Challenges Associated with Deep Decarbonization and Evolving Grid Systems

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NEPOOL Virtual Conference
June 24, 2020

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Top 10 States Unemployment Claims (3/16-05/02), Top 10 States for Employment in Key Energy Job Categories (2019)

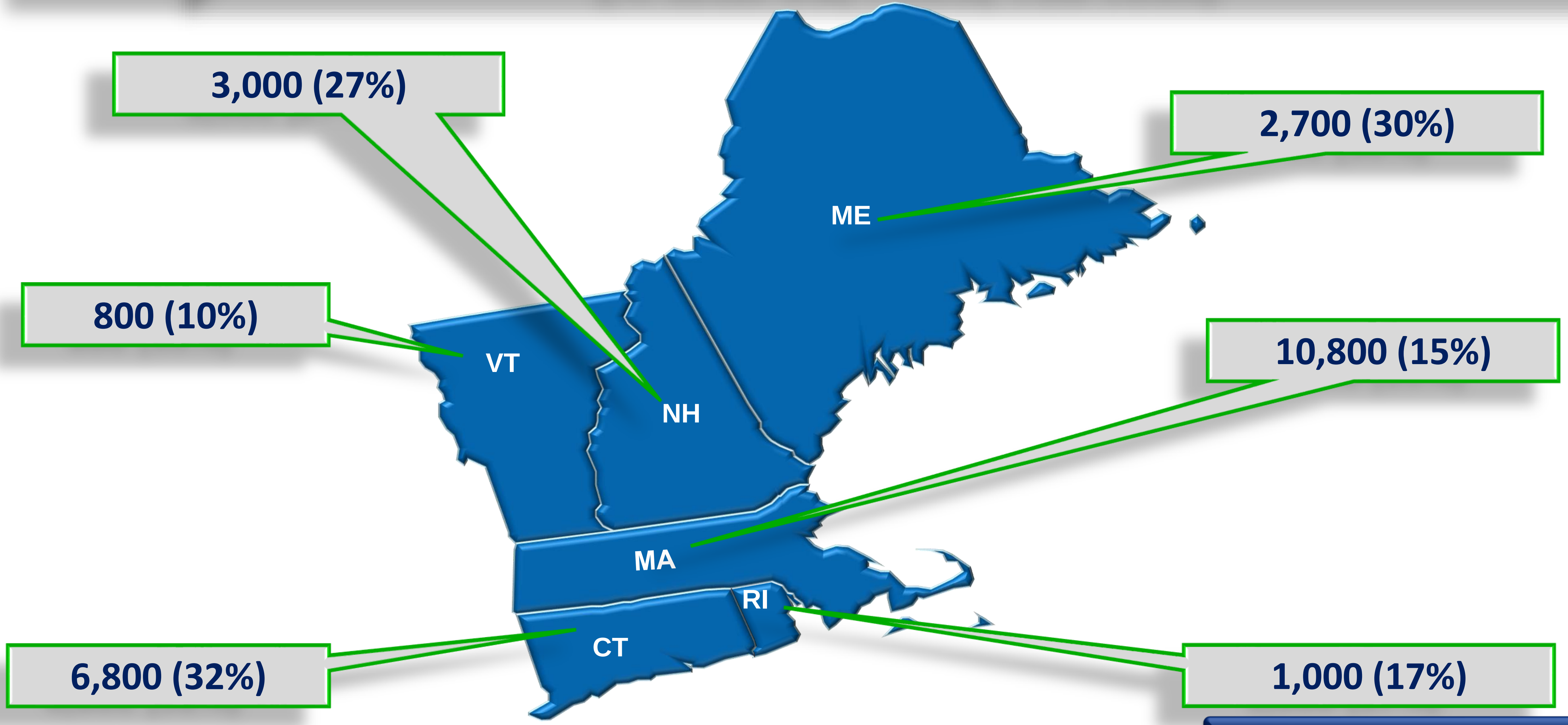
Ranking of Top 10 States, Highest to Lowest	Total Unemploy-ment Claims (03/16-05/02)	Claims as % of Workforce	Natural Gas and Oil Fuels Jobs Actual	Natural Gas and Oil Fuels Jobs as % of Workforce	Efficiency Jobs Actual	Efficiency Jobs as % of Workforce	Gas/Oil Generation Actual	Gas/Oil Generation as % of Workforce	Solar Generation Jobs Actual	Solar Generation Jobs as % of Workforce	Wind Generation Jobs Actual	Wind Generation Jobs as % of Workforce
1	CA	KY	**TX**	WY	**CA**	VT	**CA**	KS	**CA**	NV	**TX**	ND
2	NY	GA	**LA**	ND	**TX**	WY	**FL**	**HI**	**MA**	**HI**	IL	SD
3	TX	HI	OK	AK	**NY**	DE	**TX**	**NH**	**NY**	**CA**	CO	CO
4	FL	RI	**CA**	OK	**FL**	**RI**	KS	UT	**FL**	VT	IN	IA
5	GA	NV	**PA**	**LA**	IL	**MA**	**NY**	**FL**	**TX**	UT	**CA**	IN
6	MI	MI	CO	NM	**MA**	MD	**MA**	AK	**NV**	**MA**	**FL**	ME
7	PA	WA	NM	**TX**	NC	WI	IL	**MA**	AZ	NM	**MI**	**TX**
8	OH	NH	IL	WV	**MI**	OR	AZ	SC	NJ	OR	IA	**NH**
9	NJ	LA	ND	CO	**OH**	UT	**MI**	AZ	NC	AZ	**NY**	KS
10	WA	MA	**OH**	KS	VA	CT	**OH**	MS	**OH**	CO	**WA**	IL
Total US*	30,300,990		906,998		2,378,893		128,031		345,393		114,774	

Bold denotes top 10 states that are in top 10 for actual unemployment claims or claims as percent of workforce and are also in top 10 jobs for specific energy sector, both actual and as % of workforce

* Includes DC, Puerto Rico

Source: BLS, USEER data, 2020

Total Jobs in Oil, Gas, Coal, Pipelines (% total EG, Fuels, TSD Jobs)



Source: USEER data, 2020

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Emissions Sources by Economic Sector, US & New England

	Transportation	Electricity	Industry	Agriculture / Non-energy	Commercial	Residential
CA (2017)	39%	16%	23%	8% (Agriculture)	4%	5%
US (2017)	29%	28%	22%	9% (Agriculture)	6%	5%
NE (2016)	45%	15%	6%	7% (Non-energy)	10%	17%

Source: EIA Website, accessed 02/18/20

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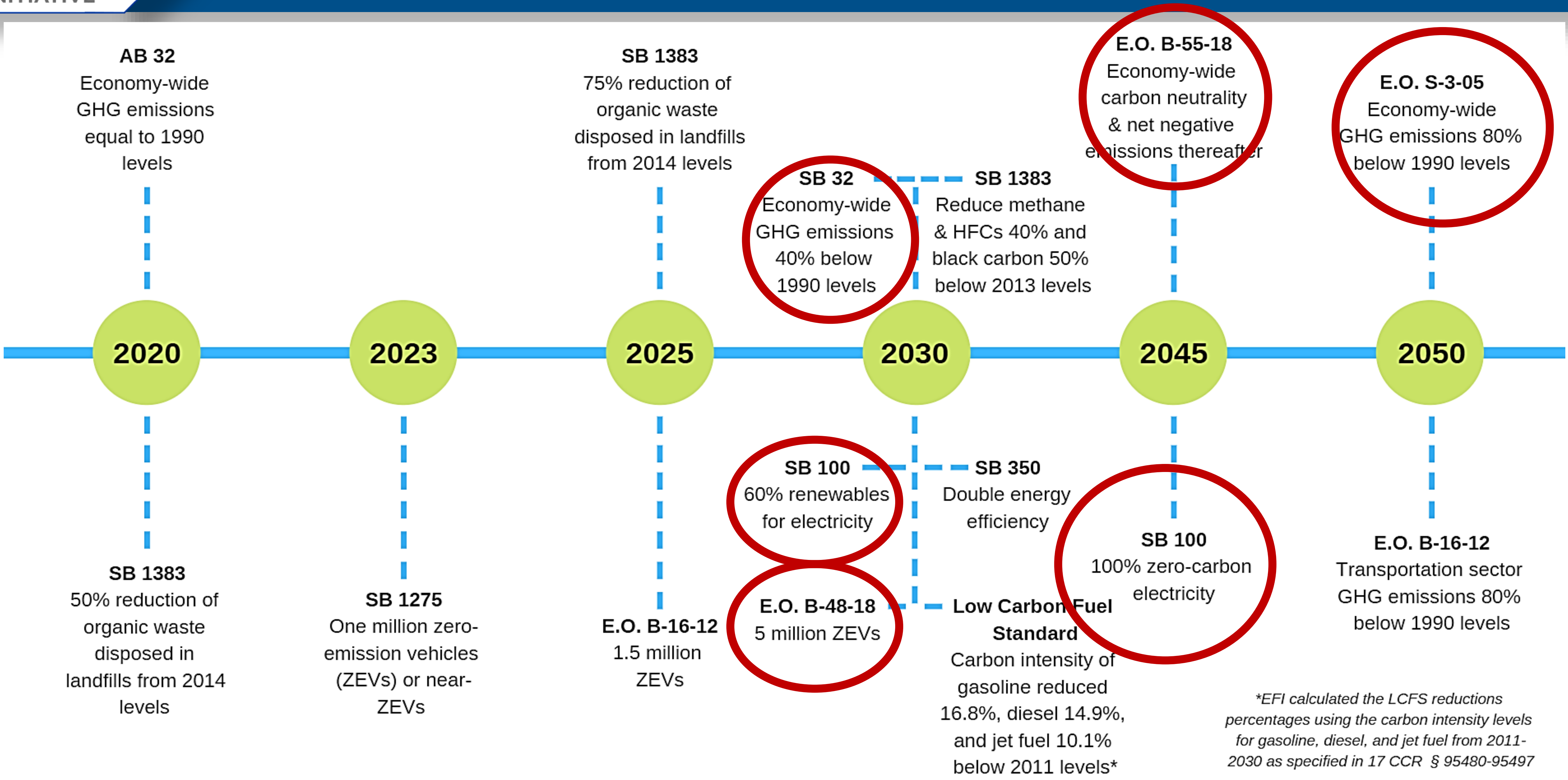
Timeline of Key California Policies for GHG Reductions

