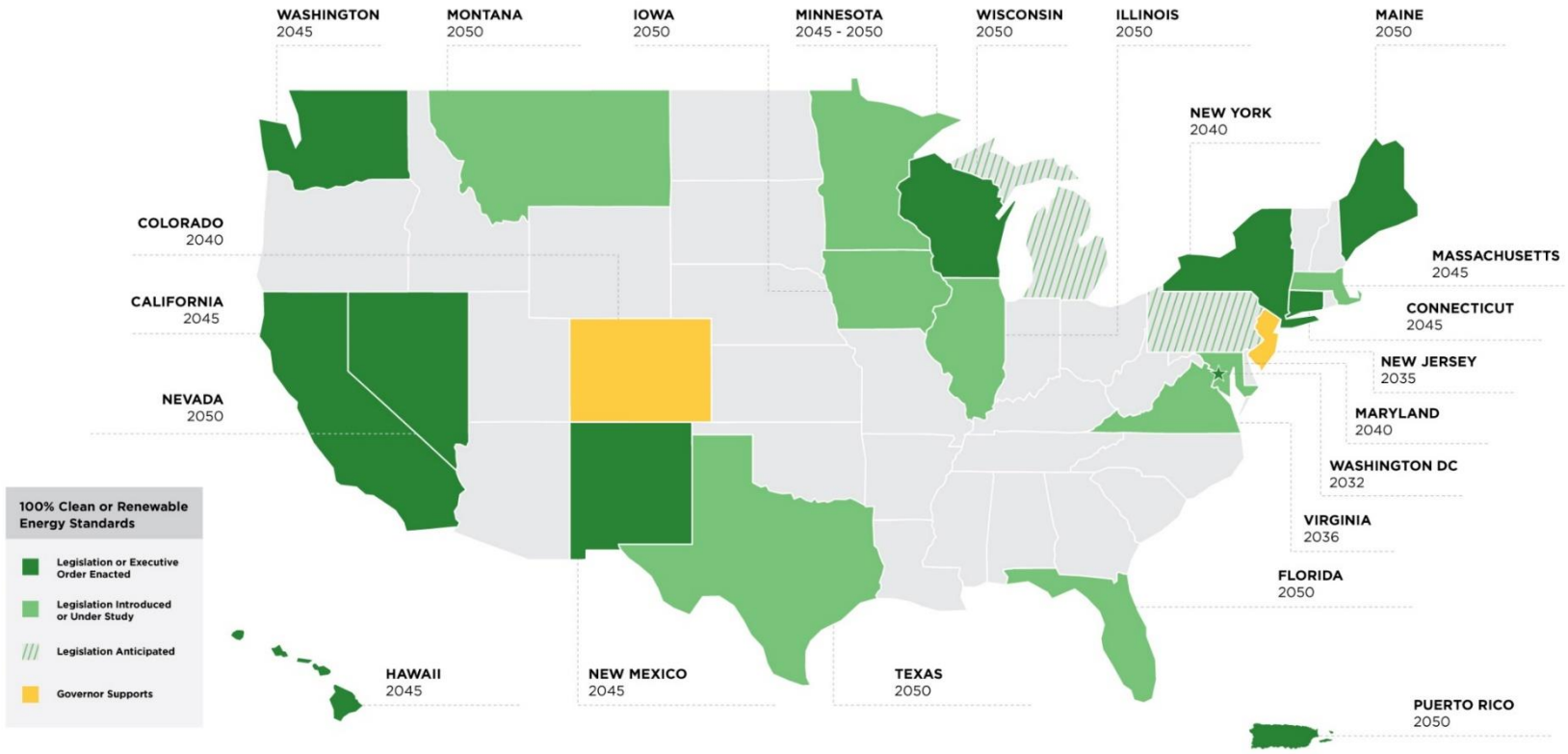


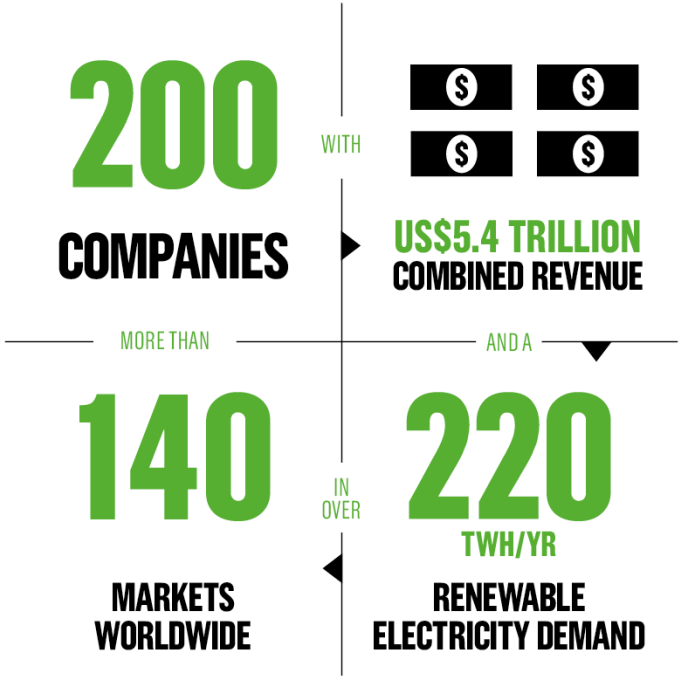
Resource	Solar PV/CSP)	Wind	Geothermal	Water Power	Biopower
Theoretical Potential	155,000 GW (PV) 38,000GW (CSP)	11,000 GW (onshore) 4,200 GW (offshore to 50 nm)	38 GW (conventional) 4,000 GW (EGS)	68 GW	62 GW

NEARLY 30% OF AMERICANS LIVE IN A COMMUNITY THAT IS GOING 100% CLEAN ENERGY



Source: EQ Research Policy Vista™ Legislative Tracking Database as of March 15, 2019, California Energy States Alliance.

200 OF THE WORLD'S LARGEST COMPANIES HAVE COMMITTED TO 100% RENEWABLE ENERGY



Google

Microsoft

amazon

RE 100 | THE CLIMATE GROUP

CDP
DISCLOSURE INSIGHT ACTION

CLIMATE WEEK NYC

California's leaders are aggressively pursuing a low carbon future.

- Aggressive renewable energy goals

33% by 2020 → 60% by 2030 → 100% by 2045

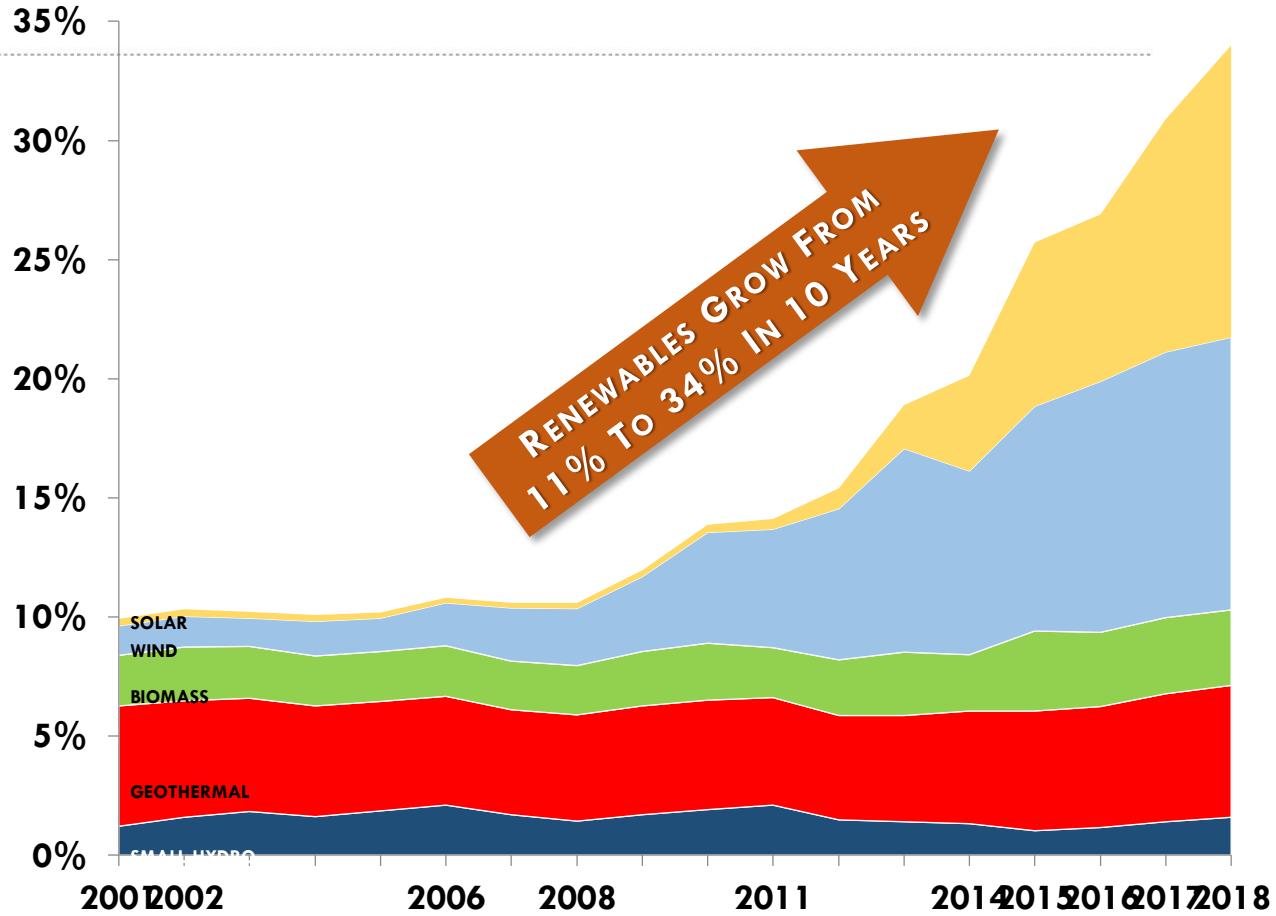
- Deep greenhouse gas (GHG) reduction goals

2020 Target	2030 Target	2050 Target
Reduce GHG emissions to 1990 levels	40% below 1990 levels	80% below 1990 levels

- Robust electric vehicles goal: 5.0 million by 2030, $2.5B investment in new charging stations
- 10,000 MW of distributed generation by 2021; 1.3 GW of battery storage by 2024

Decarbonization is creating opportunities to develop a high renewables and high DER energy service industry.

CALIFORNIA MAKING RAPID PROGRESS ON RENEWABLE ENERGY



Source: California Energy Commission, Tracking Progress Report

CALIFORNIA CLEAN JOBS

California has

5x

more clean energy jobs than fossil fuel jobs.

Nearly

4 in 10

solar jobs in America are in California.

