Electronic Participation Guidelines
June 24, 2020 Participants Committee WebEx Event

NEPOOL meetings, while not public, are open to all NEPOOL Participants, their authorized representatives and, except as otherwise limited for discussions in executive session, consumer advocates, federal and state officials and guests whose attendance has been cleared with the Committee Chair. All those in attendance or participating, either in person or by phone, are required to identify themselves and their affiliation at the meeting. Official records and minutes of meetings are posted publicly. No statements made in NEPOOL meetings are to be quoted or published publicly.

BEFORE THE MEETING

- **Download event materials** from the NEPOOL or ISO-NE websites**.** Will minimize disruptions from WebEx or internet service interruptions.

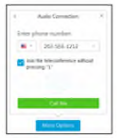
JOIN THE WEBEX EVENT

Join Event

WebEx Link

- Click <Classic View> on right side of menu. Do not use <Modern View>. Use **WebEx Events** Tab.
- Enter first name, last name and e-mail address.
- Enter event password: **nepool.**
- Click <Join>.

CONNECT TO WEBEX AUDIO



- **Call Me** - Enter a phone number, select **Call Me** (encouraged) and WebEx calls you.
- **Call Using Computer** – choose this option to connect to audio using VoIP. Use of headset when using VoIP strongly encouraged.
- **Call In** – If you prefer to use your phone for audio, dial the phone number shown on your screen. When prompted, use your phone keypad to enter the access code, and the Attendee ID shown on your screen. Choose this option if your Internet connection is slow. **Turn off sound from your computer to avoid feedback**.

DURING THE MEETING

- **TURN OFF YOUR VIDEO** – Choose Active Speaker View. Only Presenters should be seen on video.

- **MUTE YOUR MIC OR PHONE** when not speaking.
- **ASK AND WAIT** to be recognized by the Chair.
- **IDENTIFY** yourself/your Participant once recognized and before continuing.

SERVICE INTERRUPTIONS

- Report issues by e-mail to the Chair or Secretary.
- If WebEx system has failed, stand by on e-mail for updates via NPC distribution list.
- PATIENCE. We thank you for your patience during these unprecedented times of remote workforce deployment and strain on teleconference and WebEx services.

Stay Safe and Healthy

v. June 16, 2020

NEW ENGLAND POWER POOL

Participants Committee
19th Annual Summer Meeting

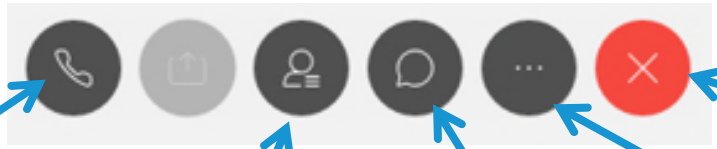
NEW ENGLAND'S
TRANSITION TO A FUTURE GRID:
CHALLENGES & OPPORTUNITIES

NEW ENGLAND POWER POOL

WEBEX FEATURES OVERVIEW

Webex meeting controls (desktop)

You can view meeting controls and panels by hovering over the presentation window and using the buttons toward the bottom of the screen.



If you are not connected to meeting audio, click the phone icon to connect.
If you are connected, this icon will appear as a microphone

Open the Participants panel. Only your and presenter names will be visible in this panel

Open the Chat panel

Change your audio connection (e.g., switch from computer to phone audio)