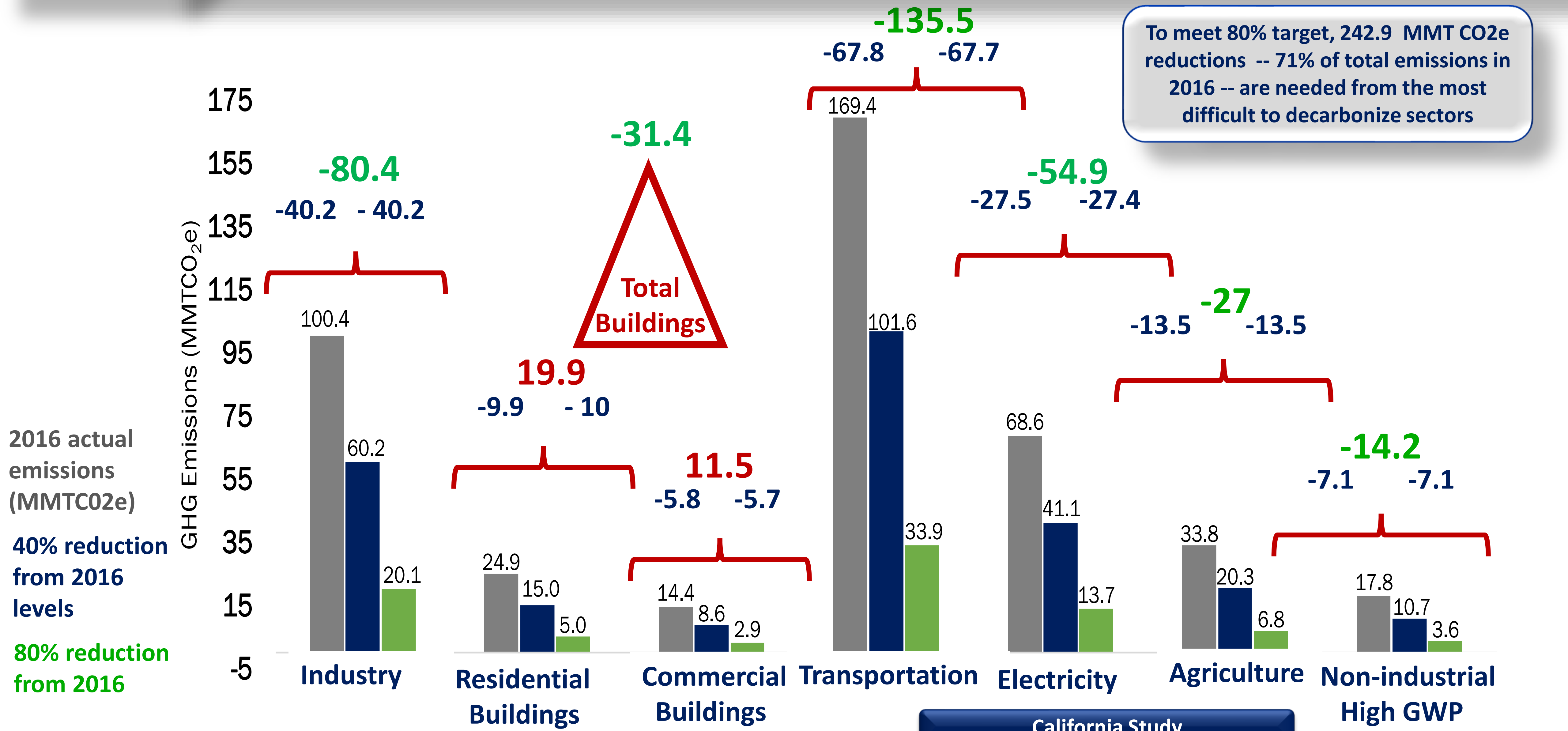


EFI calculated the LCFS reductions percentages using the carbon intensity levels for gasoline, diesel, and jet fuel from 2011-2030 as specified in 17 CCR § 95480-95497

California Study

Study Approach: 2030 & 2045 Emissions Reduction Targets by Sector from 2016 Baseline (MMTCO2e)

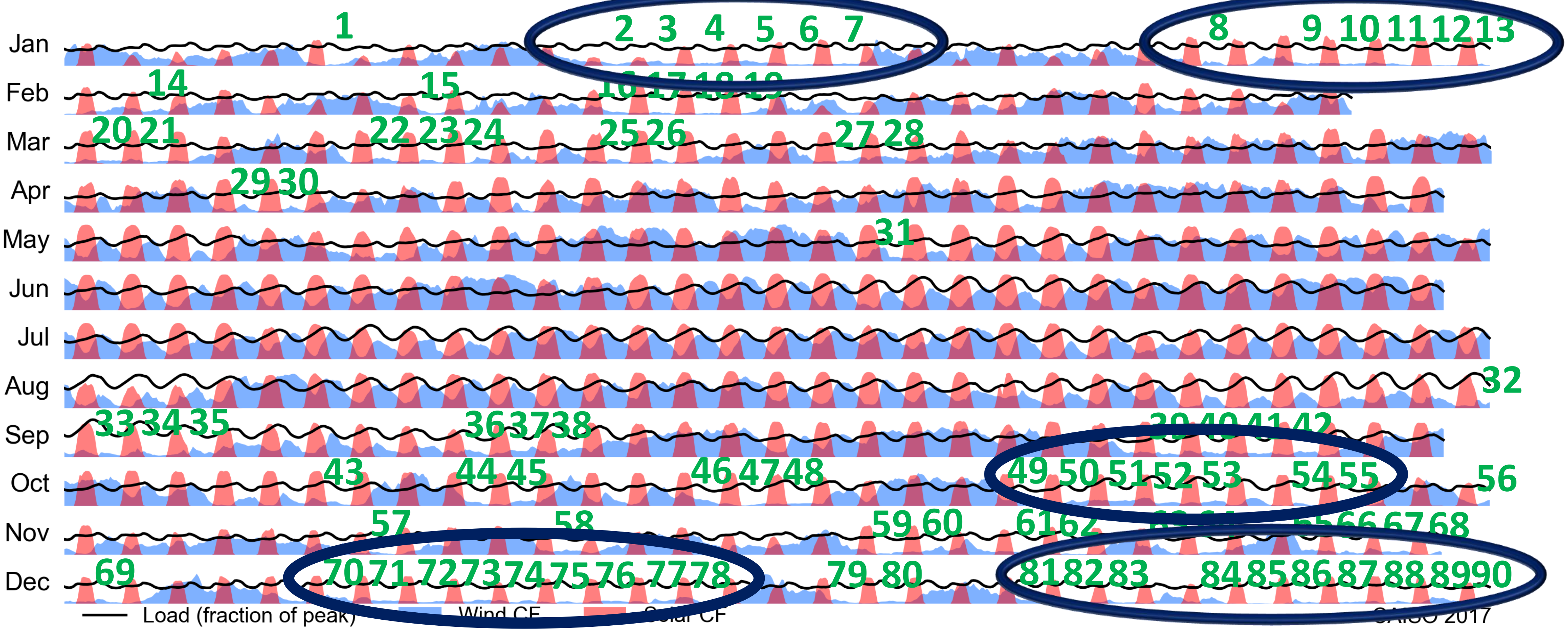
To meet 80% target, 242.9 MMT CO2e reductions -- 71% of total emissions in 2016 -- are needed from the most difficult to decarbonize sectors



California Study

Challenges with Integrating Intermittent Renewables in California

Over the course of a year large-scale dependence on both wind and solar will result in significant periods requiring very large-scale back-up options

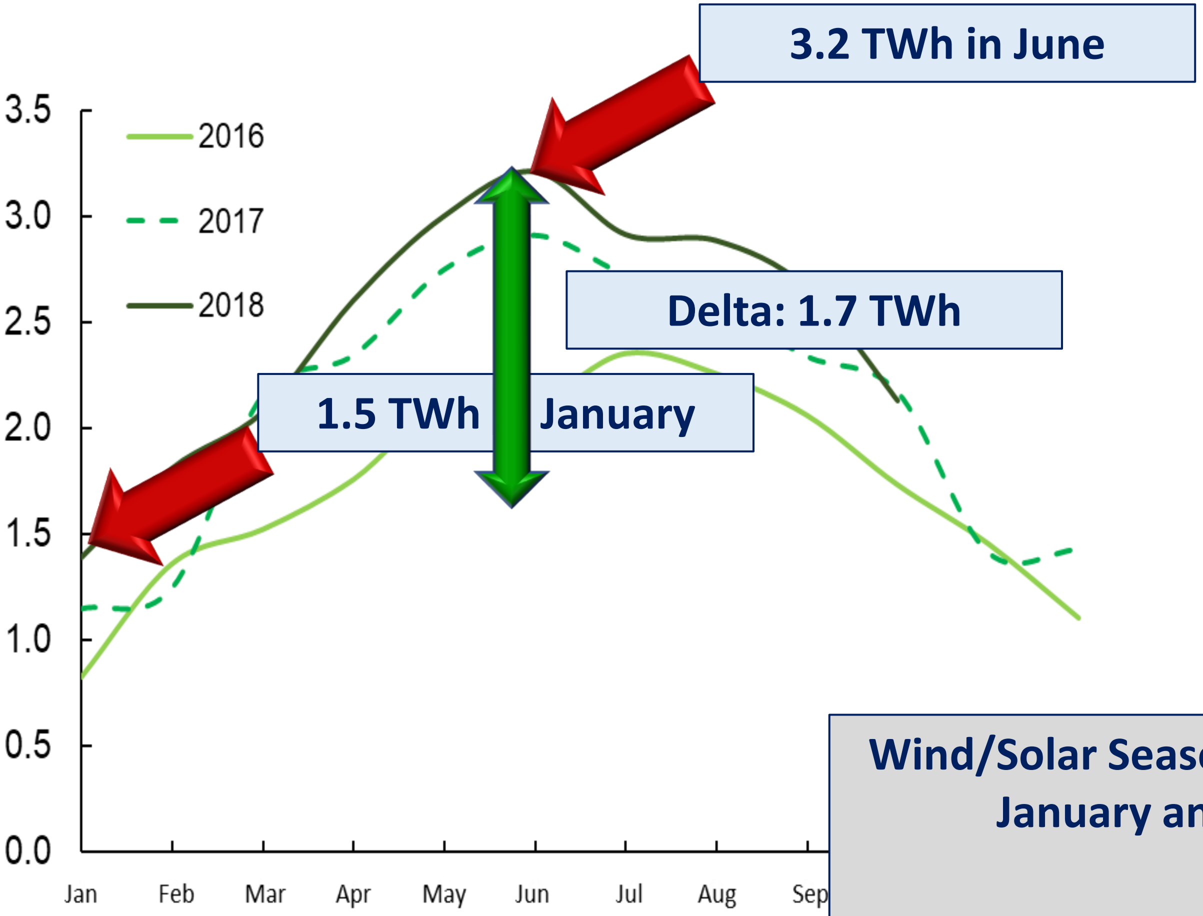


Hourly trends in solar and wind capacity factors in CA for 2017 aligned to normalized variation in hourly load relative to peak daily load

Source: CAISO data, EFI analysis

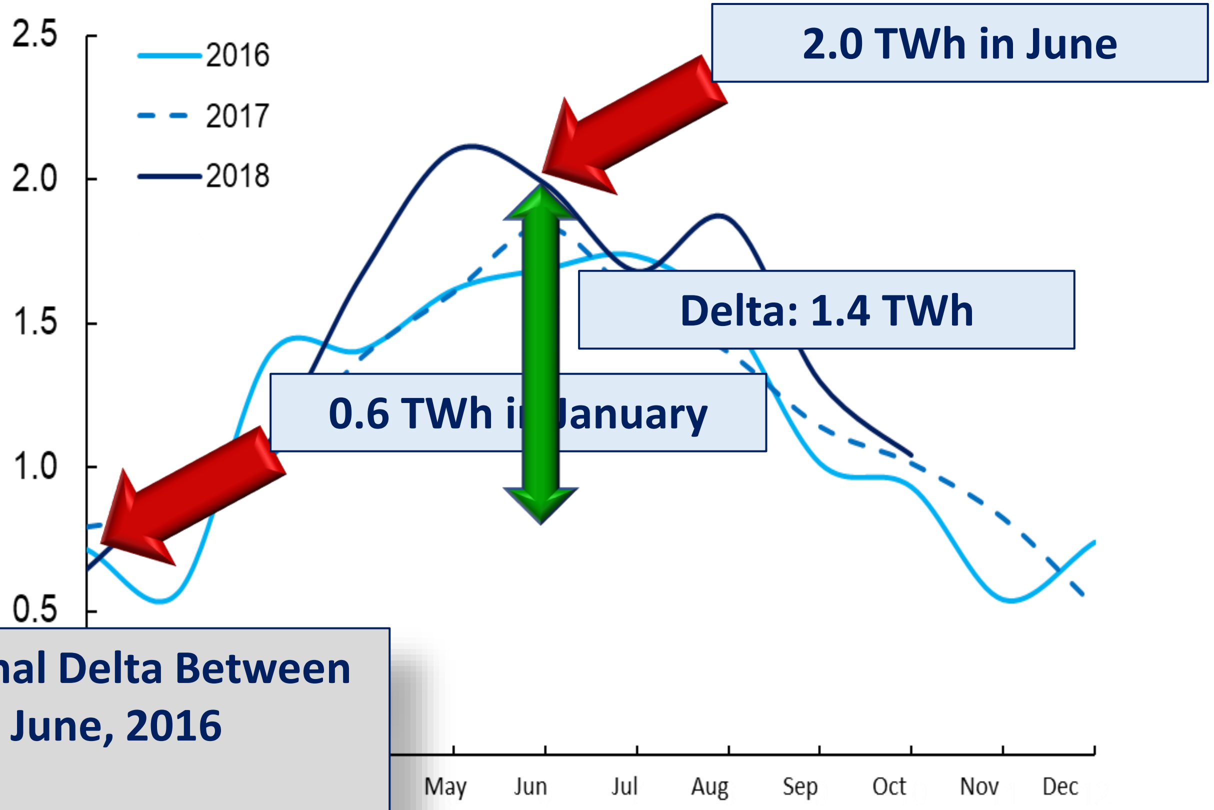
Seasonal Variation in Solar & Wind in CA, 2016