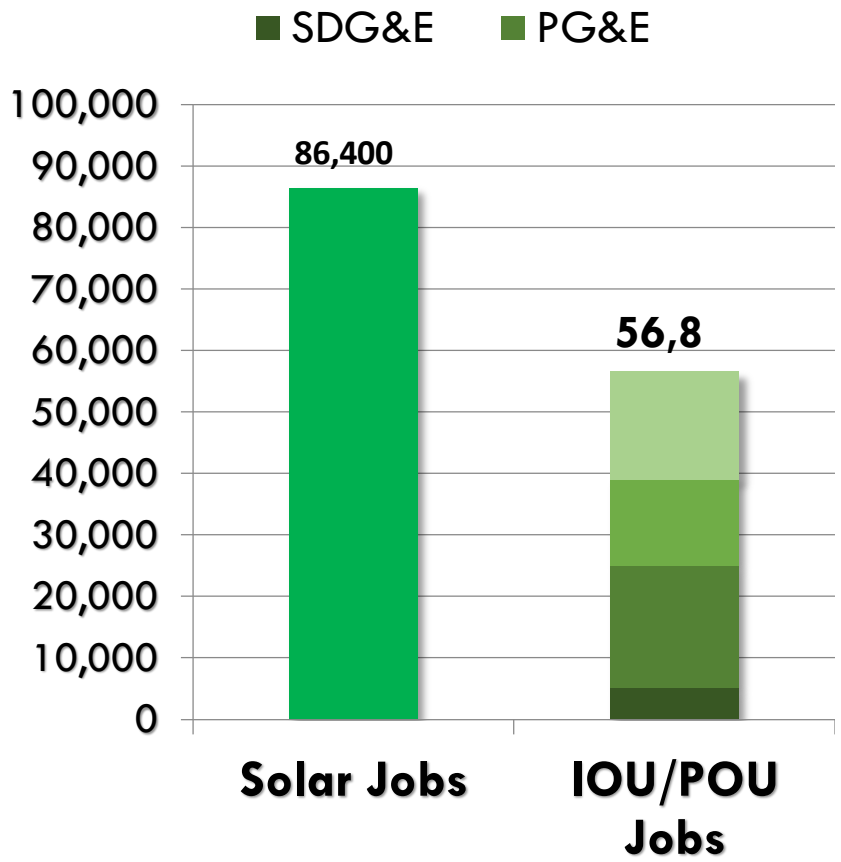
Statewide, there were

512,934

jobs in the clean energy industry in 2018.

Source: AEE 2019 jobs study

MORE CALIFORNIANS WORK IN THE SOLAR INDUSTRY THAN FOR ALL CA ELECTRIC UTILITIES COMBINED



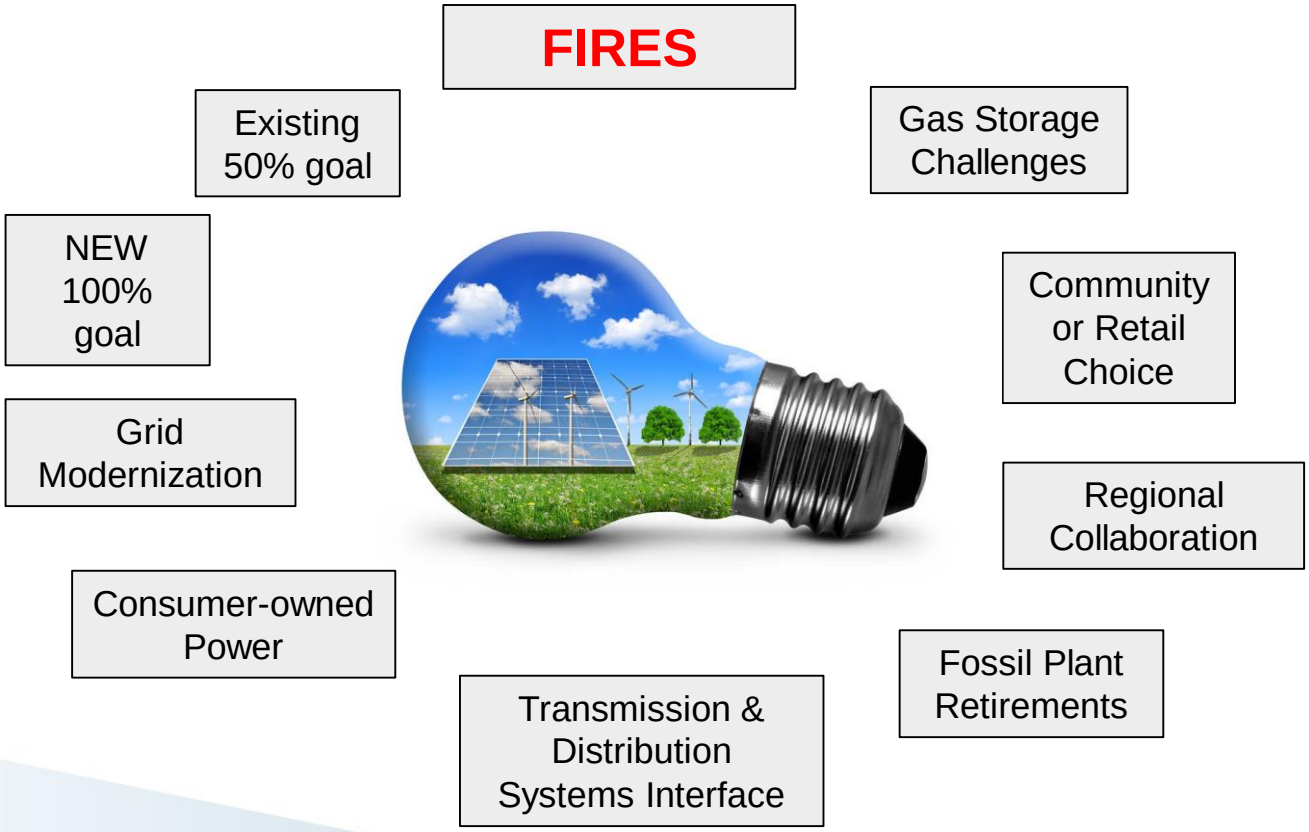
Sources:

Solar Foundation, 2017 Solar Jobs Census

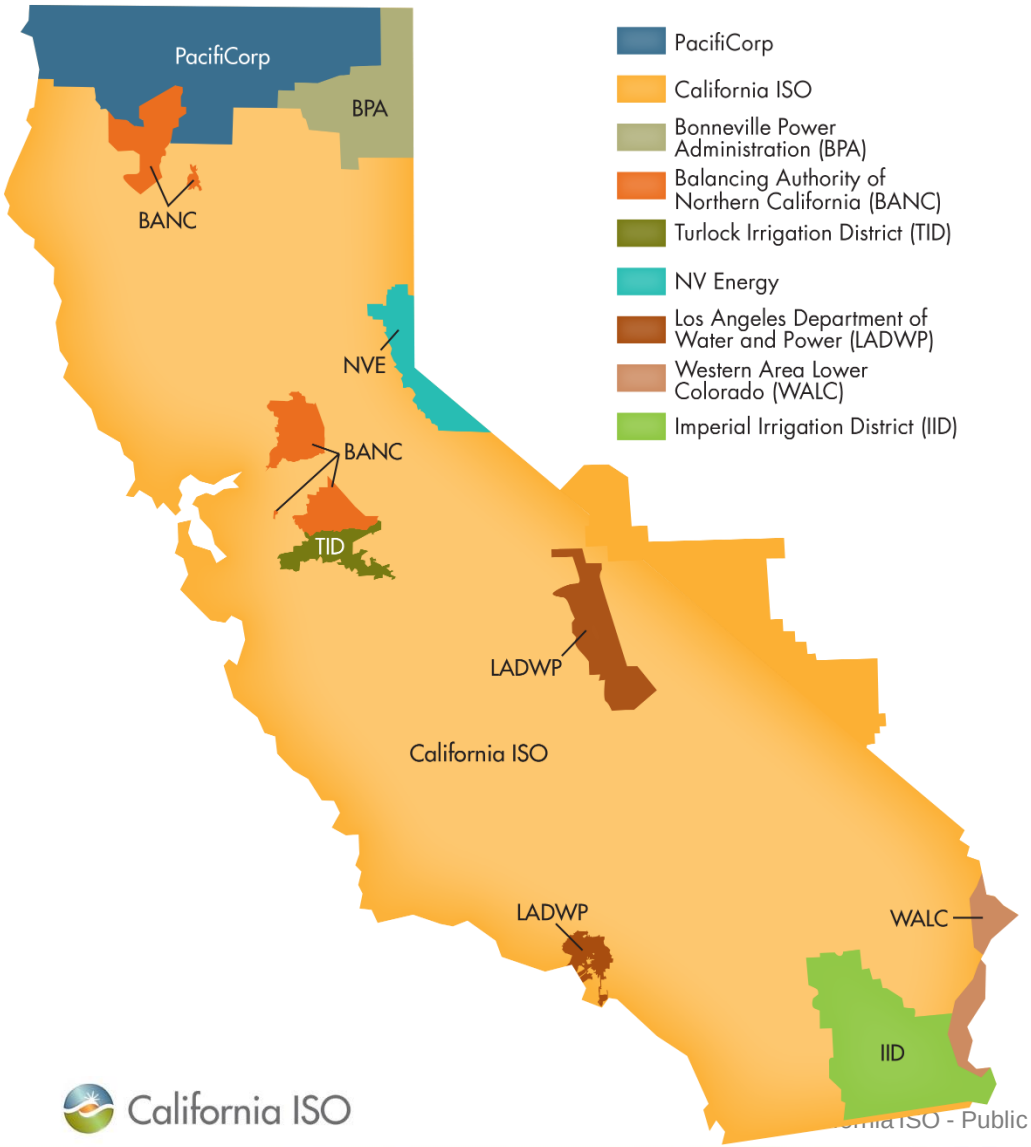
- U.S. Securities and Exchange Commission, Form 10-K, 2014 http://www.sec.gov/edgar/searchedgar/companysearch.html