Leave the meeting

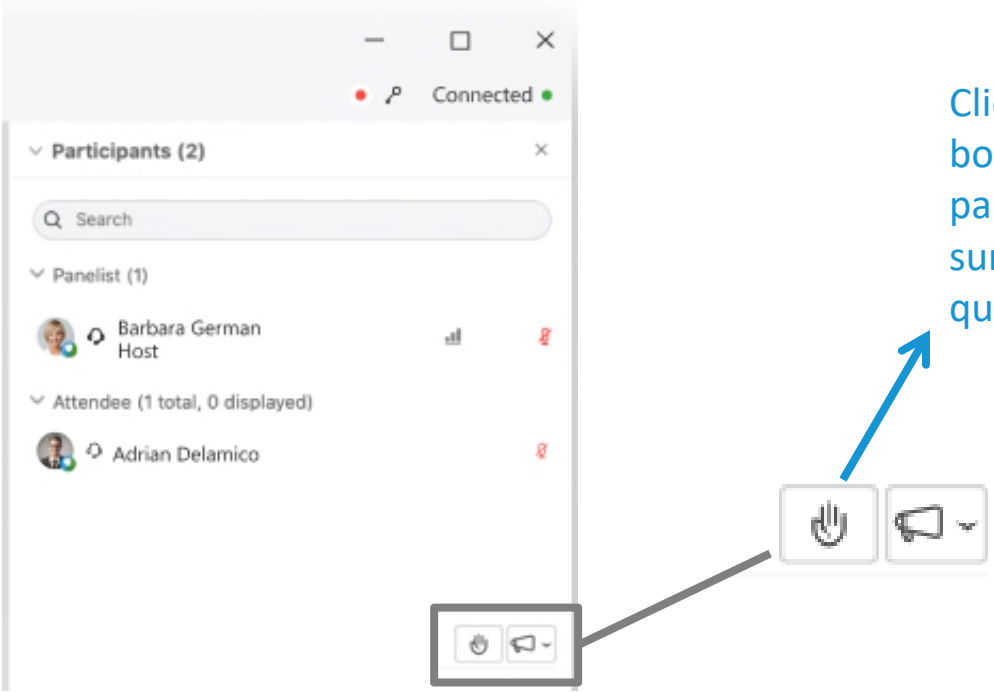
If you do not see these options, try pressing Ctrl+Shift+Q.

For today's meeting

- Questions will be taken throughout the meeting by phone.
- Attendee lines will be unmuted. If you are not speaking, **you must mute your line manually** either from the Webex window or from your phone.

Questions

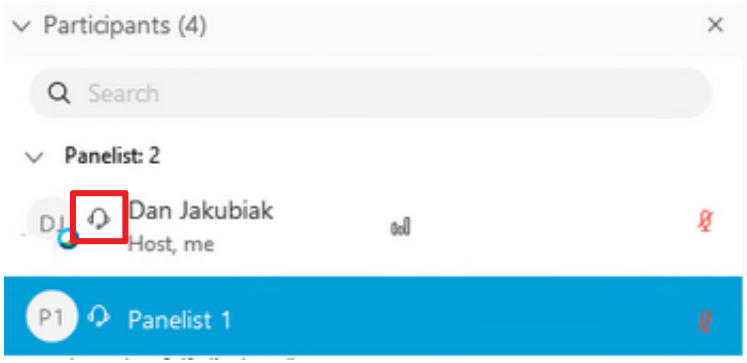
Enter the question/comment queue by **raising your hand** in the Webex window.



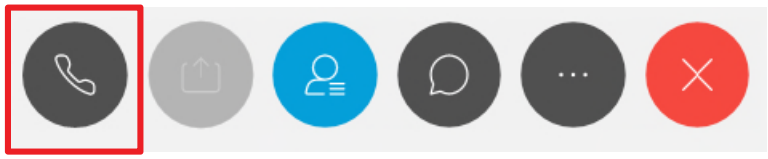
Click the **Raise Hand** icon in the bottom right of the Participants panel to be added to the queue. Be sure to lower your hand once your question has been answered.

Checking your audio connection

- Check for the audio icon to the left of your name in the Participants panel.

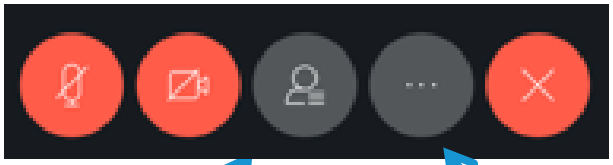


- If you do NOT see an audio icon to the left of your name:



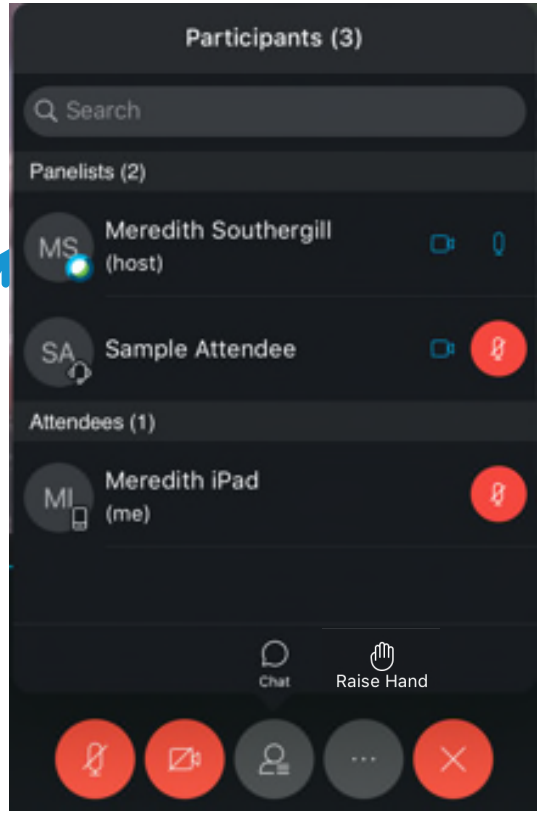
Questions (Webex mobile app)