Metered Solar Generation



Source: EFI, compiled using data from CAISO

Wind Generation

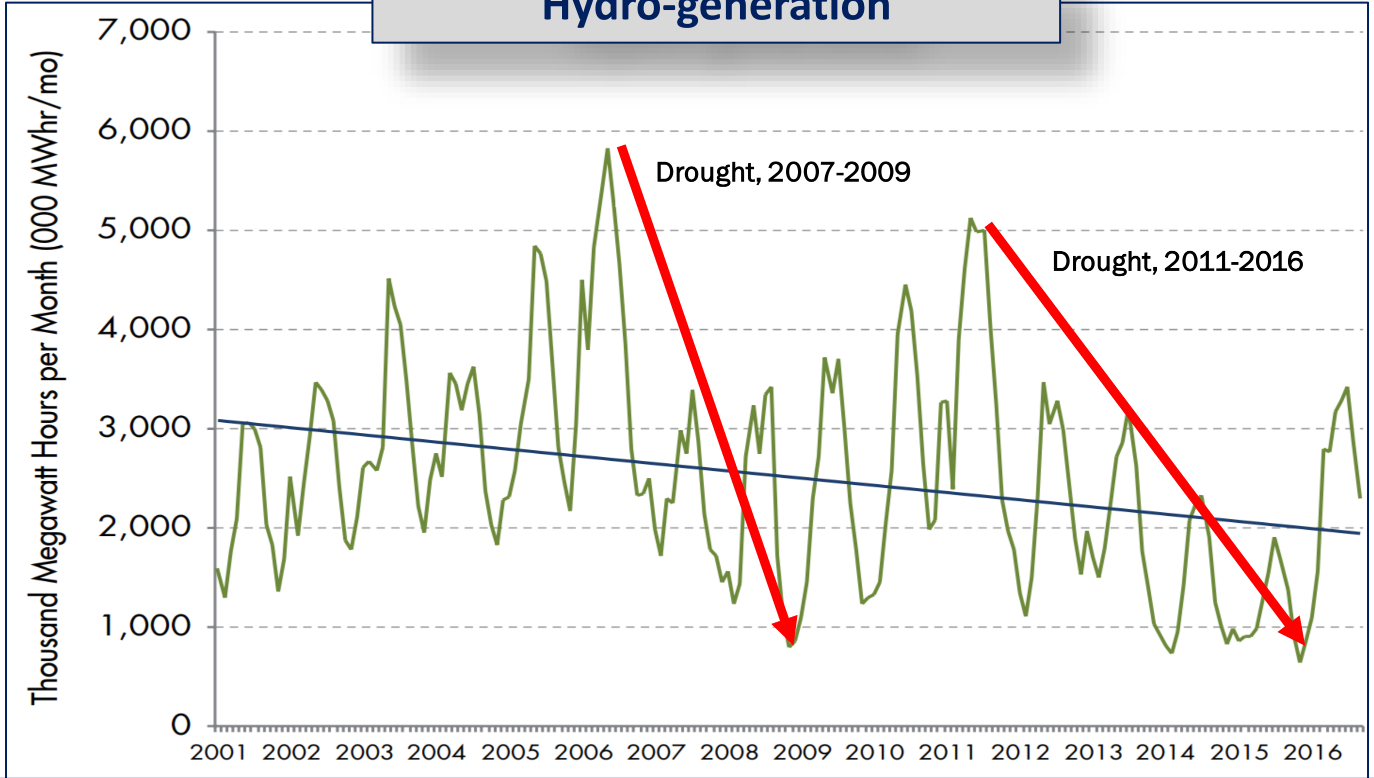


Wind/Solar Seasonal Delta Between January and June, 2016

3.1 TWh

Impacts of Drought (and Climate Change) on Hydro Generation

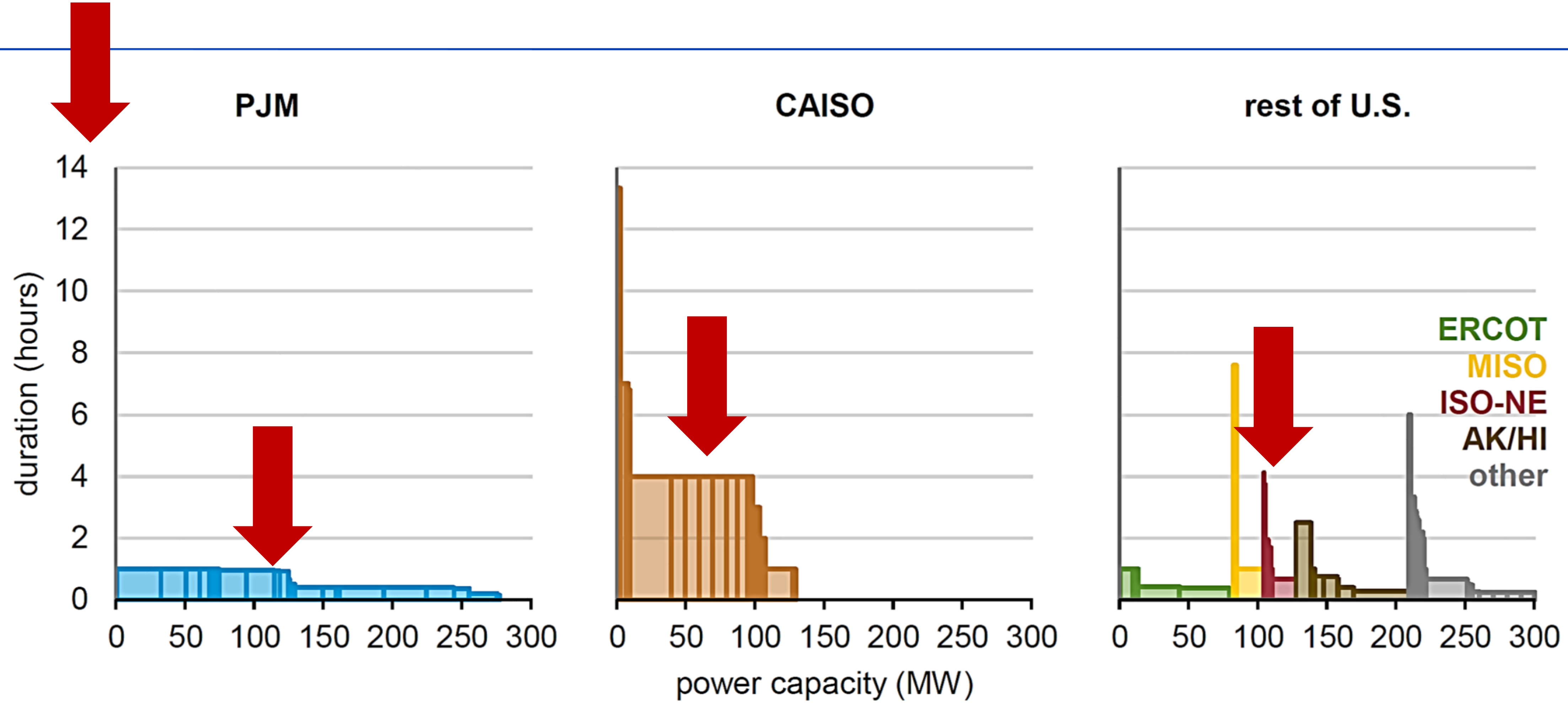
Hydro-generation



…between 2007-2009, a period of significant drought, hydro generation fell to about 13 percent of California's total generation, down from a peak of 18 percent, with monthly hydro production falling from 5,000 MWh/month to less than 1,000. In the most recent and more severe drought, hydro generation was under seven percent of total generation.

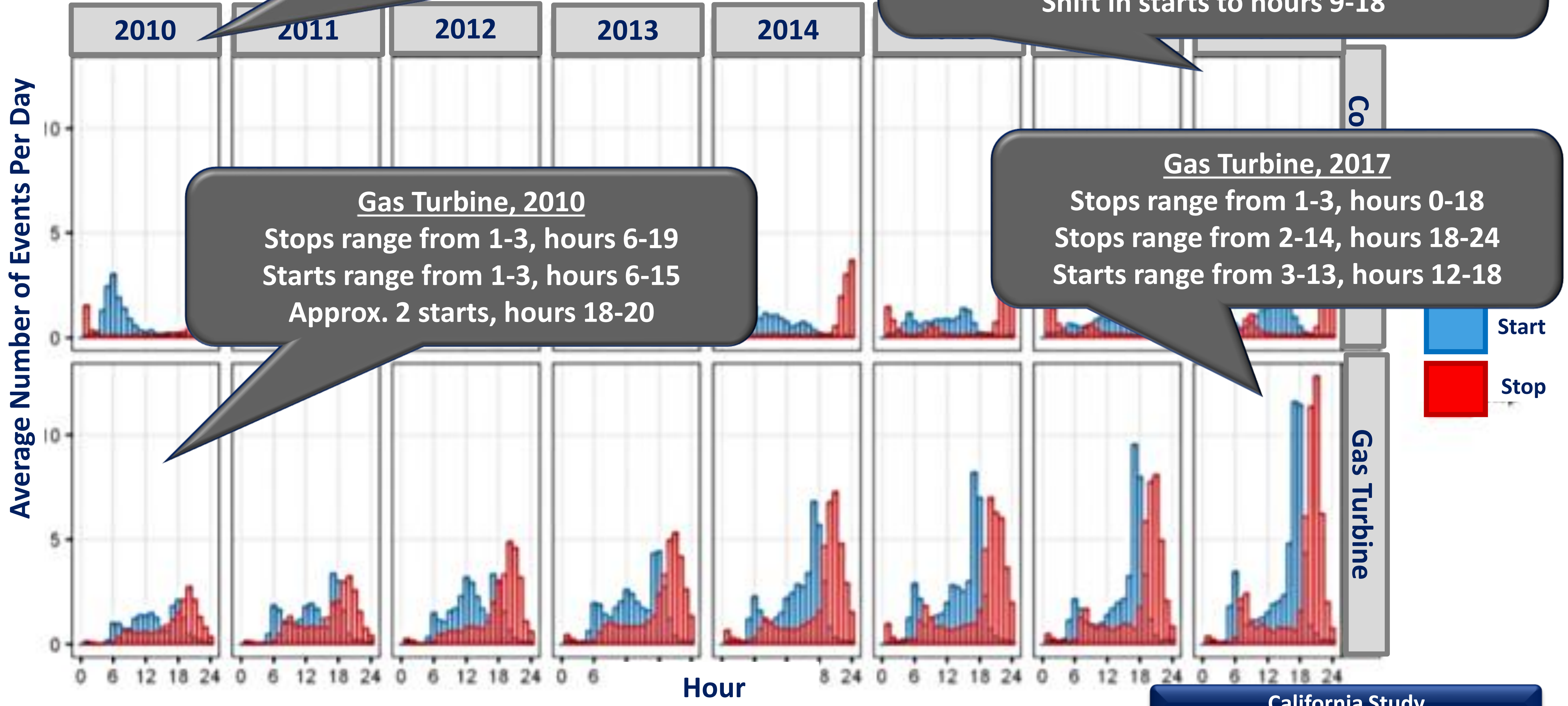
Source: Pacific Institute, 2017

Challenges with Integrating Intermittent Renewables: Electricity Storage Capacity by Region, 2017



Source: EIA, 2018

Hourly average start and st... showing CC unit starts shi... ups. Source: EFI, 2019. Co...