Electric industry in the midst of unprecedented change

- *Driven by fast-growing mix of interrelated issues*

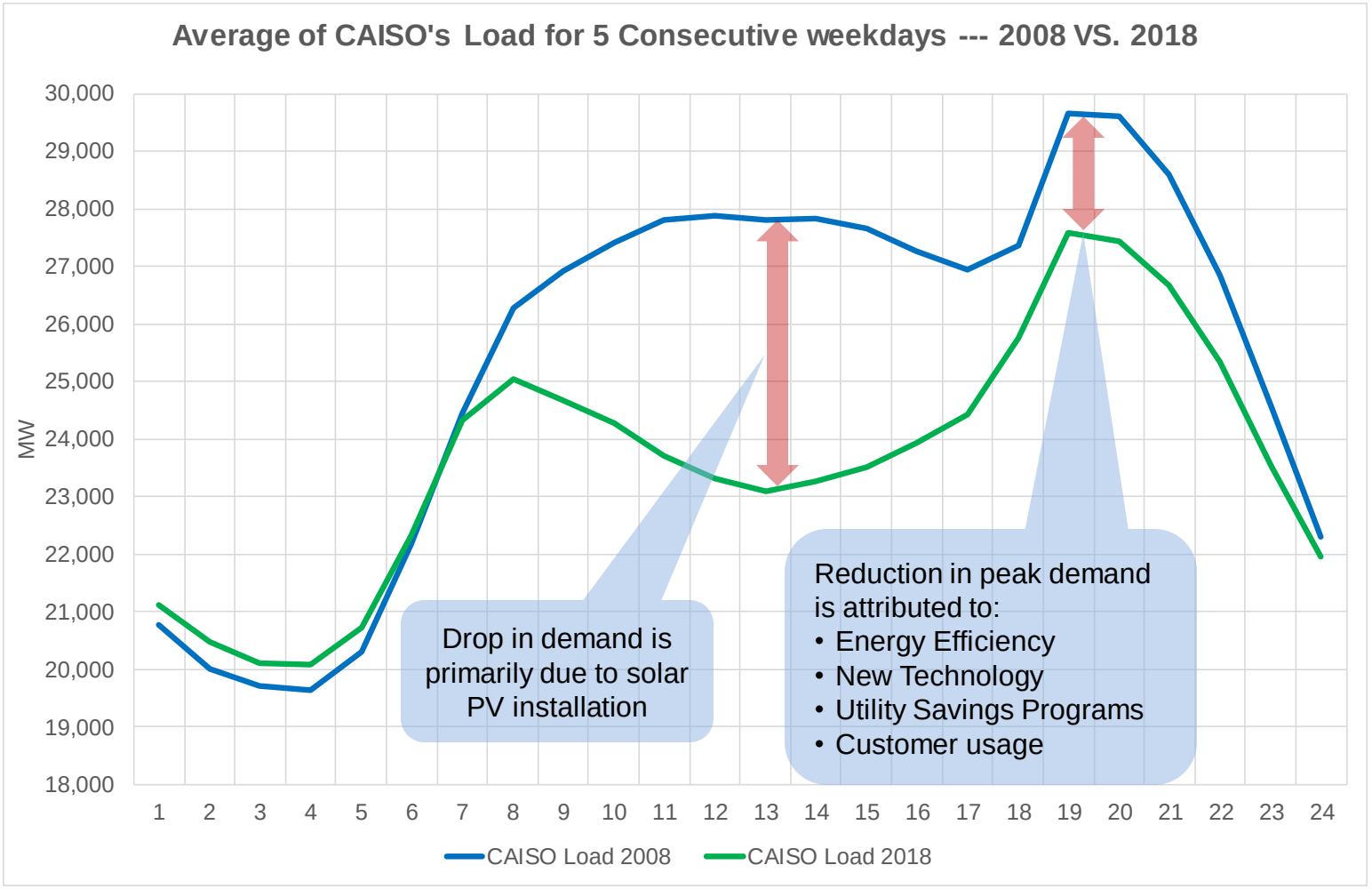


California ISO footprint is about 80% of California

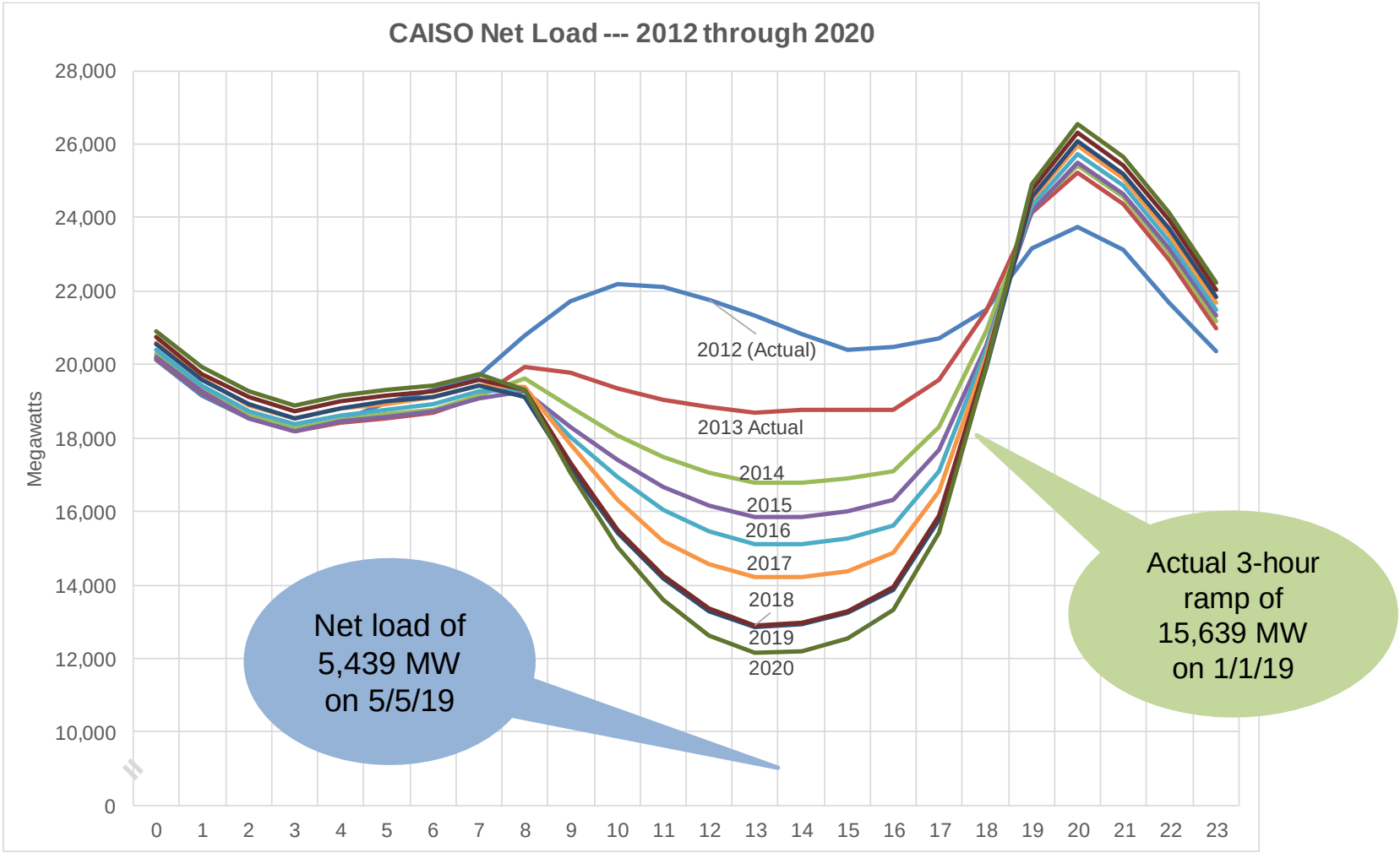


- **72,461** MW of power plant capacity (net dependable capacity)
- **50,270** MW record peak demand (July 24, 2006)
- **31,208** market transactions daily
- **~26,000** circuit-miles of transmission lines
- **30 million** people served
- **239 million** MWh annually

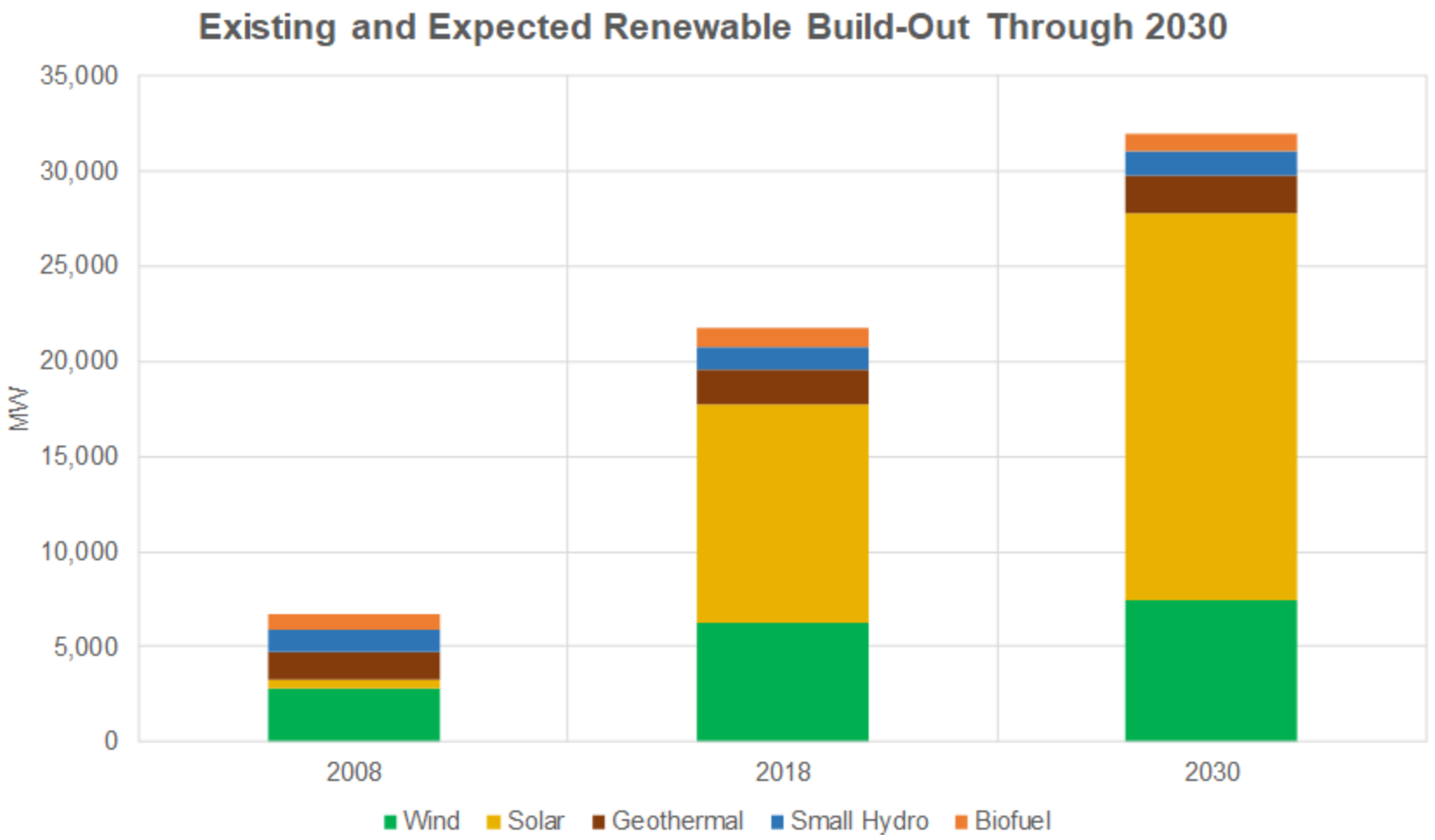
Average demand curve: March 2008 vs. March 2018



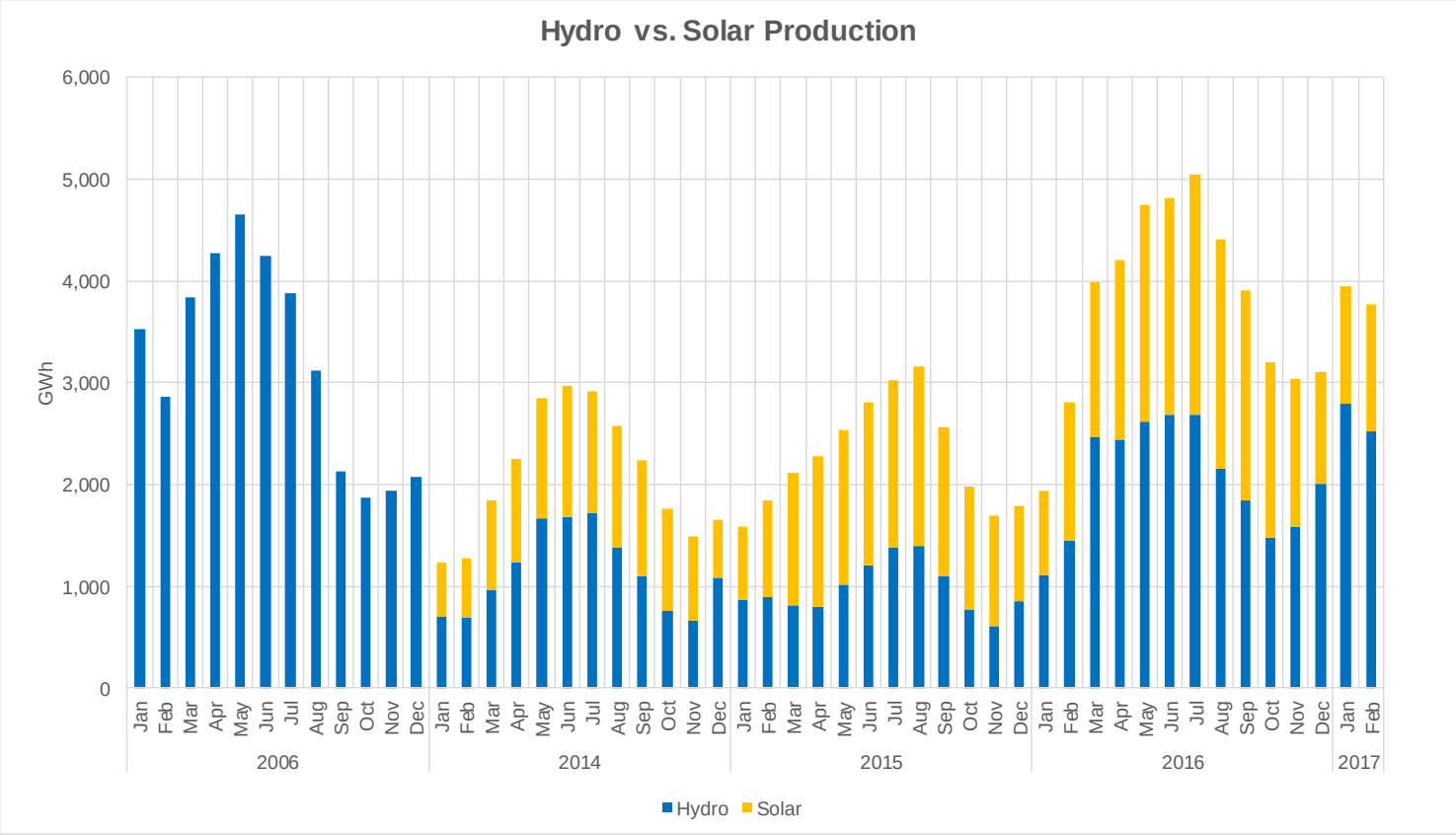
The duck turns 10 years old: Actual results are approximately four years ahead of the original estimate