These features are also available via the mobile Webex app.



Open the Participants panel

Change your audio connection

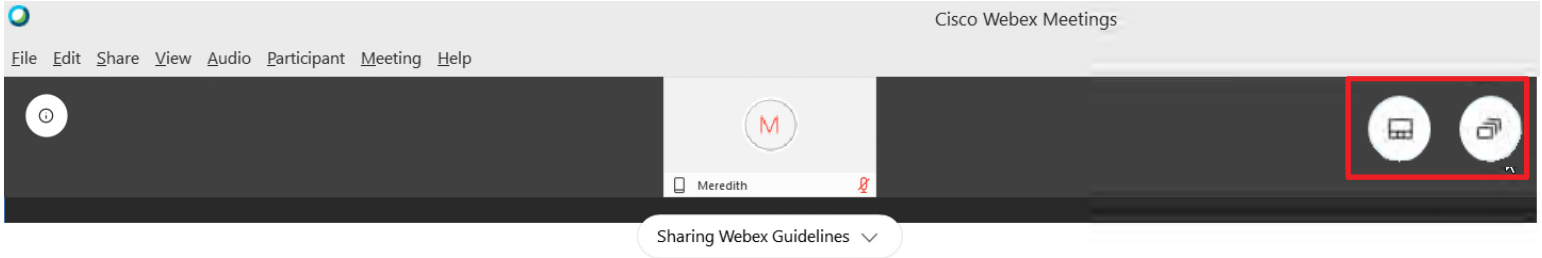


From the Participants list, **tap the panelist name** to send a private chat message.

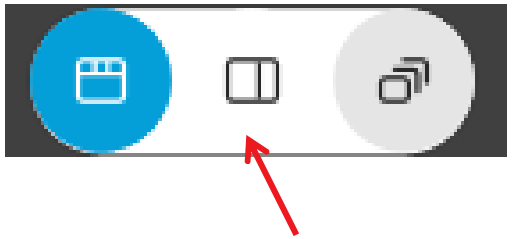
Depending on your device, button controls and screen layout may appear differently.

Changing Your View (desktop)

To change between view options in the Webex window, hover over the white circles in the top **right** corner of the Webex window.



Select one of the view options available:

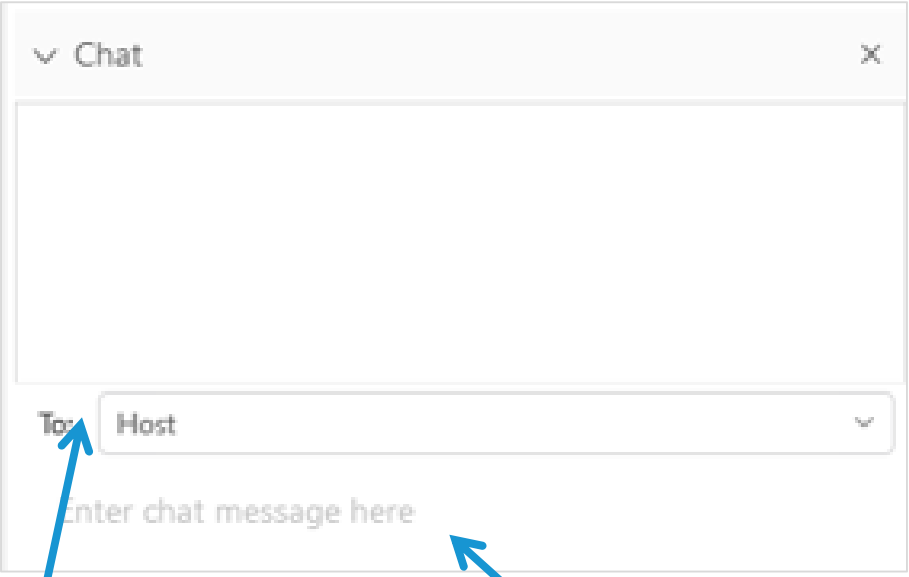


Side panel view recommended when presentation is displayed

Grid view recommended when no presentation is displayed

Technical issues

If you are experiencing technical issues, send a message via **Chat** to the **host**.