Combined Cycle, 2010
Stops at 0 hour, hours 19-24
events/day peak in early morning, late evening
Starts hours 6-12

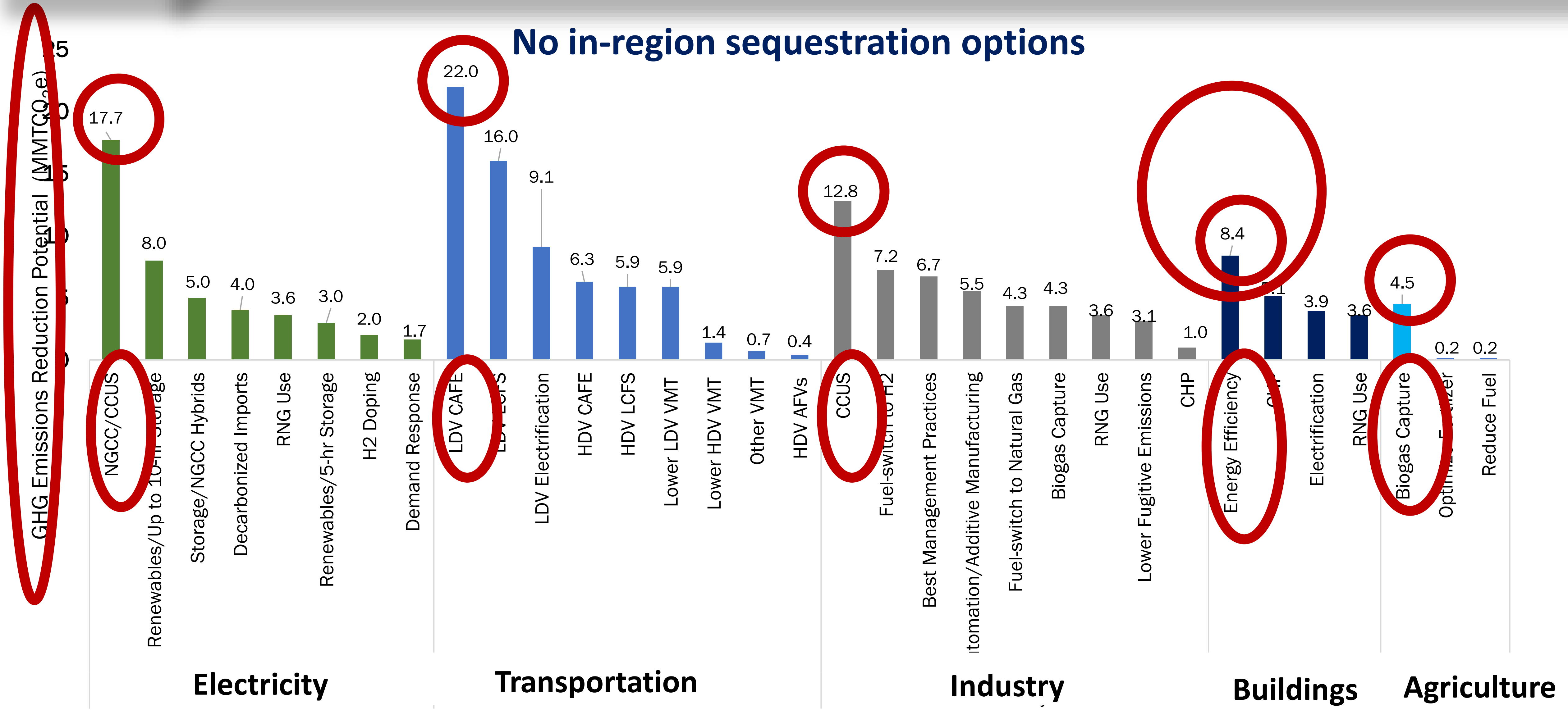
Combined Cycle, 2017
Increased stops, hours 0-4,
New peak stops, hours 6-12,
Stops, hours 19-24
Shift in starts to hours 9-18

Gas Turbine, 2010
Stops range from 1-3, hours 6-19
Starts range from 1-3, hours 6-15
Approx. 2 starts, hours 18-20

Gas Turbine, 2017
Stops range from 1-3, hours 0-18
Stops range from 2-14, hours 18-24
Starts range from 3-13, hours 12-18

Identified Emissions Reduction Potential of Sector-Specific Pathways for Meeting CA's 2030 Targets

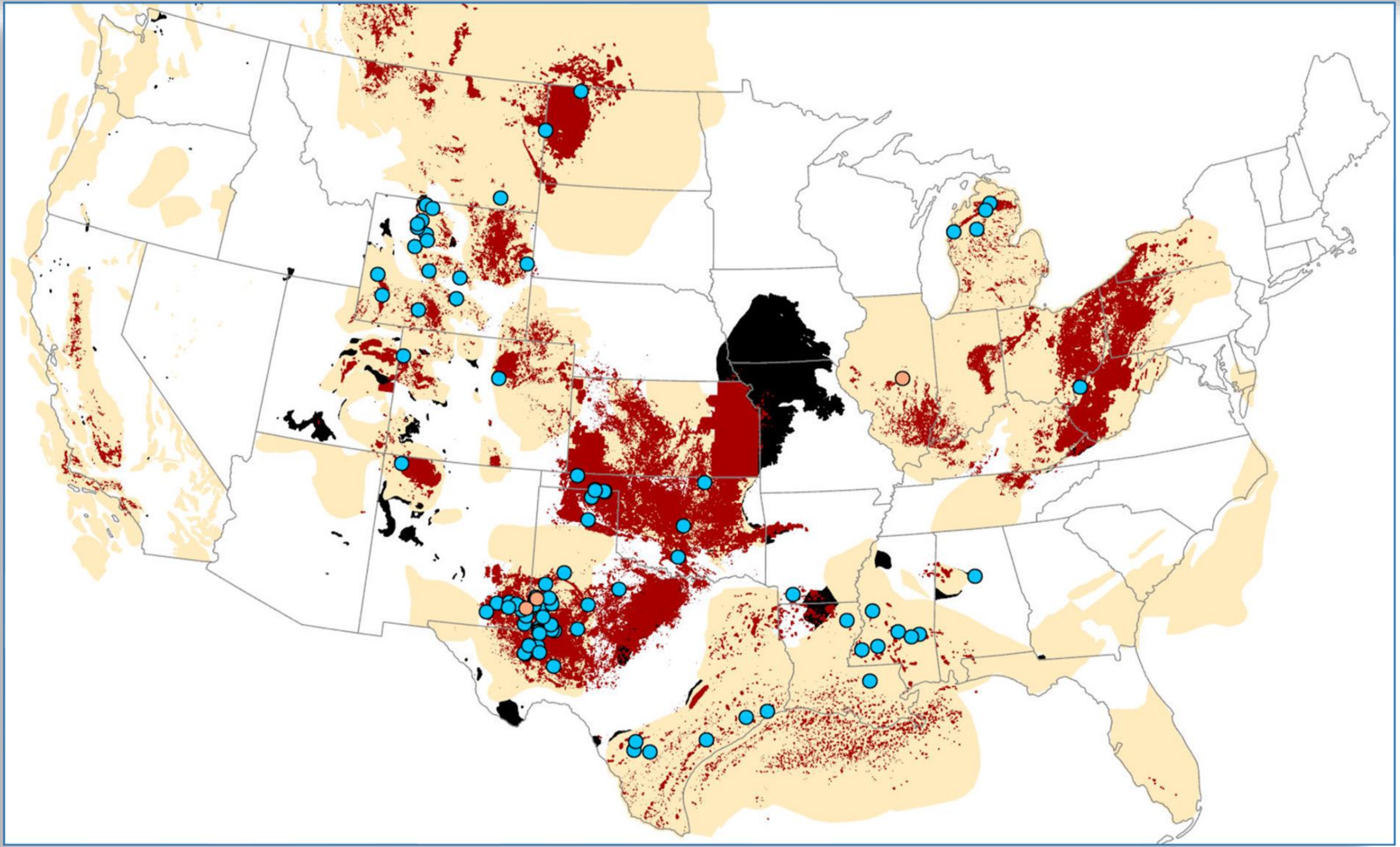
No in-region sequestration options



Source: EFI analysis

California Study

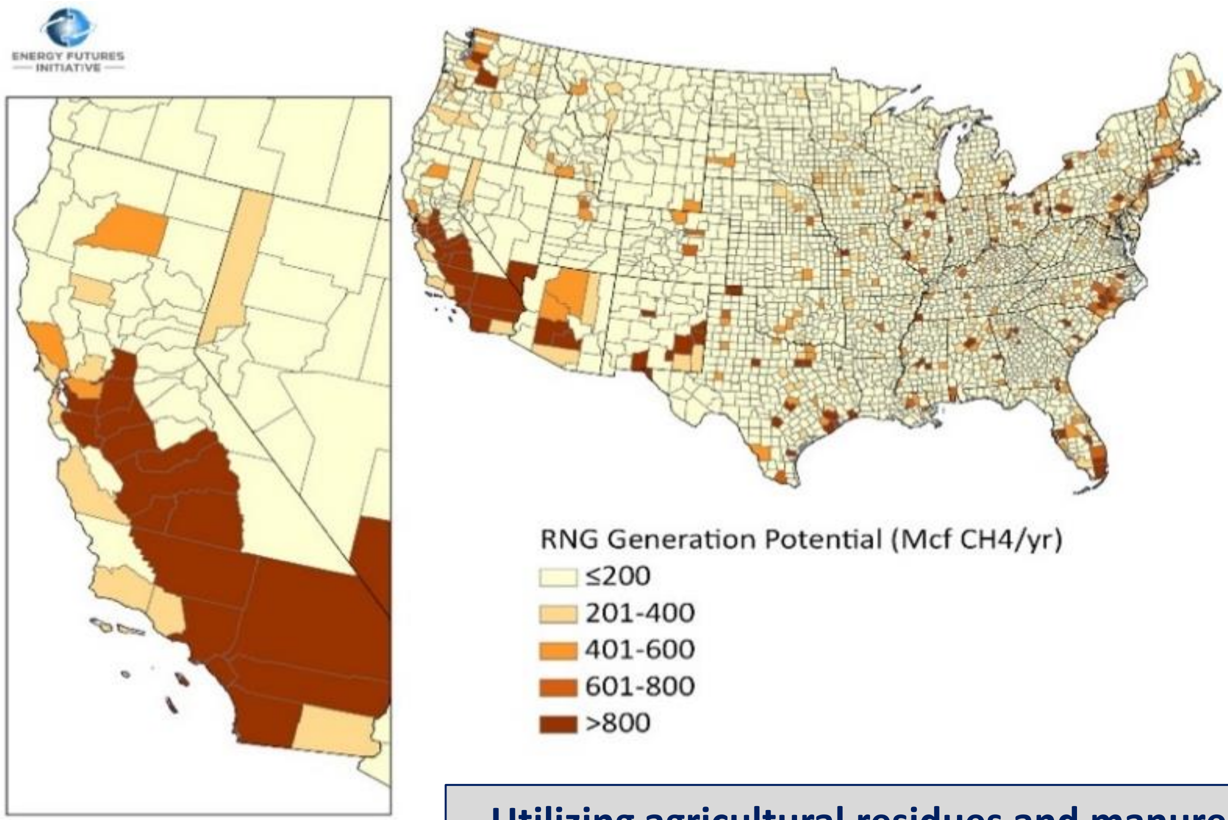
US Subsurface Sequestration Potential



Source: EFI analysis

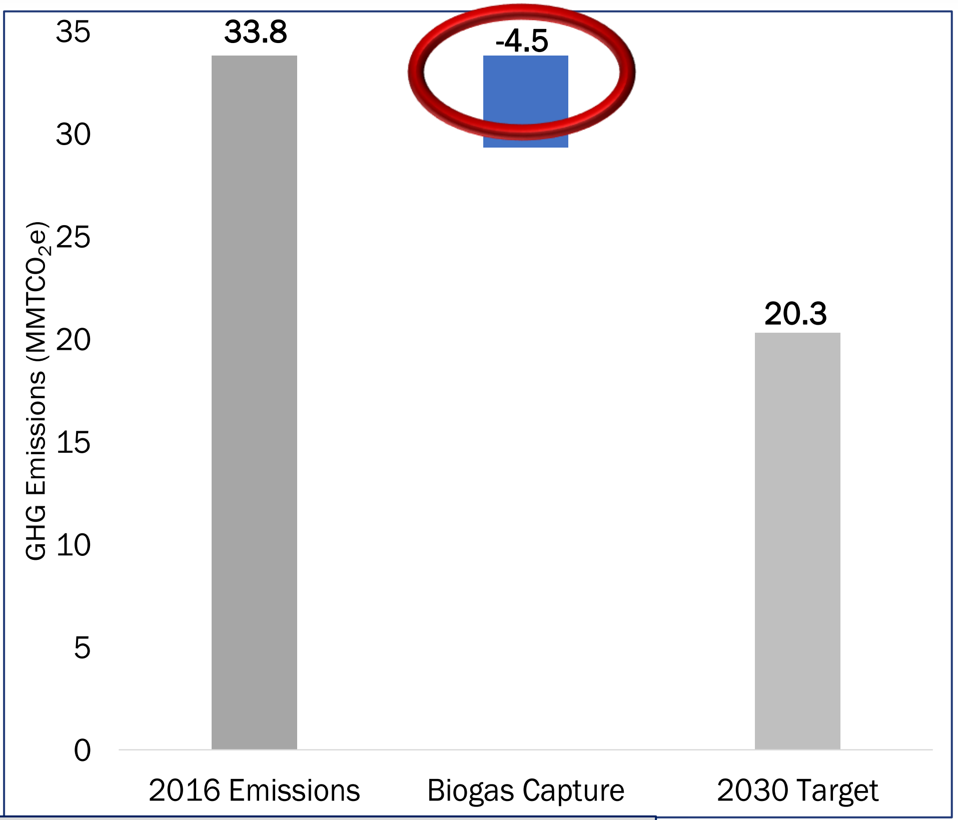
Biogas/Renewable Gas for Decarbonizing Agriculture Sector