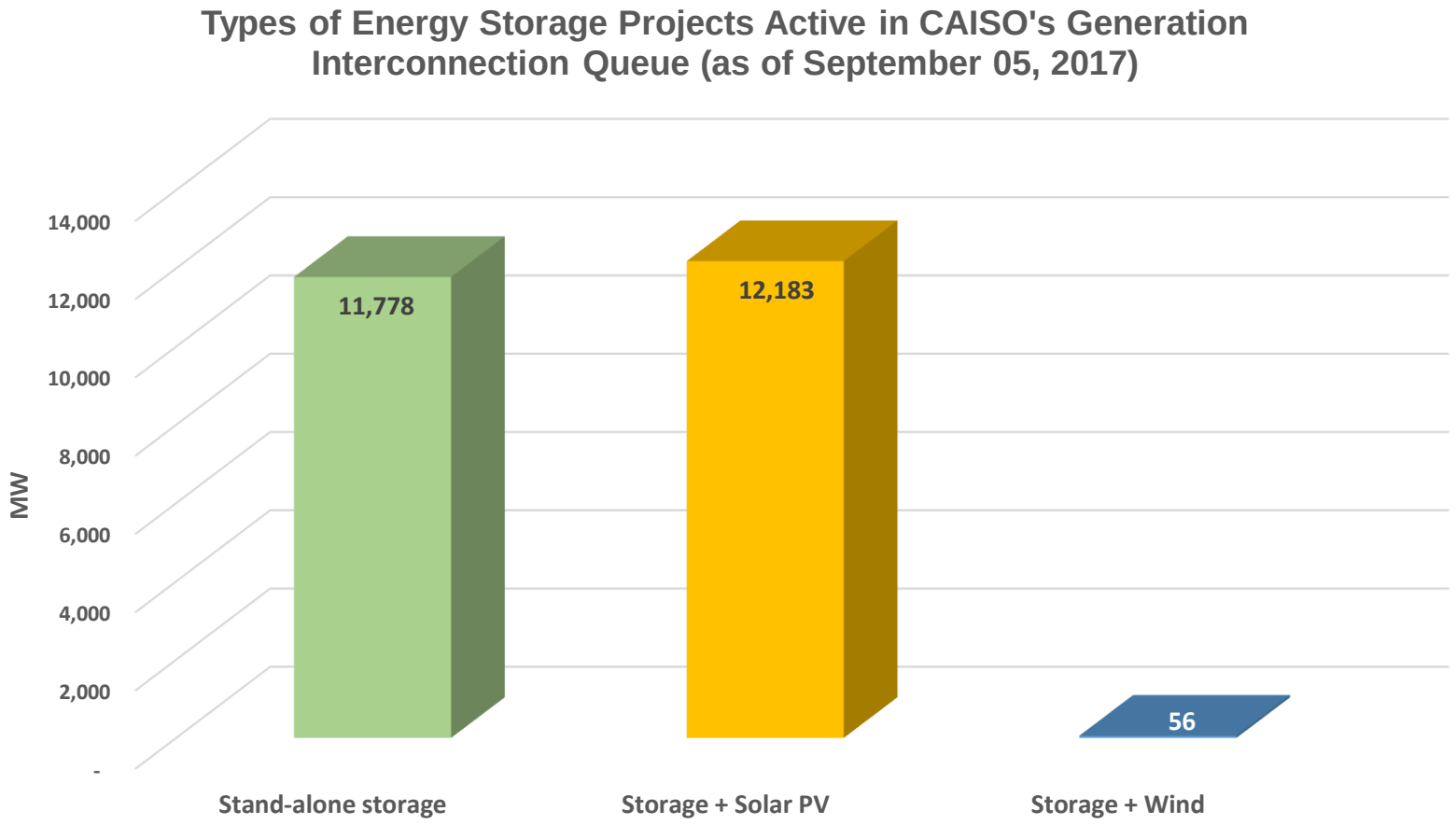
Growth of renewables to achieve 60% by 2030 is expected to be largely solar



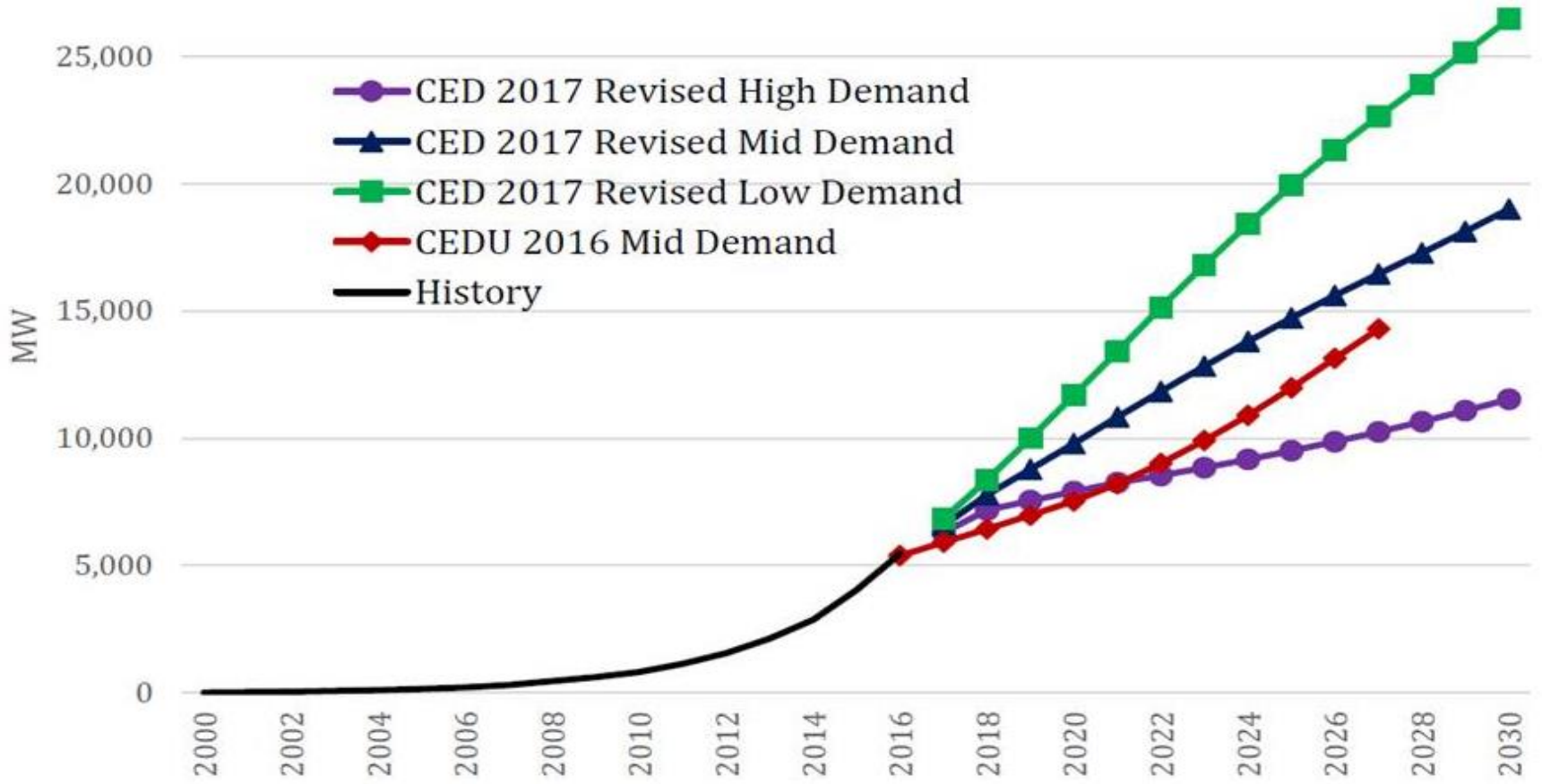
Solar production complemented the hydro production during the drought years as compared to 2006, which was a high hydro year



Hybrid energy storage projects in the interconnection queue are dominated by solar + battery configuration