Select the **Host** from the **To** field.

Type your message in the space provided. Press **Enter** to send.

19th Annual
Participants Committee Summer Meeting
June 24, 2020 Session

NEW ENGLAND'S TRANSITION TO A FUTURE GRID: CHALLENGES & OPPORTUNITIES

In New England, and across the country and globe, vigorous discussions, analyses and debates are underway regarding how best to address the challenges and opportunities associated with the transition of the electric grid. In organized markets, the market participants, consumers and their advocates, environmentalists, state officials, and RTOs are examining the future of the grid, and the implications for wholesale electricity markets, in light of state environmental and energy policies and in the context of deep decarbonization goals, which will require electrification of many sectors of the economy and a very high deployment of clean energy/renewable resources, over the next two to three decades.

To promote a broader understanding of these issues and to assist and expand the understanding of stakeholders in New England, NEPOOL has invited four distinguished panelists who have been studying and working on these issues across the country, and in some cases across the world, to share their knowledge, experiences and thoughts. Detailed bios of each of the panelists are included with this outline. The panelists have been asked to discuss their views on the potential future implications for the bulk power system in connection with efforts to satisfy decarbonization goals that are being set by policy leaders. As best as possible given the virtual meeting format, at least 30 minutes has been reserved following presentations by the first and second panels for audience participation, questions, and comments.

Panel I: 8:30 AM - 10:25 AM
ASSESSMENT OF CHALLENGES ASSOCIATED WITH EVOLVING GRID SYSTEMS

SETTING THE STAGE

Presenter: ***Melanie Kenderdine***, Managing Principal, Energy Futures Initiative (EFI)

The morning panel will begin with a presentation by Ms. Kenderdine sharing with the group the various efforts studied by or with which EFI has been involved, regarding the evolving electric grid in light of changing technologies, public policies and priorities. Through building coalitions, thought leadership, and evidence-based analysis, Energy Futures Initiative is a not-for-profit organization founded by former Energy Secretary Ernest J. Moniz dedicated to driving innovation in energy technology, policy and business models to accelerate the transition to a clean-energy global economy. Ms. Kenderdine, a Managing Principal of EFI, and a non-resident senior fellow at the Atlantic Council, served at the Department of Energy from May 2013 - January 2017, as the Energy Counselor to the Secretary and concurrently as the Director of DOE's Office of Energy Policy and Systems Analysis.

RELIABILITY CHALLENGES

Presenter: ***James B. Robb***, President and Chief Executive Officer, North American Electric Reliability Corporation (NERC).

Jim Robb will continue the first morning panel discussion, sharing his views on potential future reliability challenges facing the industry with the expected transition to a future resource mix that, in New England and elsewhere, will see an accelerated penetration of variable resources. The North American Electric Reliability Corporation was founded in 1968 with the mission to assure the reliability and security of the North American bulk power system. Prior to assuming the role of President and Chief Executive Officer of NERC in April 2018, Mr. Robb held major leadership roles in the energy sector including as Senior Vice President of Enterprise Planning and Development at Northeast Utilities (now Eversource Energy).