RNG Generation Potential in California (Mcf CH_4/year)



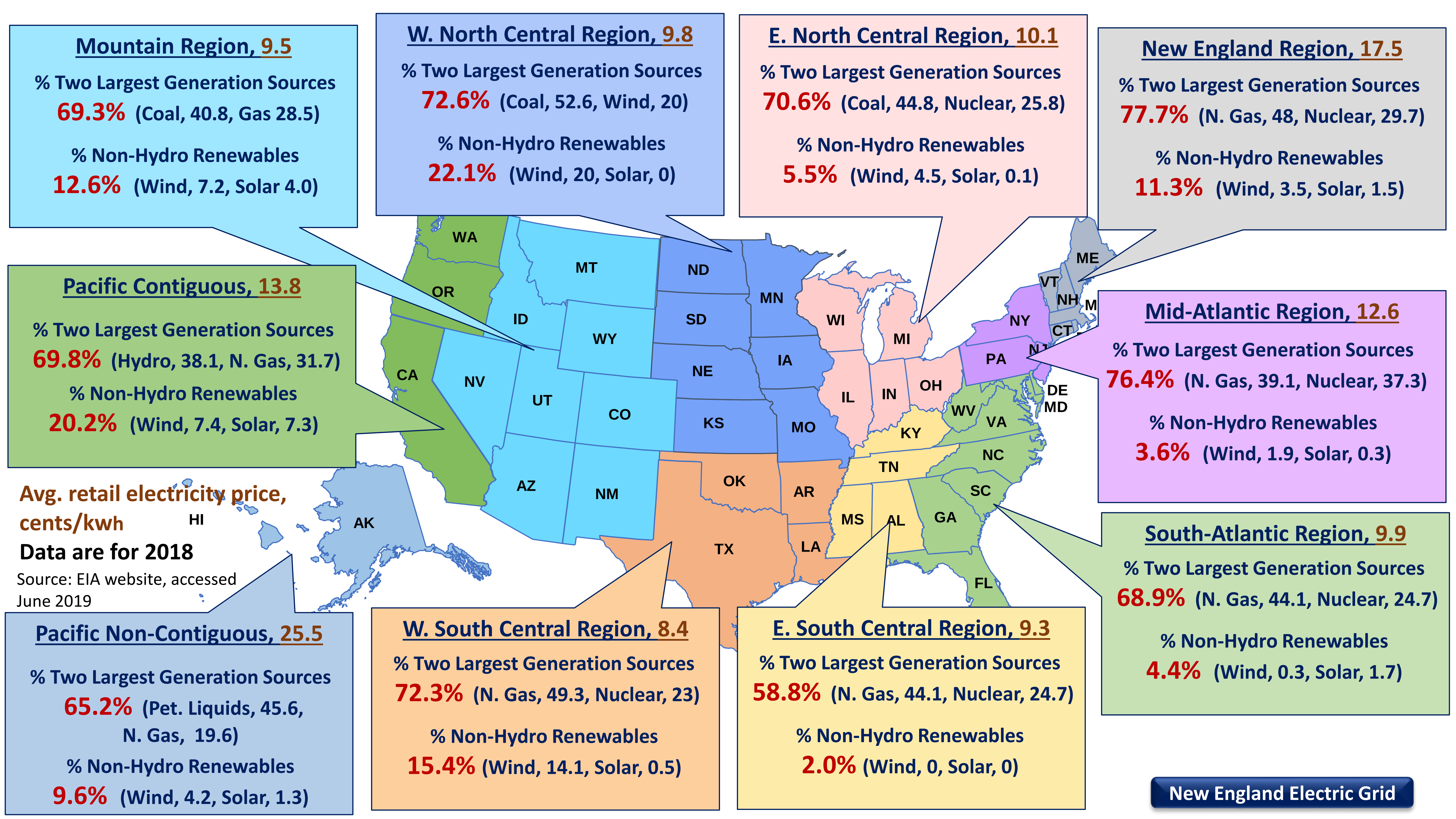
Source: EFI Analysis

Biogas Capture Pathway and 2030 Target (MMTCO_2e)

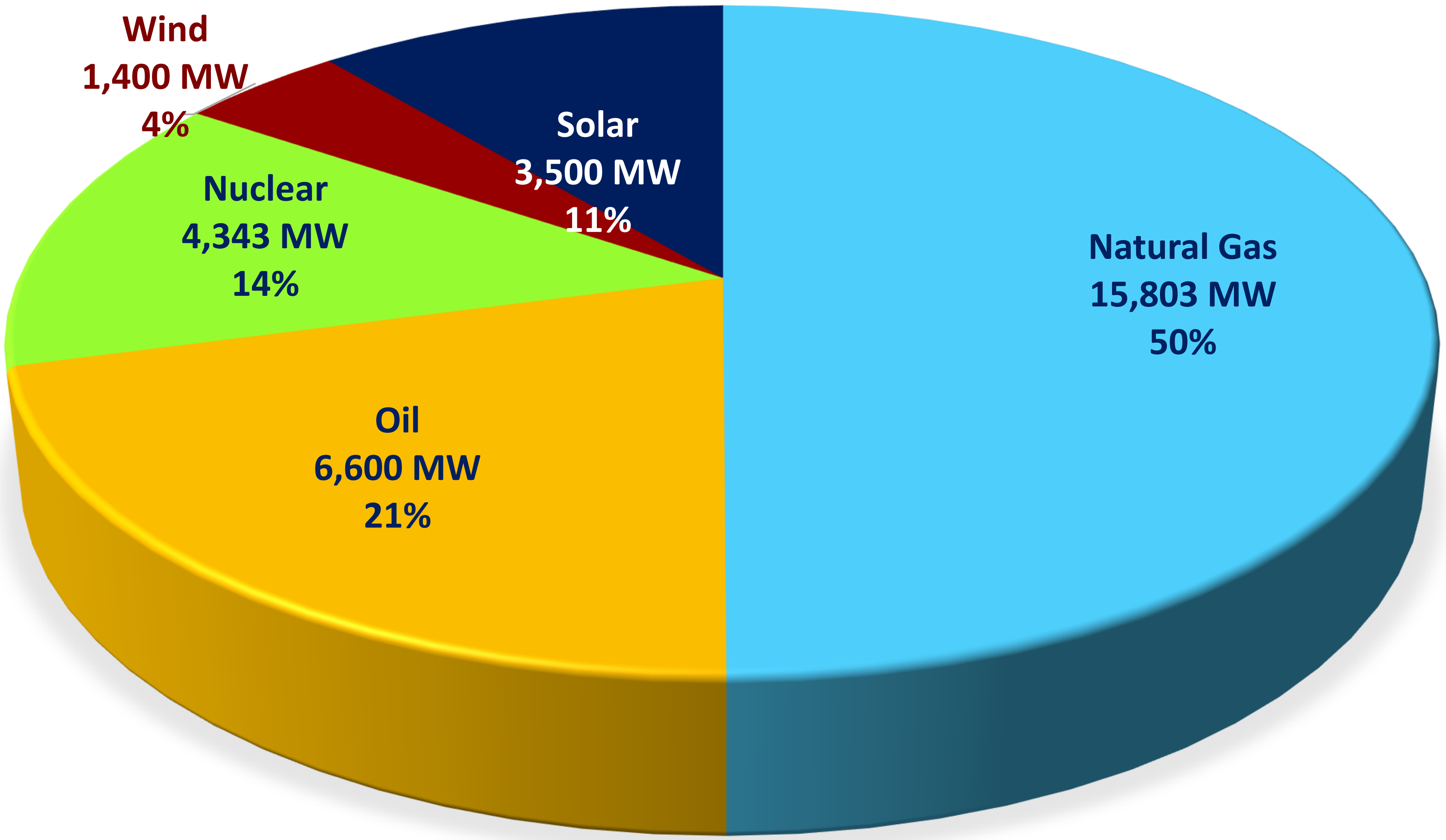


Utilizing agricultural residues and manure as biogas feedstocks for RNG could provide up to 46.6 Bcf/year of carbon-neutral gas by 2030…Biogas capture also could provide emissions reductions and economic benefits to the Agriculture sector ….Diverting methane into a useable product in the form of RNG can have a significant net impact on CO_2e levels—potentially reducing the Agriculture sector's emissions 13 percent by 2030.

California Study


Mountain Region, 9.5
% Two Largest Generation Sources
69.3% (Coal, 40.8, Gas 28.5)
% Non-Hydro Renewables
12.6% (Wind, 7.2, Solar 4.0)
W. North Central Region, 9.8
% Two Largest Generation Sources
72.6% (Coal, 52.6, Wind, 20)
% Non-Hydro Renewables
22.1% (Wind, 20, Solar, 0)
E. North Central Region, 10.1
% Two Largest Generation Sources
70.6% (Coal, 44.8, Nuclear, 25.8)
% Non-Hydro Renewables
5.5% (Wind, 4.5, Solar, 0.1)
New England Region, 17.5
% Two Largest Generation Sources
77.7% (N. Gas, 48, Nuclear, 29.7)
% Non-Hydro Renewables
11.3% (Wind, 3.5, Solar, 1.5)
Pacific Contiguous, 13.8
% Two Largest Generation Sources
69.8% (Hydro, 38.1, N. Gas, 31.7)
% Non-Hydro Renewables
20.2% (Wind, 7.4, Solar, 7.3)
Mid-Atlantic Region, 12.6
% Two Largest Generation Sources
76.4% (N. Gas, 39.1, Nuclear, 37.3)
% Non-Hydro Renewables
3.6% (Wind, 1.9, Solar, 0.3)
Avg. retail electricity price, cents/kwh
Data are for 2018
Source: EIA website, accessed June 2019
South-Atlantic Region, 9.9
% Two Largest Generation Sources
68.9% (N. Gas, 44.1, Nuclear, 24.7)
% Non-Hydro Renewables
4.4% (Wind, 0.3, Solar, 1.7)
Pacific Non-Contiguous, 25.5
% Two Largest Generation Sources
65.2% (Pet. Liquids, 45.6, N. Gas, 19.6)
% Non-Hydro Renewables
9.6% (Wind, 4.2, Solar, 1.3)
W. South Central Region, 8.4
% Two Largest Generation Sources
72.3% (N. Gas, 49.3, Nuclear, 23)
% Non-Hydro Renewables
15.4% (Wind, 14.1, Solar, 0.5)
E. South Central Region, 9.3
% Two Largest Generation Sources
58.8% (N. Gas, 44.1, Nuclear, 24.7)
% Non-Hydro Renewables
2.0% (Wind, 0, Solar, 0)
WA OR CA ID NV MT WY UT CO AZ NM ND SD NE KS MN IA MO OK TX AR LA WI MI IL IN OH KY TN MS AL GA FL SC NC VA WV DE MD PA NY VT NH ME CT HI AK
New England Electric Grid

Installed Capacity in New England, 2019 (MW)



Sources: ISO-NE Website

New England Summer Capacity Supply Obligations by Fuel, 2019 (MW)