Behind the meter solar is expected to grow by approximately 15,000 MW by 2030

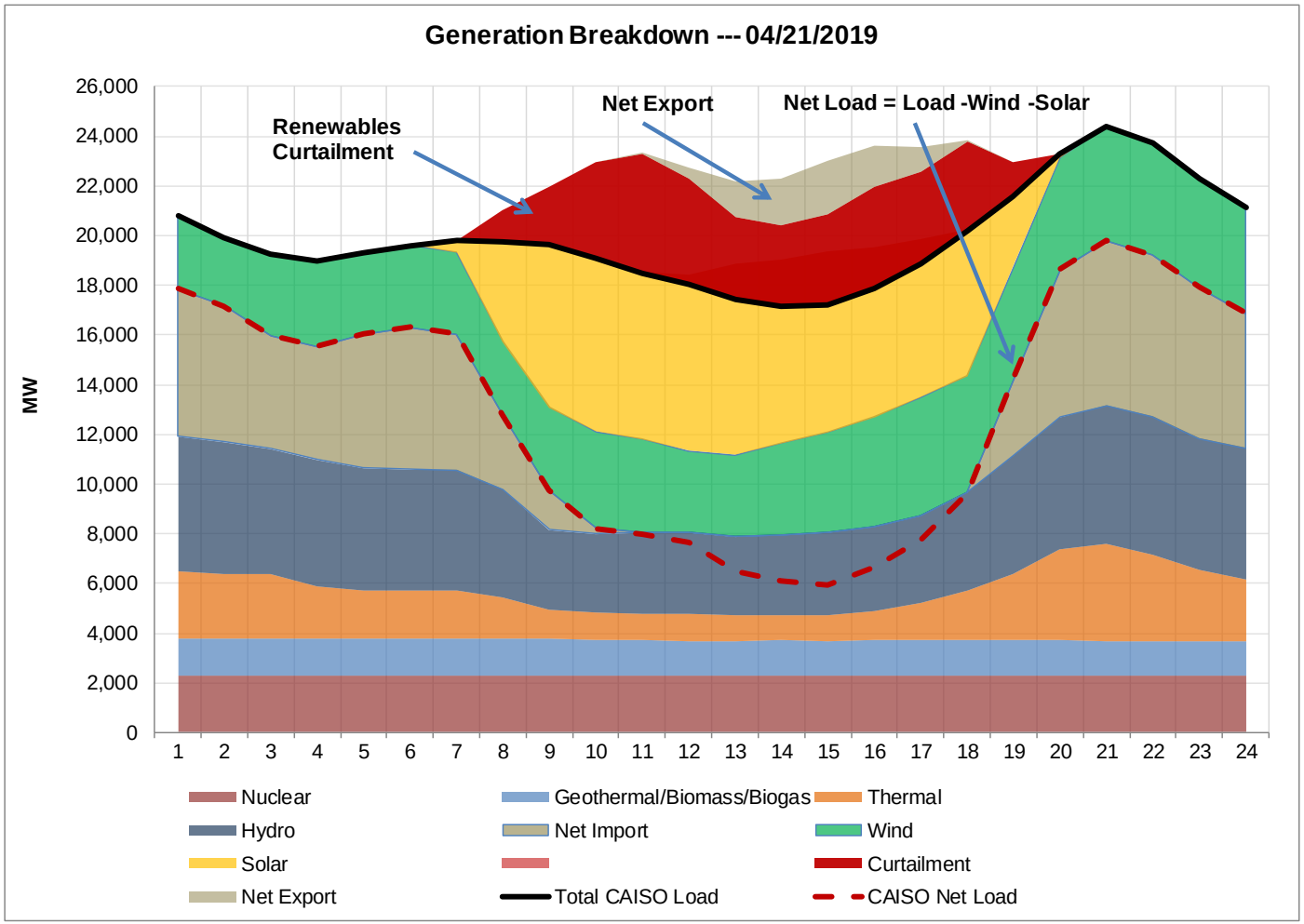


IOUs' NEM Solar Capacity by Territory and Location (As of March 31, 2018) All DER Technologies are in Play

	2013	2016/17	Percent Change
Energy Efficiency (GWh)	1,693	3,197	89%
Demand Response (MW)	2,187	1,997	-9%
Behind-the-Meter PV (MW)	2,102	5,900	180%
Plug-in Electric Vehicle (PEV) (number of registrations)	69,999	266,866	281%
Distributed Advanced Energy Storage (MW)	54	350	548%
Microgrids (MW)	122	390	220%

California Distributed Generation Statistics; accessed June 5, 2018. https://www.californiadgstats.ca.gov/charts/nem

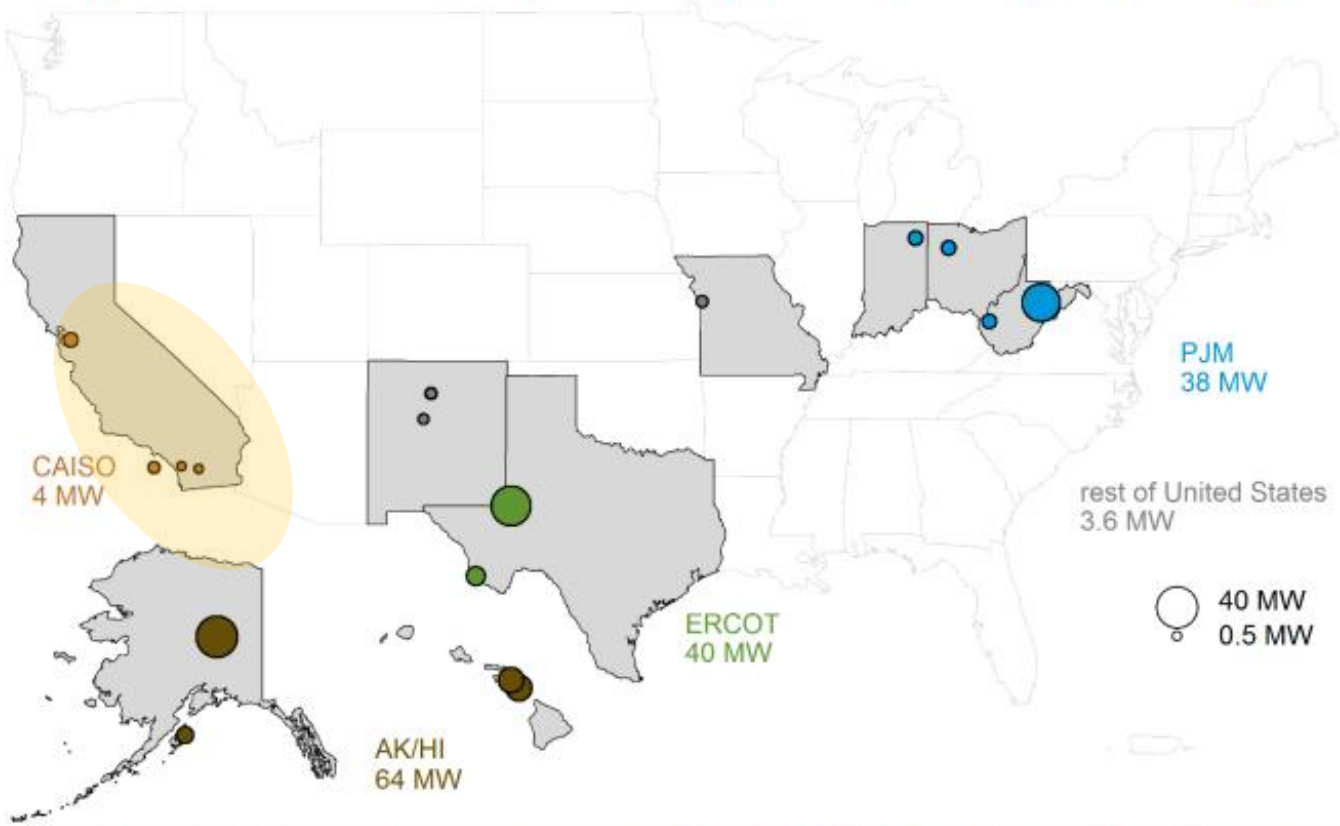
On Sunday April 21, 2019 the CAISO experienced a minimum net of 5,667 MW @ 14:37



- Maximum curtailment was 4,789 MW (31,989 MWh) of renewables
- Export as much as 2,000MW
- The CAISO continued to curtail solar during sunset to help reduce the 3-hour upward ramp
- Max simultaneous wind & solar was 11,598 MW at 14:36

CAISO has seen an explosive growth in large-scale battery storage capacity in the last five years

U.S. Large-Scale Battery Storage Capacity by Region, 2012



Sources: U.S. Energy Information Administration, Form EIA-860M, Preliminary Monthly Electric Generator Inventory; U.S. Energy Information Administration, Form EIA-860, Annual Electric Generator Report

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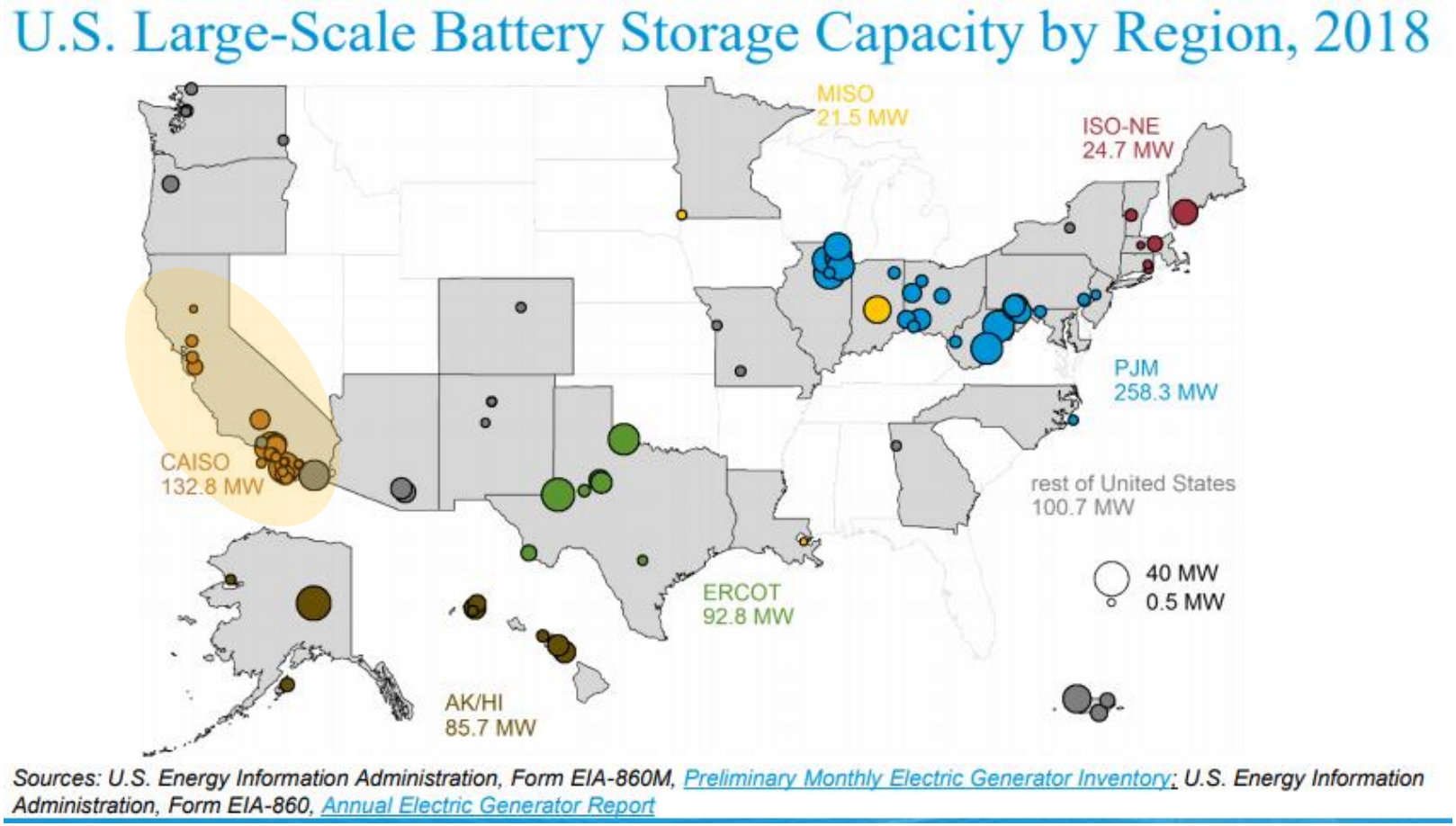
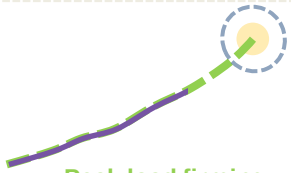
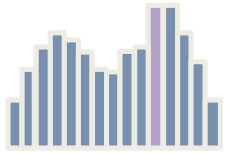
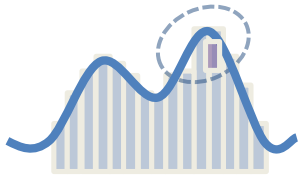


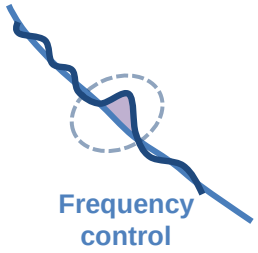
Batteries in wholesale markets deliver value in different timescales