Questions, Comments and Discussions Among Stakeholders

Break **10:25 AM - 10:35 AM**

Challenges Associated with Deep Decarbonization and Evolving Grid Systems

ENERGY FUTURES INITIATIVE

Melanie Kenderdine

NEPOOL Virtual Conference

June 24, 2020

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

ENERGY FUTURES INITIATIVE

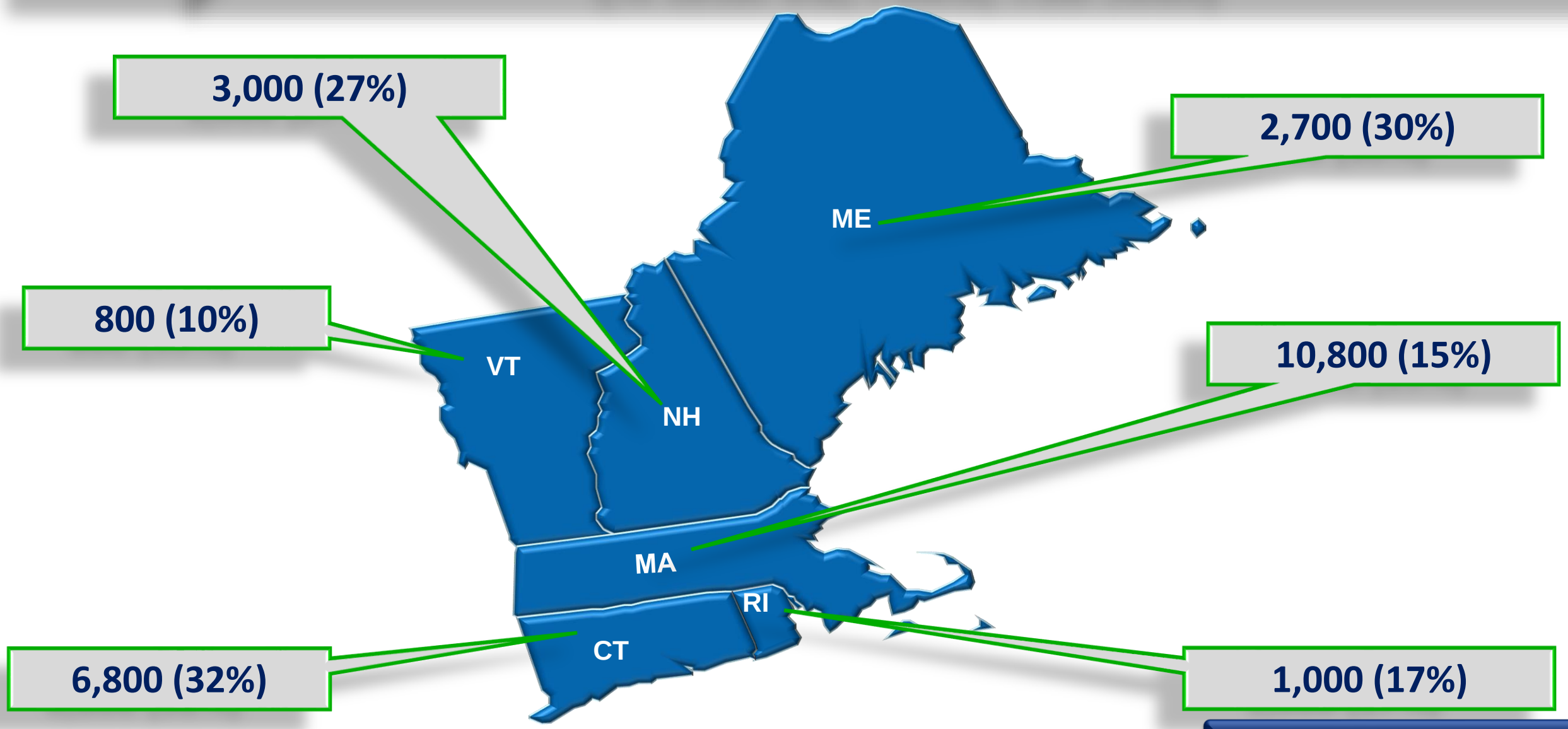
Ranking of Top 10 States, Highest to Lowest	Total Unemploy-ment Claims (03/16-05/02)	Claims as % of Workforce	Natural Gas and Oil Fuels Jobs Actual	Natural Gas and Oil Fuels Jobs as % of Workforce	Efficiency Jobs Actual	Efficiency Jobs as % of Workforce	Gas/Oil Generation Actual	Gas/Oil Generation as % 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