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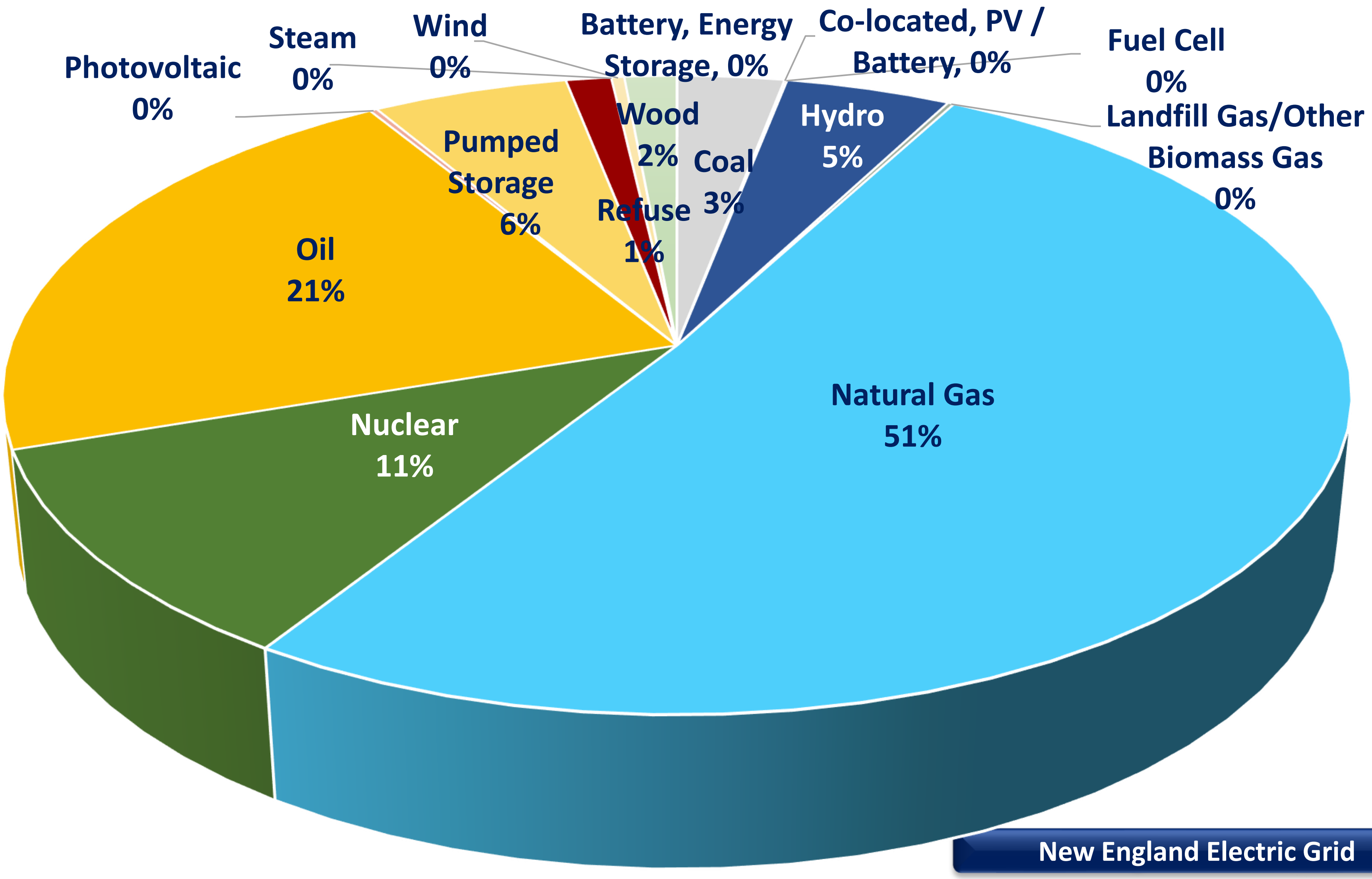
Summer Capacity Supply Obligation, MW

Battery, Energy Storage	5
Coal	917
Co-located, PV/Battery	0
Fuel Cell	23
Hydro	1,422
Landfill/Other Biomass Gas	54
Natural Gas	15,803
Nuclear	4,343
Oil	6,618
Photovoltaic	63
Pumped Storage	1,682
Refuse	390
Steam	0
Wind	112
Wood	449
Demand Capacity	3,088
Total Capacity	35,396

Sources: ISO-NE Website

Summer Capacity Supply, 2019 (MW)



New England Electric Grid

Reference Frames for Installed Capacity/ Dispatchable Technologies: 100% Wind & Solar Replacing Oil, Gas & Nuclear

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2019 Installed Capacity/Avg. Capacity Factors*

			MW Capacity Needed to Replace Gas, Oil & Nuclear Capacity	Square Miles Land Needed*
15,803 MW Natural Gas	Capacity Factor	67%		
4,343 MW Nuclear	Capacity Factor	93.5%		
6,618 MW Oil	Capacity Factor	15%		
4051 MW Solar PV	Capacity Factor	24.5%	59,826	57
2836 MW Wind **	Capacity Factor	35% (onshore)	41,878	194

Source: land use for wind solar NREL, 10 MW PV 6.1 acres, 10 MW onshore wind 44.7 acres, 640 acres = sq. mile
Capacity factors, solar PV, Gas, nuclear onshore wind: EIA
Capacity factors offshore wind: https://energynumbers.info/uk-offshore-wind-capacity-factors
***Assumes no onshore wind, assume 15 MW per installed turbine

				# Turbines Needed**
112 MW Wind ***	Capacity Factor	45% (offshore)	32,752	2,183***

This and previous slide demonstrate the obvious – massive amounts of storage are needed when dispatchable generation is eliminated and….

New England

Demand Response, Capacity by RTO/ISO, 2017-2018

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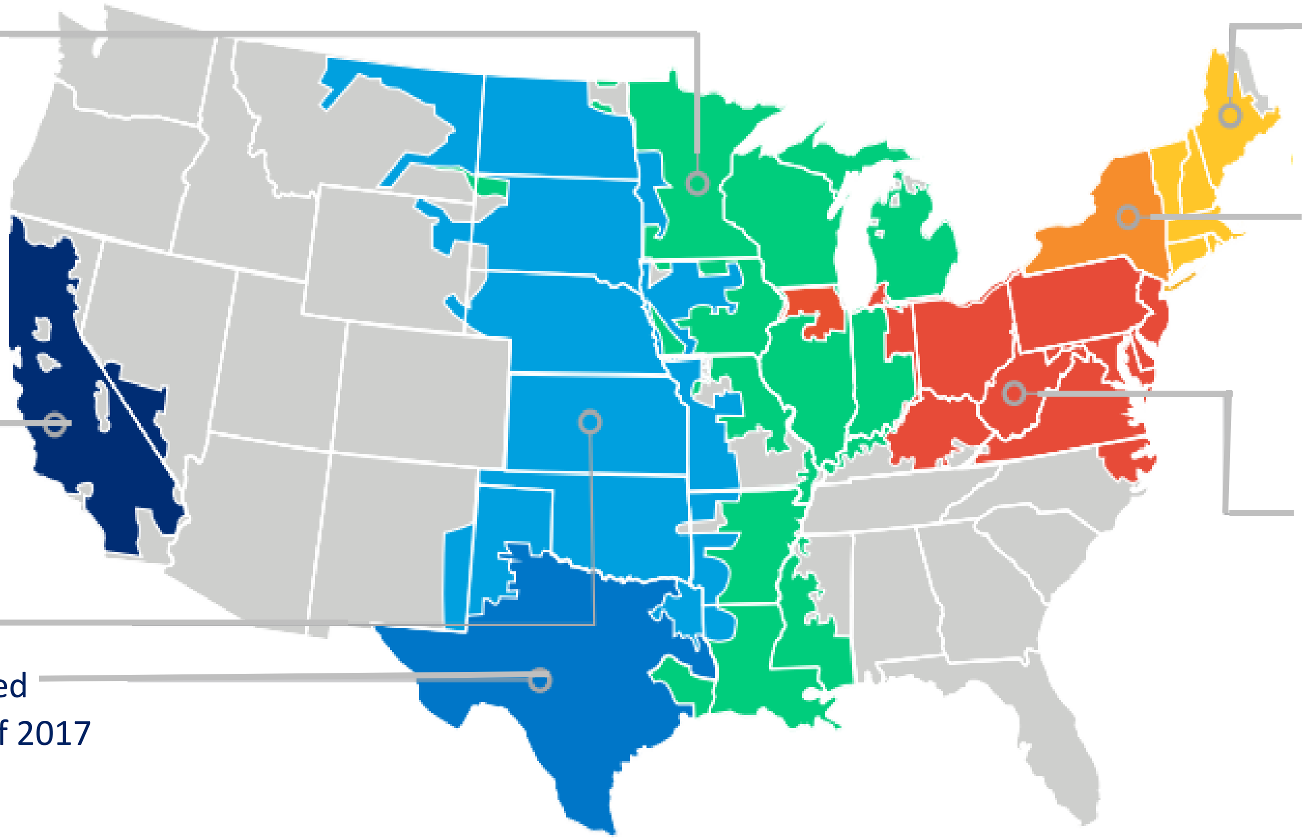
...we need an even greater focus on demand response

MISO: 6,014 MW cleared in the 2017-18 resource auction but is generally retail and not included in wholesale power markets

CAISO: 1,023 MW of total availability reliability DR in 2017 was integrated into the CAISO market

SPP: NA

ERCOT: 2,170 MW of combined RRS and ERS programs as of end of 2017



ISONE: 750 MW of DR assets were enrolled in the market in the summer of 2017

NYISO: 1,237 MW of enrolled capacity as of July 2017 or 4.2% of NYISO's 2017 summer peak

PJM: 8,120 MW of demand response was committed for 2017/2018, 4.2% of total committed capacity for that year

file:///C:/Users/Melanie%20Kenderline/Downloads/266___2018_Utility_Demand_Response_Market_Snapshot.pdf