Market	Resource Adequacy Capacity markets	Energy (Day-Ahead)	Energy (Real-Time)	Ancillary Services
Delivery Window	Years	Hours	Minutes	Seconds





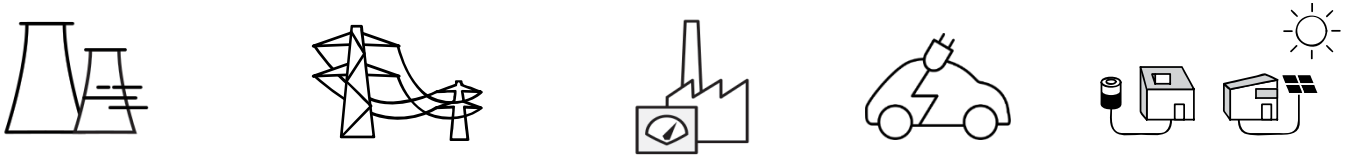




Passive market

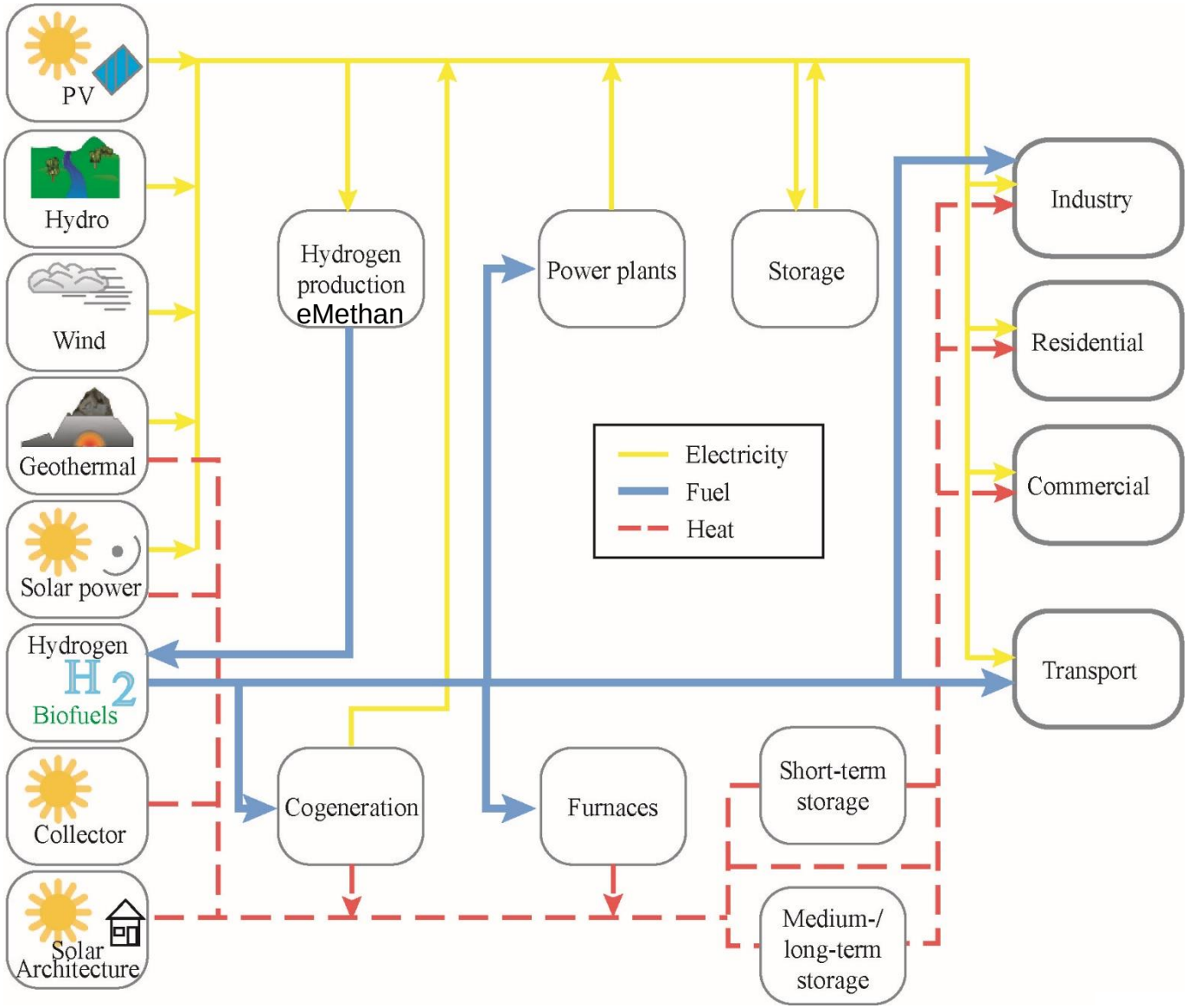
Active markets

Additional use-cases will add complexity and value

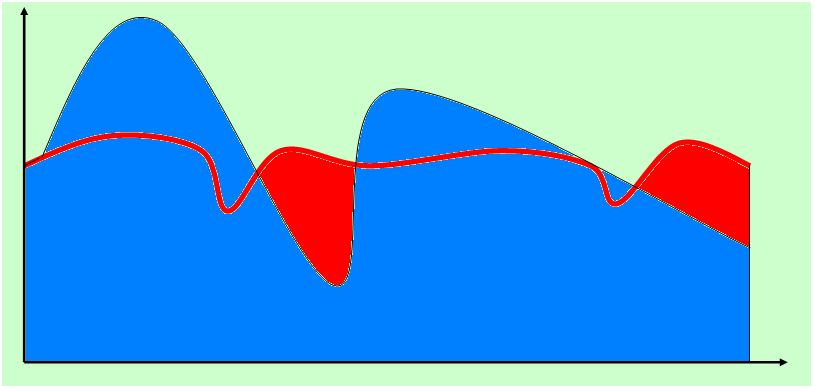


Source: Bloomberg NEF (CAISO Symposium-2018)

A Energy System based 100% on renewable sources

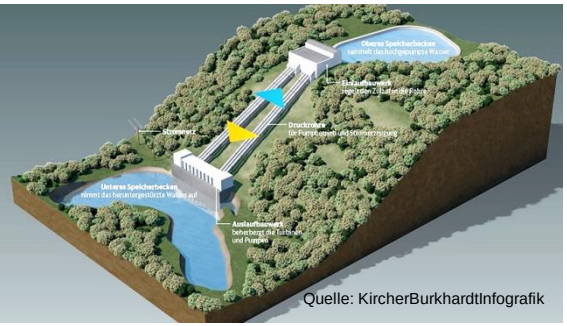


Source: Harry Lehmann, 1996



Storage needed

Gravitational Storage



Chemical Storage

H2 or eMethan (SolarMethan)

Electric Storage

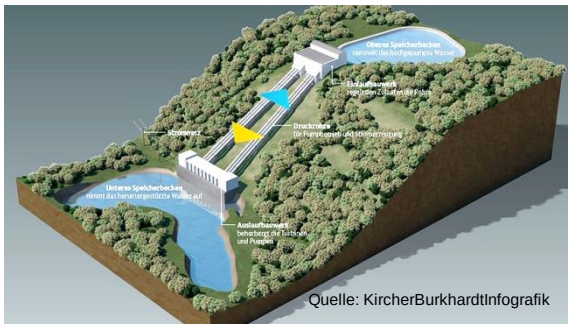
Source H.Lehmann

Power to storage / power to power

- In a renewable system storage is necessary to ensure a stable supply of electricity

- We need different storage solutions
  - **For short term to compensate daily/several days-fluctuation**
    - ✓ Load management (Power to X - all sectors)
    - ✓ Battery storage
    - ✓ Pump storage
  - **And long term to compensate weeks/months/years-fluctuation**
    - ✓Chemical storage:
      - renewable hydrogen storage (η=42%)
      - renewable methane storage (η=35%)