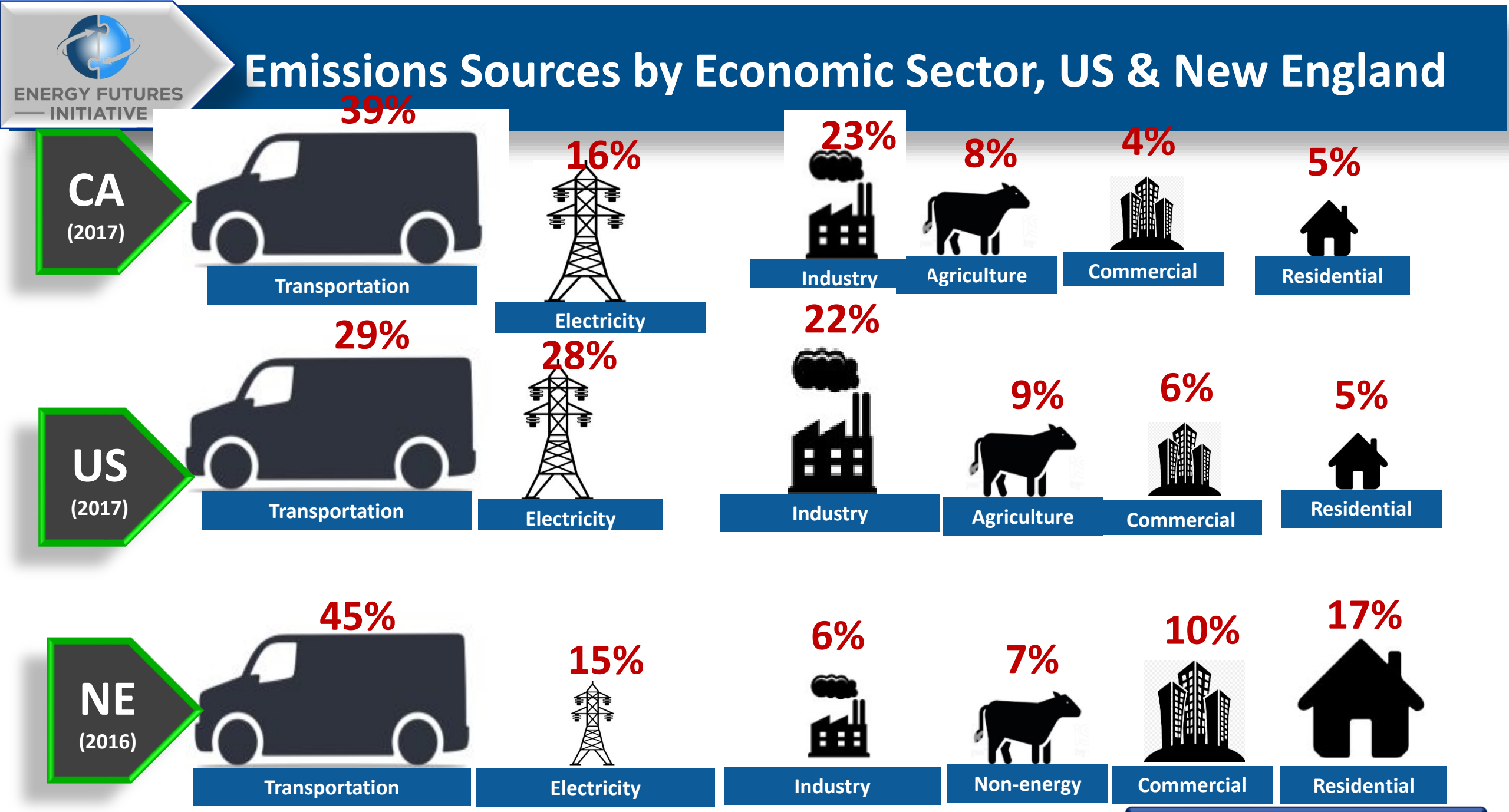
Source: BLS, USEER data, 2020

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



Source: USEER data, 2020

Emissions Sources by Economic Sector, US & New England



Source: EIA Website, accessed 02/18/20

Timeline of Key California Policies for GHG Reductions

2020

AB 32
Economy-wide GHG emissions equal to 1990 levels

SB 1383
50% reduction of organic waste disposed in landfills from 2014 levels

2023

SB 1275
One million zero-emission vehicles (ZEVs) or near-ZEVs

2025

SB 1383
75% reduction of organic waste disposed in landfills from 2014 levels

E.O. B-16-12
1.5 million ZEVs

2030

SB 32
Economy-wide GHG emissions 40% below 1990 levels

SB 1383
Reduce methane & HFCs 40% and black carbon 50% below 2013 levels

SB 100
60% renewables for electricity

SB 350
Double energy efficiency

E.O. B-48-18
5 million ZEVs

Low Carbon Fuel Standard
Carbon intensity of gasoline reduced 16.8%, diesel 14.9%, and jet fuel 10.1% below 2011 levels*