Sources: Navigant, 2018

New England

Generation Technologies, LCOE for Plants Entering Service in 2022

Advanced Nuclear → $92.6

Advanced CC → $48.1

Advanced CC w/ CCS → $74.9

Coal with 30% CCS → $130.1

Advanced CT → $85.1

Hydroelectric → $61.7

Biomass → $95.3

Geothermal → $44.6

Onshore Wind → $59.1

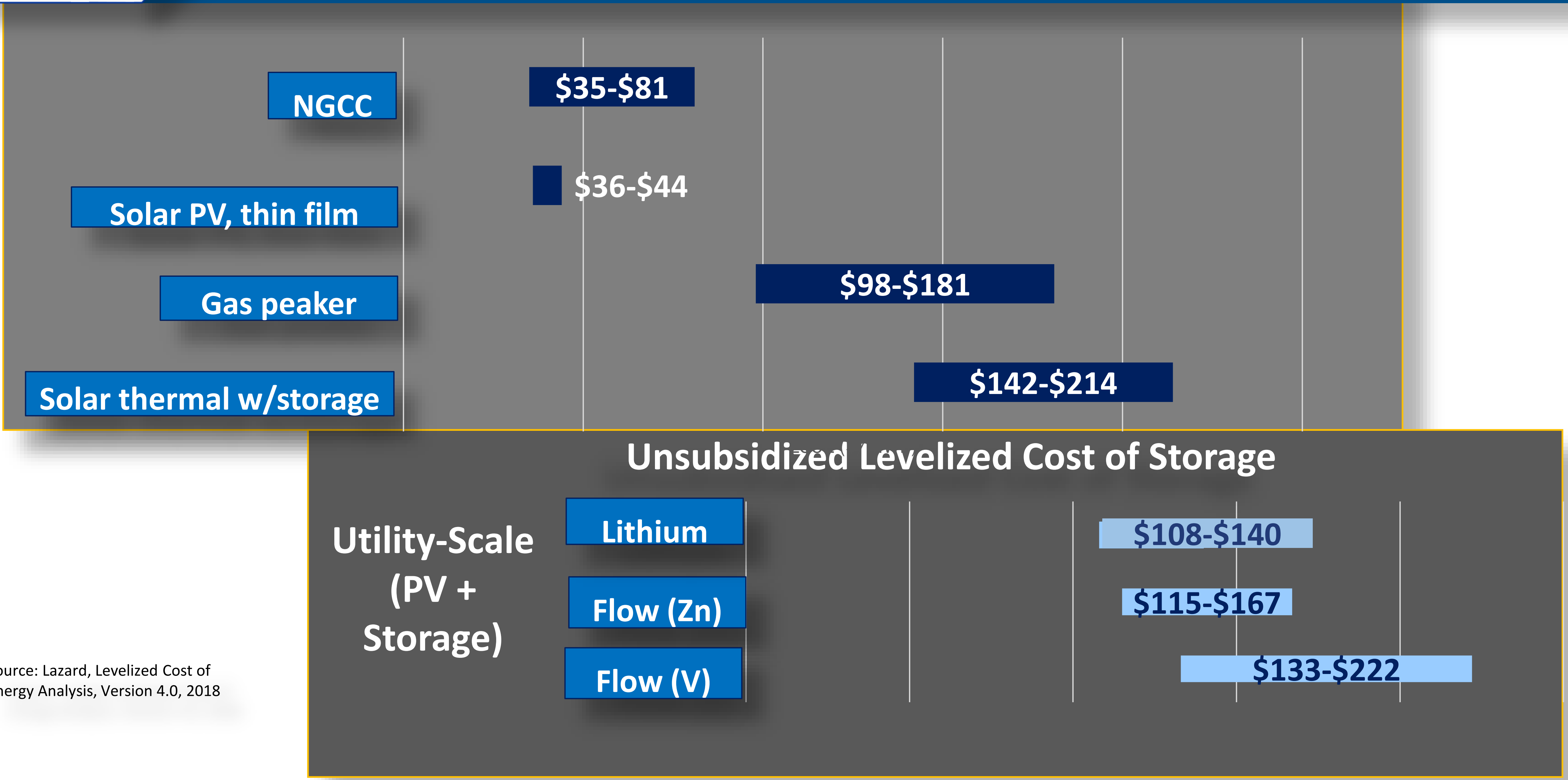
Solar PV → $63.2

Offshore Wind → $138.0

Solar Thermal → $165.1

LCOE Source: EIA

Generation Technologies, LCOE/LCOS ($MWh), 2018

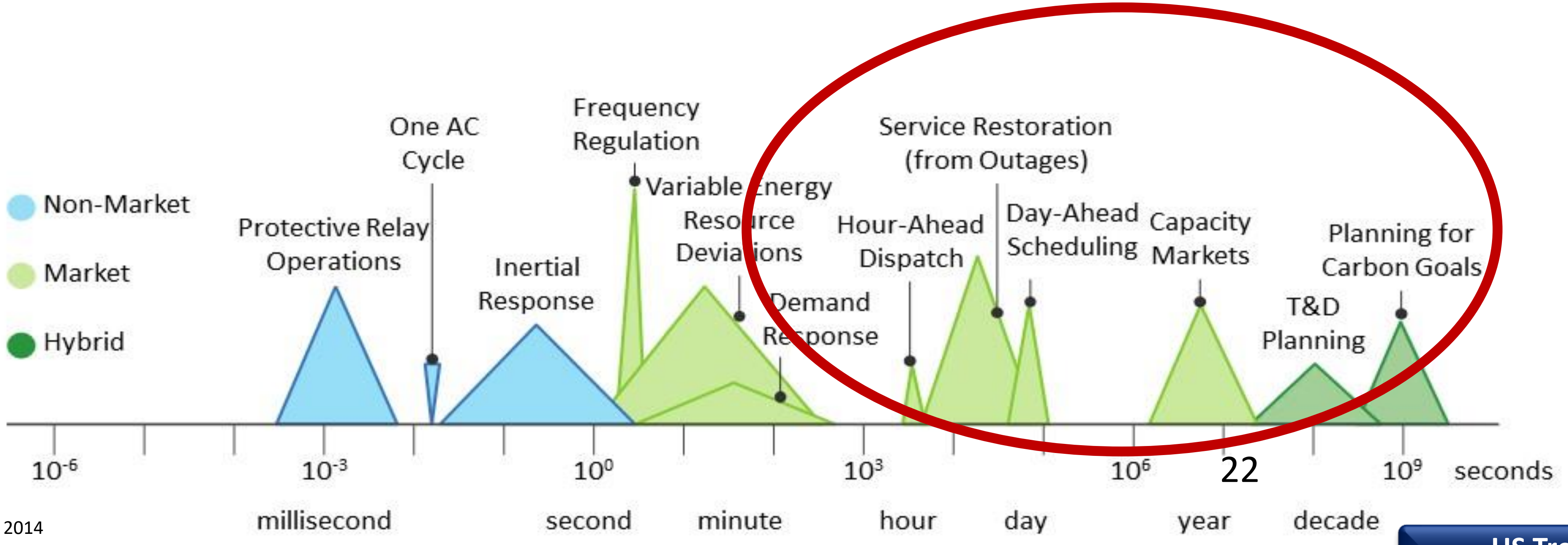


Source: Lazard, Levelized Cost of Energy Analysis, Version 4.0, 2018

Evolving Requirements for System Operations

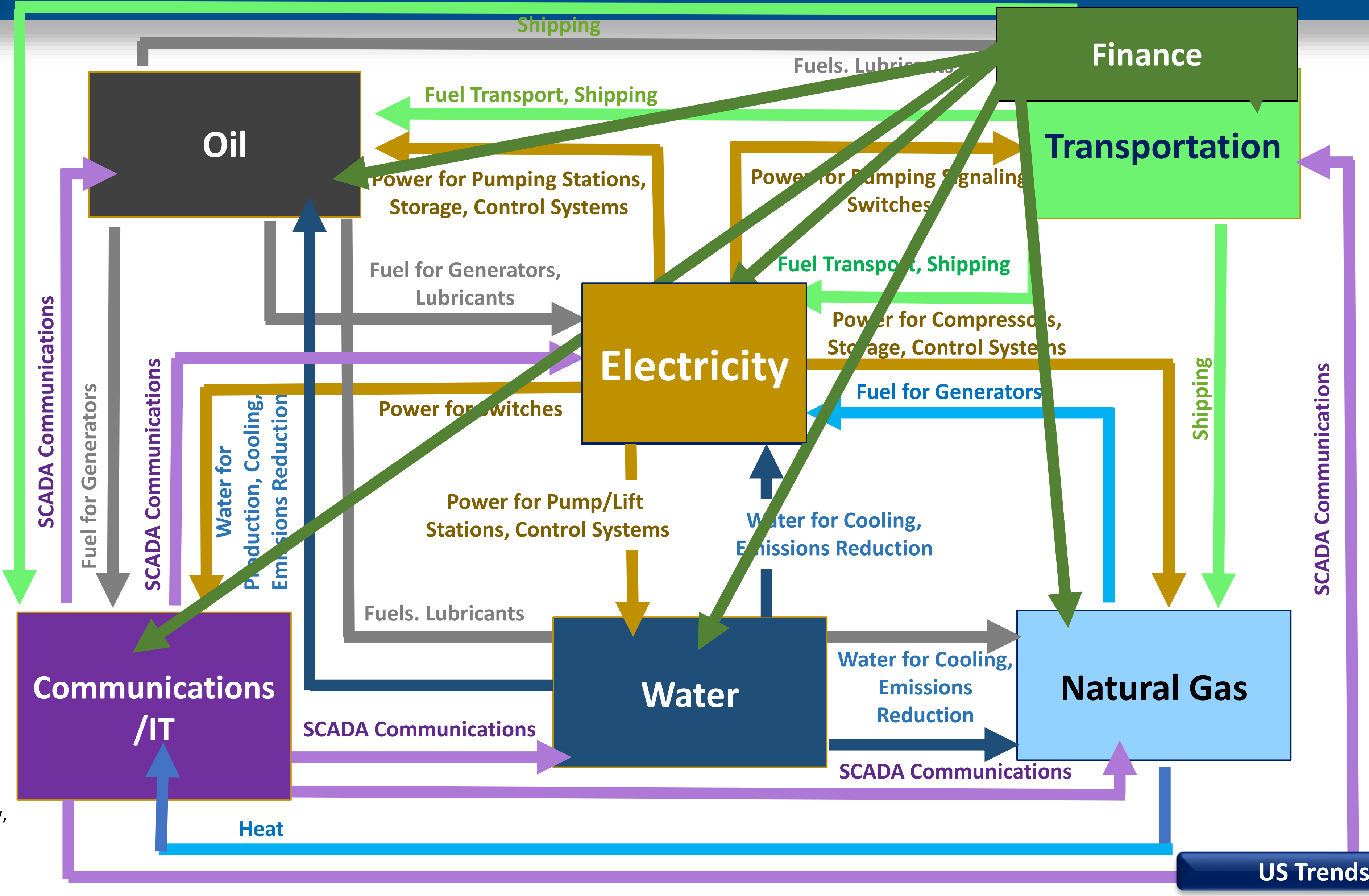
- The widespread integration of VERs at both utility scale and distributed across all consumer segments significantly expands the time dimensions in which grid operators must function and complicates operations.
- Dispatch effectiveness will require the integration of automated grid management with continuing human oversight as well as an increase in the granularity, speed, and sophistication of operator analytics.

System Reliability Depends on Managing Multiple Event Speeds



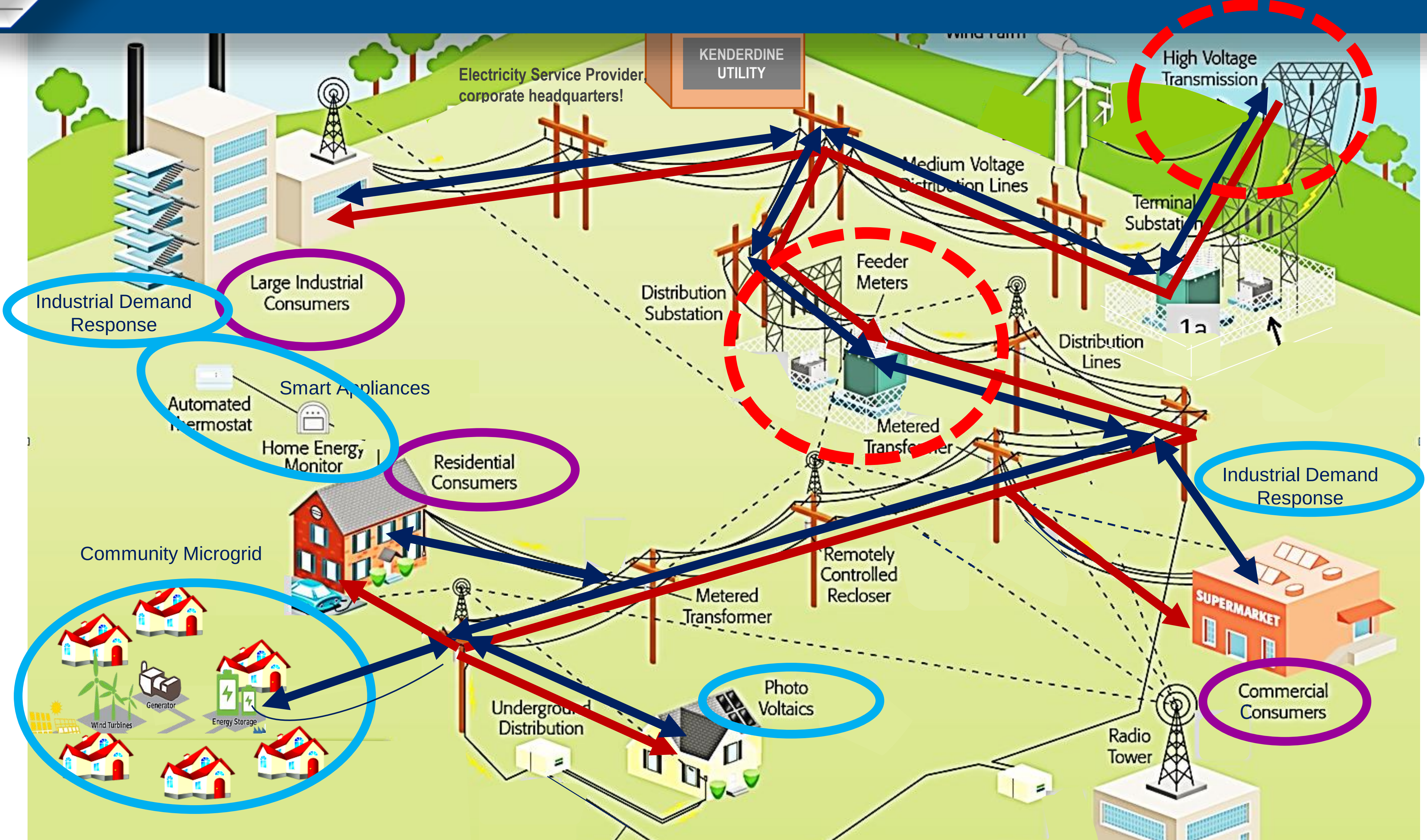
Source: von Meier, 2014

Electricity and Lifeline Network Interdependencies



Source: Modified from the Second Installment of the Quadrennial Energy Review, Transforming the Nation's Electricity Systems, 2017

Two Way Electricity Flows and Grid Security



Source: Annual Energy Conservation Progress Report, 2010 (Volume One): Managing a Complex Energy System. Toronto, ON, modified for presentation

Two Way Electricity Flows and Grid Security, contd.