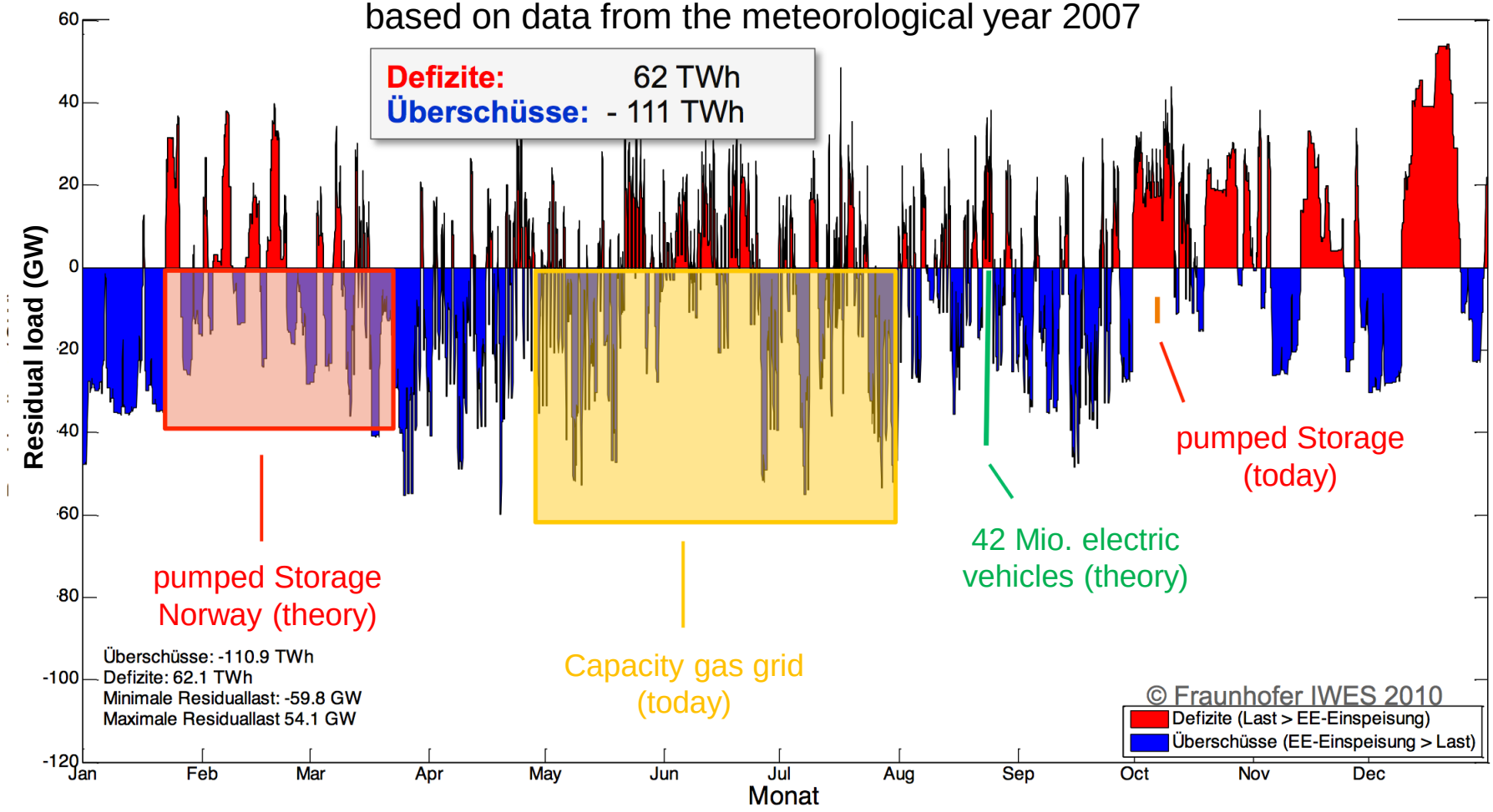

Quelle: Younicos.com


Quelle: KircherBurkhardtInfografik


Quelle:powertogas.info

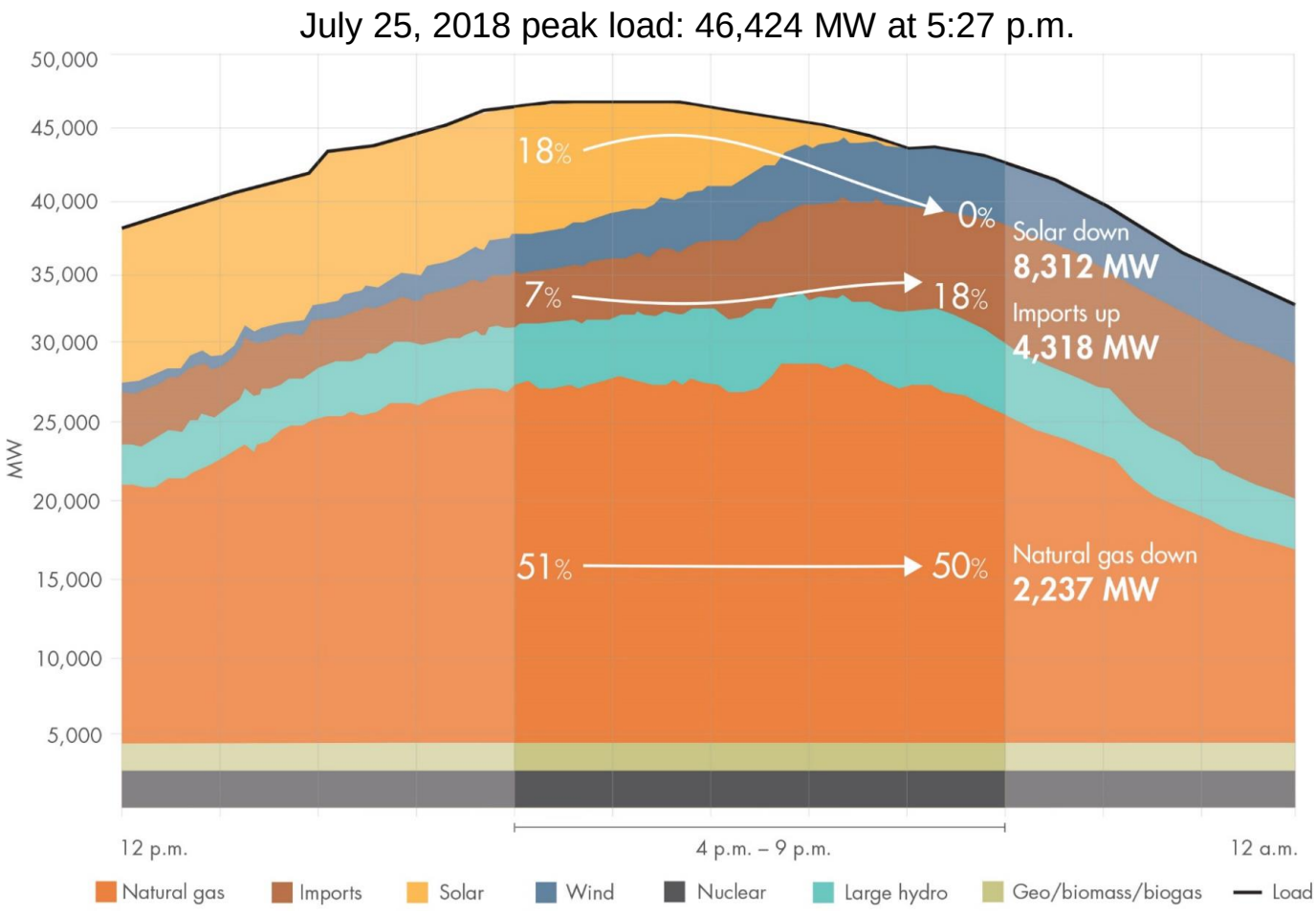
100% RE Germany Study of UBA Different Storage Systems – EU and Germany

Total residual load (with load management and pump storage) in the year 2050, based on data from the meteorological year 2007



Imports and gas-fired generation are being relied upon to meet ramping and late afternoon peaks

- Increasing behind the meter solar is also pushing the “system peak” to later in the day, further muting the capacity benefit of grid-connected solar.
- Example: gas was available, but wind made an appearance and met part of the need during declining solar output.

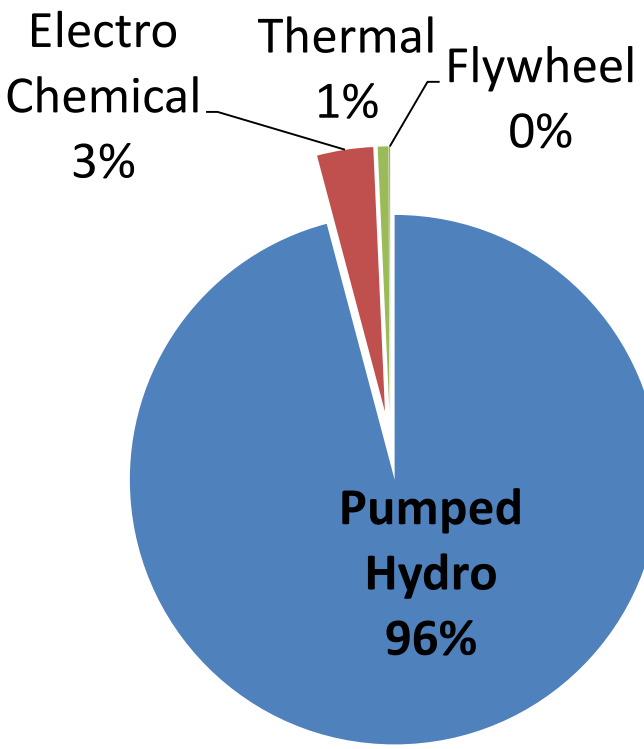


California has a variety of advanced energy storage technologies operating today

1) Thermal Energy Storage with Ice
2) Vehicle-to-grid demonstration
3) Molten Sulfur Energy Storage Used for Back-up Power
4) Revolutionizing Grid-connected Energy storage
5) Integrated Solar Photovoltaic Energy storage
6) New Life for Electric Vehicle Batteries
7) Rechargeable Electrolytes
8) Capturing Wind
9) Lithium-Ion Battery Supports Renewable Energy Integration
10) Hybrid Technology
11) Hydrogen – Electrolytic (Future under SB 1369)

Existing Storage in California

Pumped Hydro: 4087 MW
Electro-chemical: 146 MW
Thermal: 28 MW
Flywheel: 2 MW



The fleet of the future must provide essential grid services traditionally provided by a conventional fleet

	Test	Performance
Ramping	• Ramp its real-power output at a specified ramp-rate • Provide regulation up/down service	
Voltage	• Provide reactive power support in various modes - Control a specified voltage schedule - Operate at a constant power factor - Produce a constant level of MVAR - Provide controllable reactive support (droop setting) - Capability to provide reactive support at night	
Frequency	• Provide frequency response for low frequency and high frequency events - Control the speed of frequency response - Provide fast frequency response to arrest frequency decline	

A suite of solutions are necessary

Storage – increase the effective participation by energy storage resources.

Western EIM expansion – expand the western Energy Imbalance Market.

Demand response – enable adjustments in consumer demand, both up and down, when warranted by grid conditions.

Regional coordination – offers more diversified set of clean energy resources through a cost effective and reliable regional market.

Time-of-use rates – implement time-of-use rates that match consumption with efficient use of clean energy supplies.

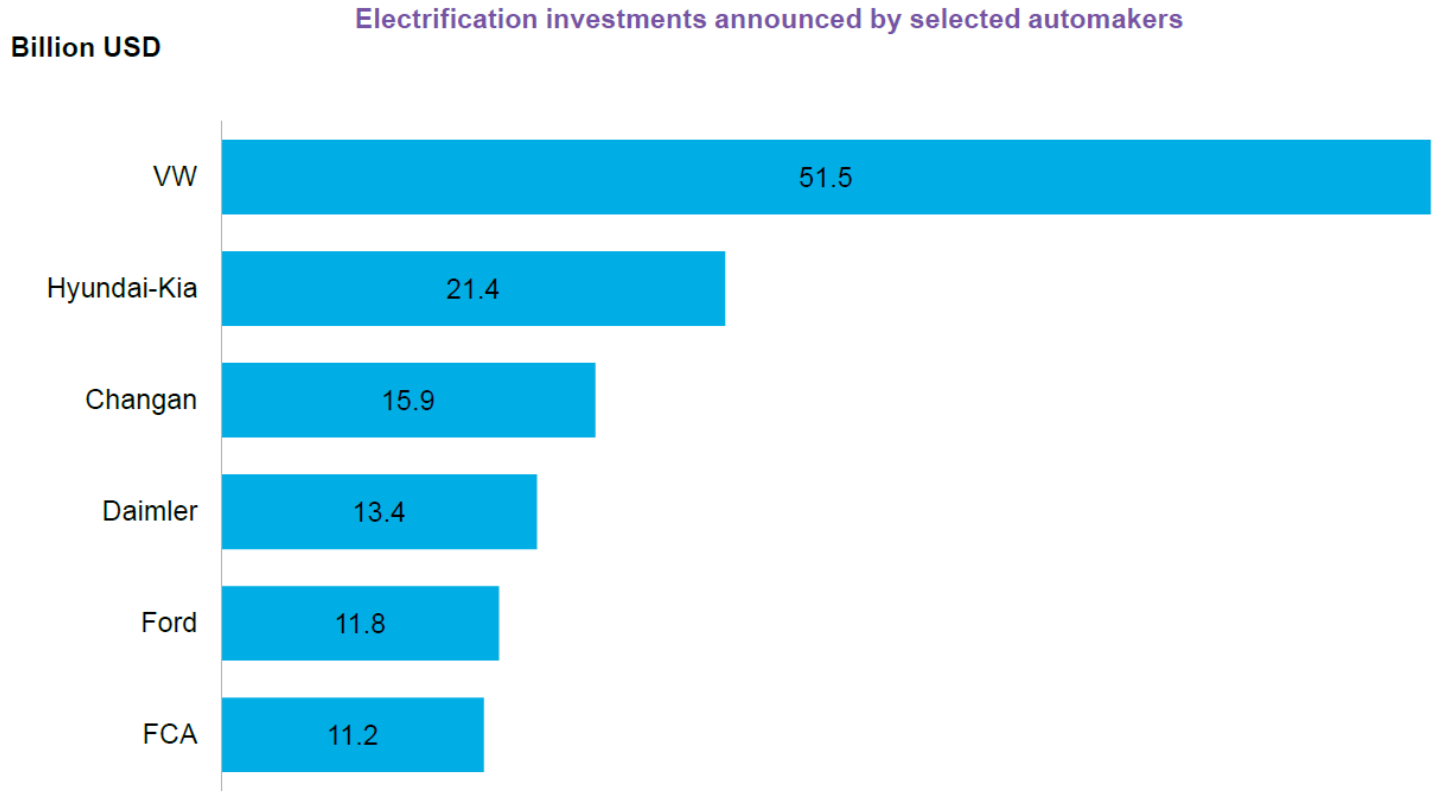
Electric vehicles – incorporate electric vehicle charging systems that are responsive to changing grid conditions.

Renewable portfolio diversity – explore procurement strategies to achieve a more diverse renewable portfolio.

Flexible resources – invest in fast-responding resources that can follow sudden increases and decreases in demand.

Demand outlook

Global automakers are investing billions in electrification

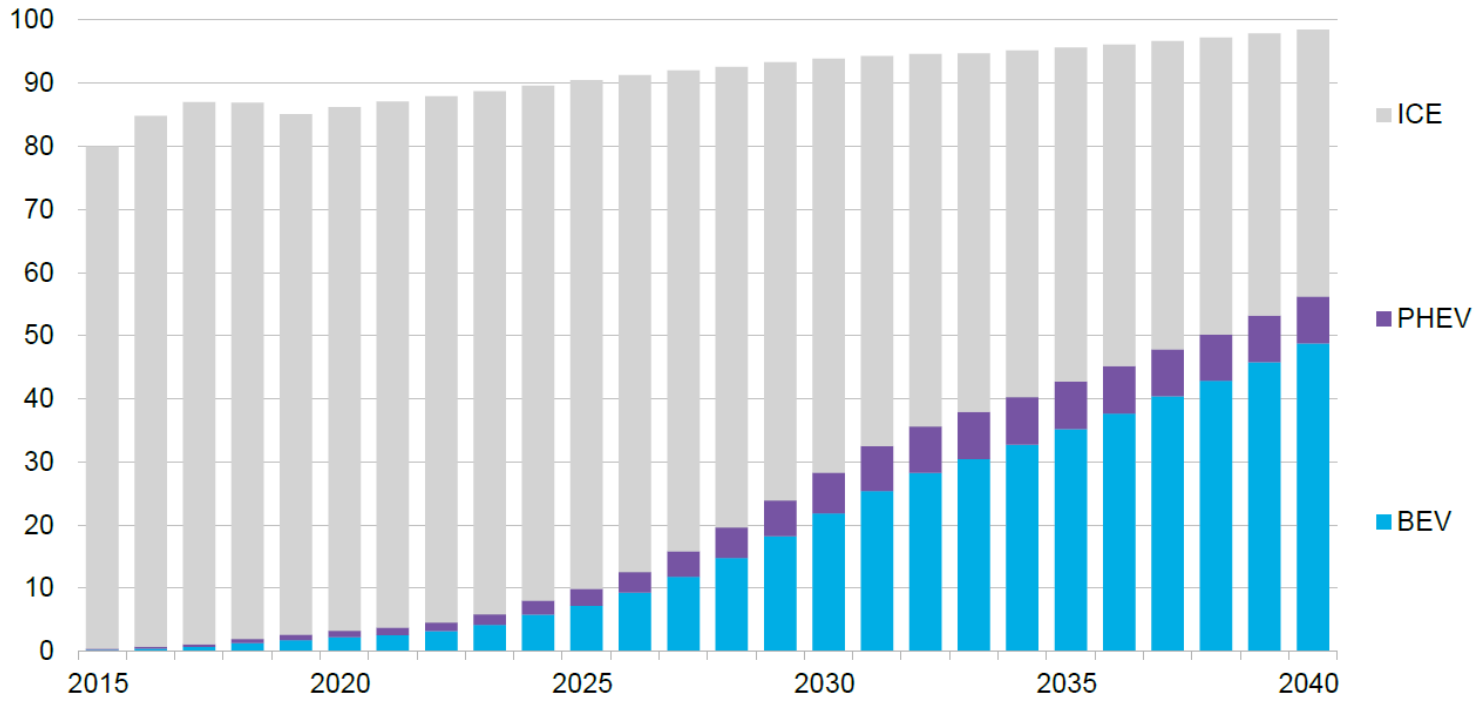


Source: BloombergNEF

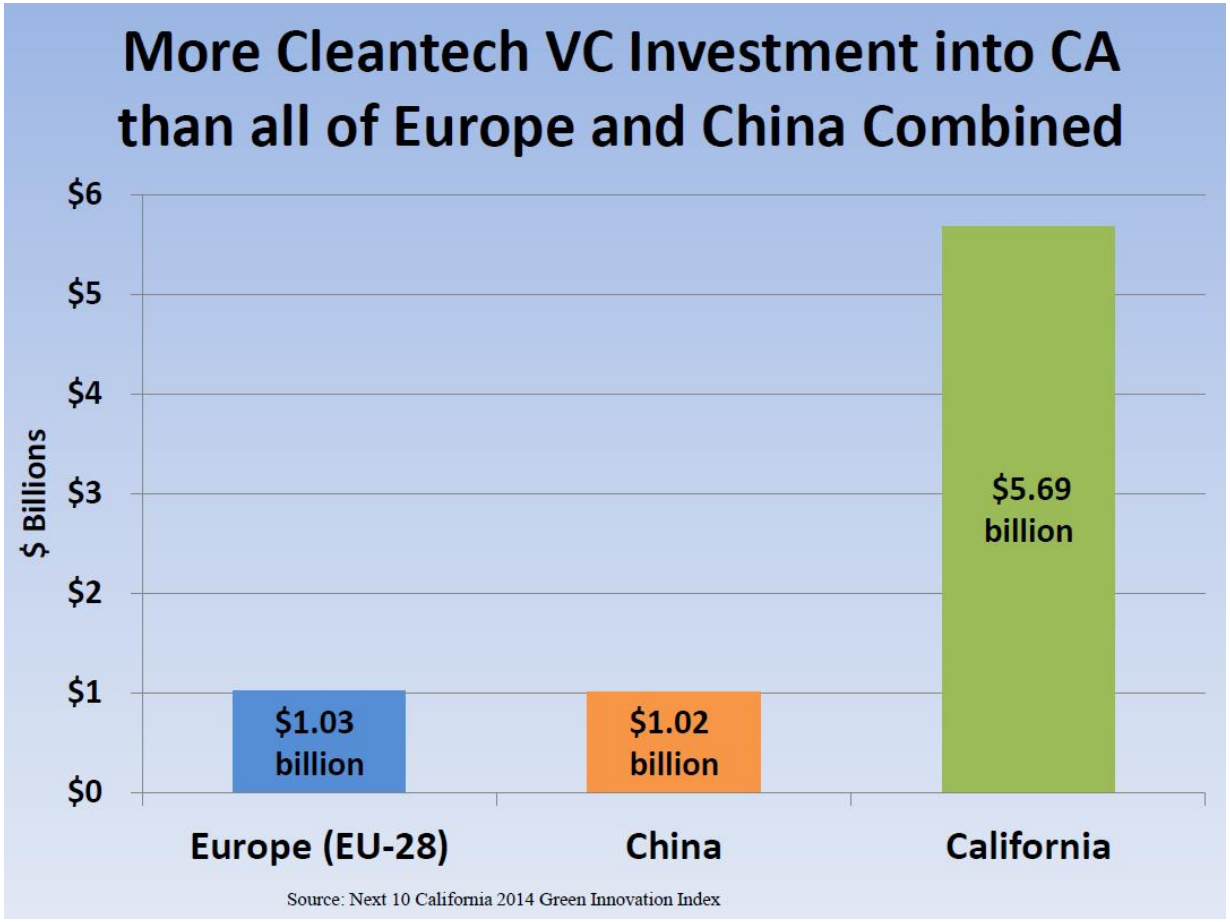
Demand outlook

Electric vehicles will make up the majority of new passenger vehicle sales by 2040

Global long-term passenger vehicle sales by drivetrain

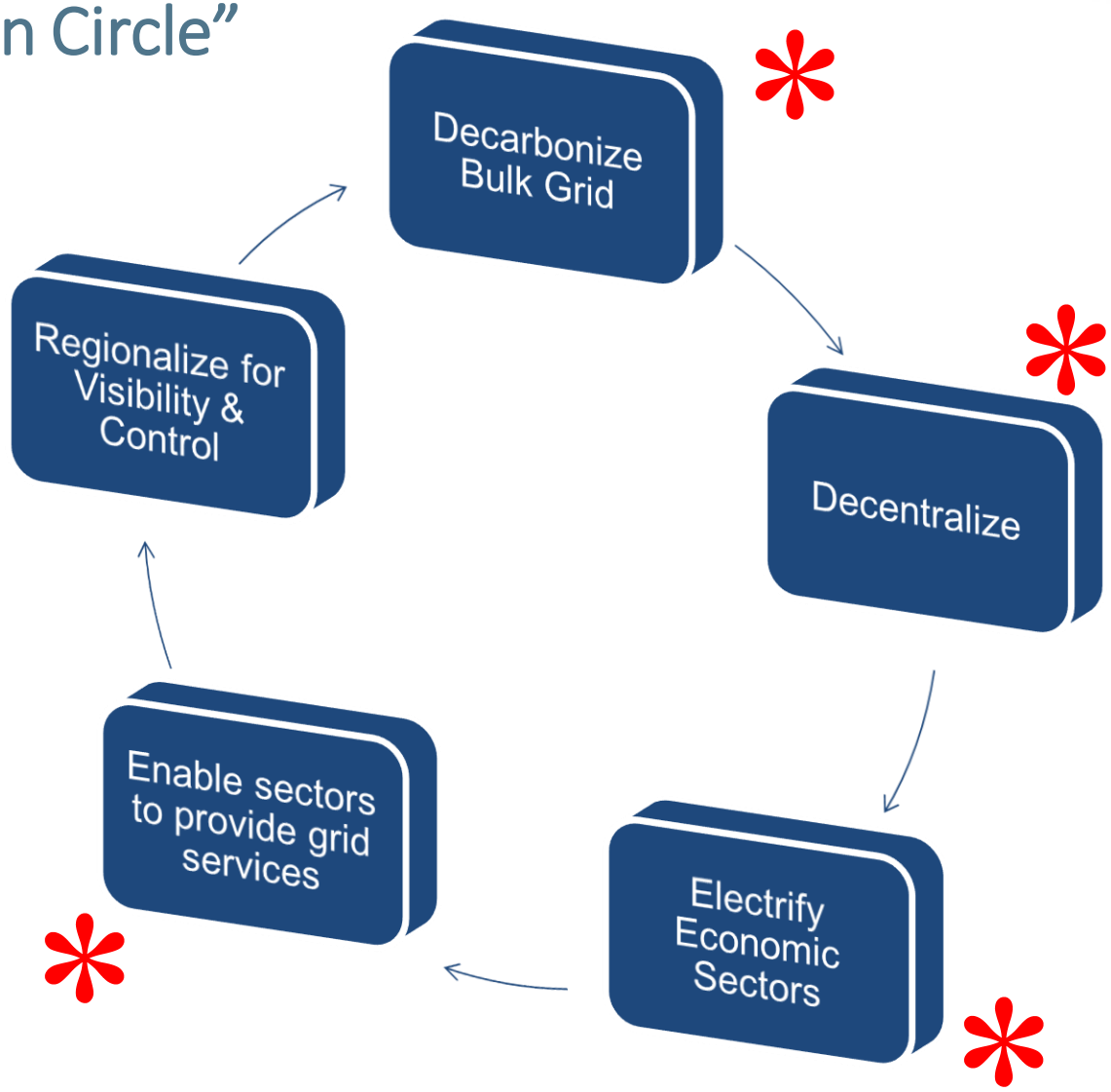


Source: BloombergNEF


More Cleantech VC Investment into CA than all of Europe and China Combined
$ Billions
$6
$5
$4
$3
$2
$1
$0
$1.03 billion
$1.02 billion
$5.69 billion
Europe (EU-28)
China
California
Source: Next 10 California 2014 Green Innovation Index

The new "Low Carbon Circle"

The future is:
Digitized,
Decentralized,
Decarbonized,
Diversified and
Democratized



= Opportunity for Storage