Traditional utility data acquisition and monitoring systems are ill-equipped to gain real-time visibility of DERs because these systems typically do not extend beyond substations, are unable to acquire measurements on DER performance, and were not designed to handle real-time processing of large volumes of data. Thus, improved sensing, monitoring, and modeling are vital."

- DOE Office of Electricity Delivery and Energy Reliability-

"Assuring that we have reliable, accessible, sustainable, and affordable electric power is a national security imperative. Our increased reliance on electric power in every sector of our lives, including communications, commerce, transportation, health and emergency services, in addition to homeland and national defense, means that large-scale disruptions of electrical power will have immediate costs to our economy and can place our security at risk.

Whether it is the ability of first responders to answer the call to emergencies here in the United States, or the readiness and capability of our military service members to operate effectively in the U.S. or deployed in theater, these missions are directly linked to assured domestic electric power."

–Center for Naval Analyses-

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Metals Demand for Low Carbon Technologies

Light Emitting Diodes (11)
Aluminum, Chromium, Copper, Indium,
Iron (cast), Lead, Manganese, Molybdenum, Nickel, Silver, Zinc

Wind (10)
Aluminum, Chromium, Copper, Indium, Iron (cast), Iron (magnet), Lead, Manganese, Molybdenum, Neodymium (proxy for rare earths), Nickel, Steel (engineering)

CCS (8)
Aluminum, Chromium, Cobalt, Copper, Indium, Manganese, Molybdenum, Nickel

Nuclear Power (8)
Chromium, Cobalt, Copper, Indium, Lead, Molybdenum, Nickel, Silver

Concentrating Solar (3)
Aluminum, Iron (cast), Silver

Electric Vehicles (6)
Cobalt, Copper, Manganese, Neodymium (proxy for rare earths), Nickel, Silver

Better Meets Reality, March, 2019

Energy Storage
Aluminum, Cobalt, Lithium, Iron (cast), Nickel

Electric Motors (3)
Aluminum, Copper, Iron (magnet)

Solar PV (6)
Aluminum, Copper, Indium, Nickel,
Silver, Zinc

In 2017, UNEP calculated that **low carbon technologies will need over 600 million metric tonnes more metal resources in a 2° C scenario compared to a 6° C scenario where fossil fuel use continues on its current path.**
(It also concluded that the 2° scenario would save more than 200 million cubic meters of water …)

Lithium, Cobalt, Nickel Production/Reserves

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Meeting the Clean Energy Ministerial's target of 30 million electric vehicle sales by 2030 would require 314 kt/yr. of cobalt, almost three times the 2017 level for all uses. At those rates, reserves would last 23 years.

Carbonbrief.org

Lithium Production/Reserves (metric tons)

	Mine production 2017	Mine production 2018e	Reserves[6]
United States	W	W	35,000
Argentina	[illegible]	[illegible]	2,000,000
Australia	40,000	51,000	[7]2,700,000
Brazil	[illegible]	[illegible]	[illegible]
Chile	14,200	16,000	8,000,000
China	[illegible]	[illegible]	1,000,000
Portugal	800	800	60,000
Namibia	—	500	NA
Zimbabwe	800	1,600	70,000
World total (rounded)	[8]69,000	[8]85,000	14,000,000

Cobalt Production/Reserves (metric tons)

	Mine production 2017	Mine production 2018e	Reserves[7]
United States	640	500	[illegible]
Australia	5,030	4,700	[illegible]
Canada	3,870	3,800	[illegible]
China	3,100	3,100	[illegible]
Congo (Kinshasa)	73,000	90,000	3,400,000
Cuba	5,000	4,900	[illegible]
Madagascar	3,500	3,500	140,000
Morocco	2,200	2,300	17,000
Papua New Guinea	3,310	3,200	56,000
Philippines	4,600	4,600	280,000
Russia	5,900	5,900	250,000
South Africa	2,300	2,200	24,000
Other countries	7,650	7,000	640,000
World total (rounded)	120,000	140,000	6,900,000

Nickel (metric tons)

	Mine production 2017	Mine production 2018e	Reserves[8]
United States	22,100	19,000	110,000
[illegible]	[illegible]	[illegible]	[illegible]
Brazil	78,600	80,000	11,000,000
[illegible]	214,000	160,000	[illegible]
China	103,000	110,000	2,800,000
Colombia	45,500	43,000	440,000
Cuba	52,800	53,000	5,500,000
Finland	34,600	46,000	NA
[illegible]	53,700	49,000	[illegible]
Indonesia	345,000	560,000	21,000,000
Madagascar	[illegible]	[illegible]	[illegible]
New Caledonia[10]	215,000	210,000	—
Philippines	366,000	340,000	4,800,000
Russia	214,000	210,000	7,600,000
South Africa	48,400	44,000	3,700,000
Other countries	146,000	180,000	6,500,000
World total (rounded)	2,160,000	2,300,000	89,000,000

Tesla's global supply manager for battery metals, told a closed-door Washington conference of miners, regulators and lawmakers that the automaker sees a shortage of key EV minerals coming in the near future…Tesla will continue to focus more on nickel, part of a plan by Chief Executive Elon Musk to use less cobalt in battery cathodes.

Electrek, May, 2019

Source: USGS, 2019

EFI Clean Energy Innovation Index

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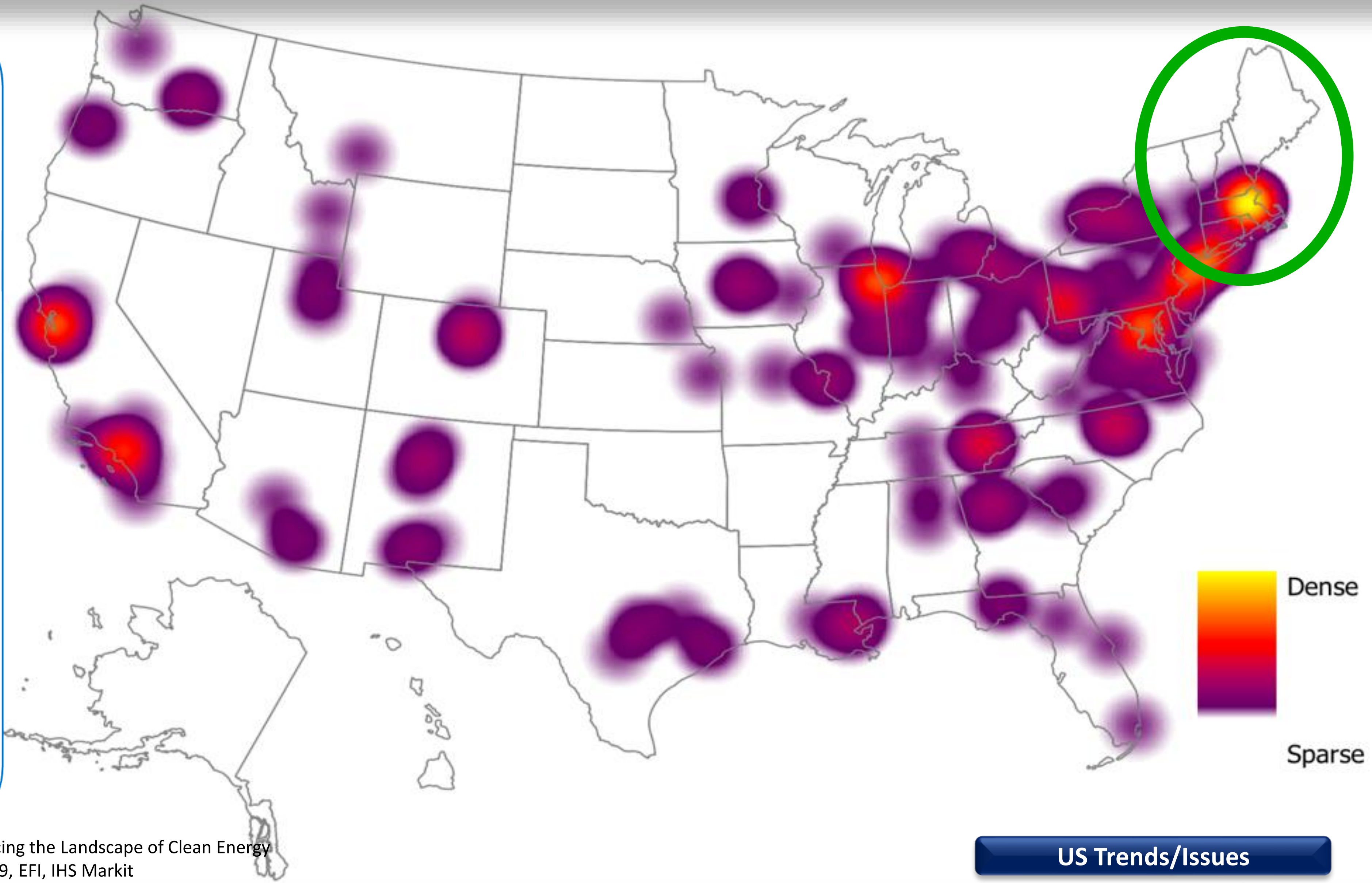
Index reflects Department of Energy (DOE) national laboratories and Energy Innovation Hubs, the DOE-funded Energy Frontier Research Centers, the National Network for Manufacturing Innovation Centers, NASA laboratories and facilities, the top 100 research universities, and the major Federally Funded Research and Development Centers (FFRDCs). There is a significant clustering of innovation capabilities



Source: Advancing the Landscape of Clean Energy Innovation, 2019, EFI, IHS Markit

US Trends/Issues

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EFI Breakthrough Clean Energy Technologies

- Federal and private clean energy innovation are complementary
- Key platform technologies hold great potential to unlock significant clean energy innovation
- A four-step process is used to identify breakthrough technologies that have the potential to aid government, industry and thought leaders in efforts to transform the energy sector

Analyze key drivers of clean energy technology breakthroughs

Digitalization, big data & smart systems

The difficult to decarbonize sectors

Integration of platform technologies

Systems and supply chains

Develop selection criteria for breakthrough technologies

Technical merit

Market viability

Compatibility

Consumer value

Identify the universe of emerging energy technologies that have critical features across various timescales

Identify innovation areas with significant breakthrough potential

Critical innovation areas identified are:

- Storage and battery technologies
- Advanced nuclear reactors
- Technology applications for industry and buildings as sectors that are difficult to decarbonize including hydrogen, advanced manufacturing technologies; and building technologies
- Systems: electric grid modernization and smart cities
- Deep decarbonization/large-scale carbon management; carbon capture, use and storage at scale; sunlight to fuels; enhanced biological and oceans sequestration

Source: Advancing the Landscape of Clean Energy Innovation, 2019, EFI, IHS Markit

Quadrennial Energy Review Recommendations, 2017: How Much Progress Has Been Made?

Increase Financing Options for Grid Modernization

- Expand DOE's loan guarantee program and make it more flexible to assist in deployment of innovative grid technologies and systems.

Increase technology demonstrations and utility/investor confidence.

- Significantly expand existing programs to demonstrate the integration and optimization of distribution system technologies.

Build Capacity at the Federal, State, and Local Levels.

- Provide funding assistance to enhance capabilities in state public utility commissions and improve access to training and expertise for small and municipal utilities.
- Create a center for Advanced Electric Power System Economics to provide social science advice and economic analysis on an increasingly transactive and dynamic 21st century electricity system.

Inform Electricity System Governance in a Rapidly Changing Environment.

- Establish a Federal Advisory Committee on alignment of responsibilities for rates and resource adequacy.