2045

E.O. B-55-18
Economy-wide carbon neutrality & net negative emissions thereafter

SB 100
100% zero-carbon electricity

2050

E.O. S-3-05
Economy-wide GHG emissions 80% below 1990 levels

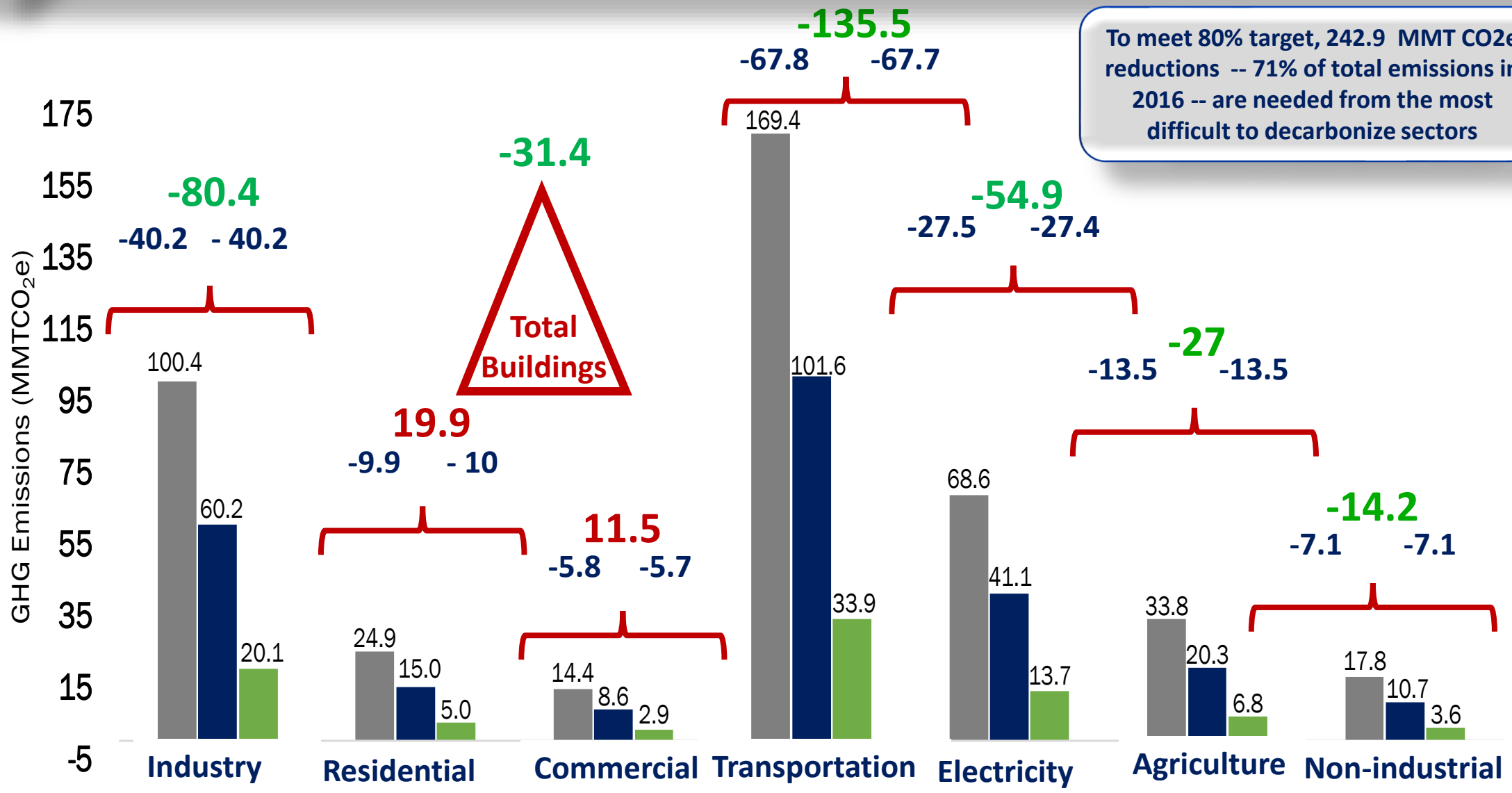
E.O. B-16-12
Transportation sector GHG emissions 80% below 1990 levels

**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*

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

ENERGY FUTURES INITIATIVE

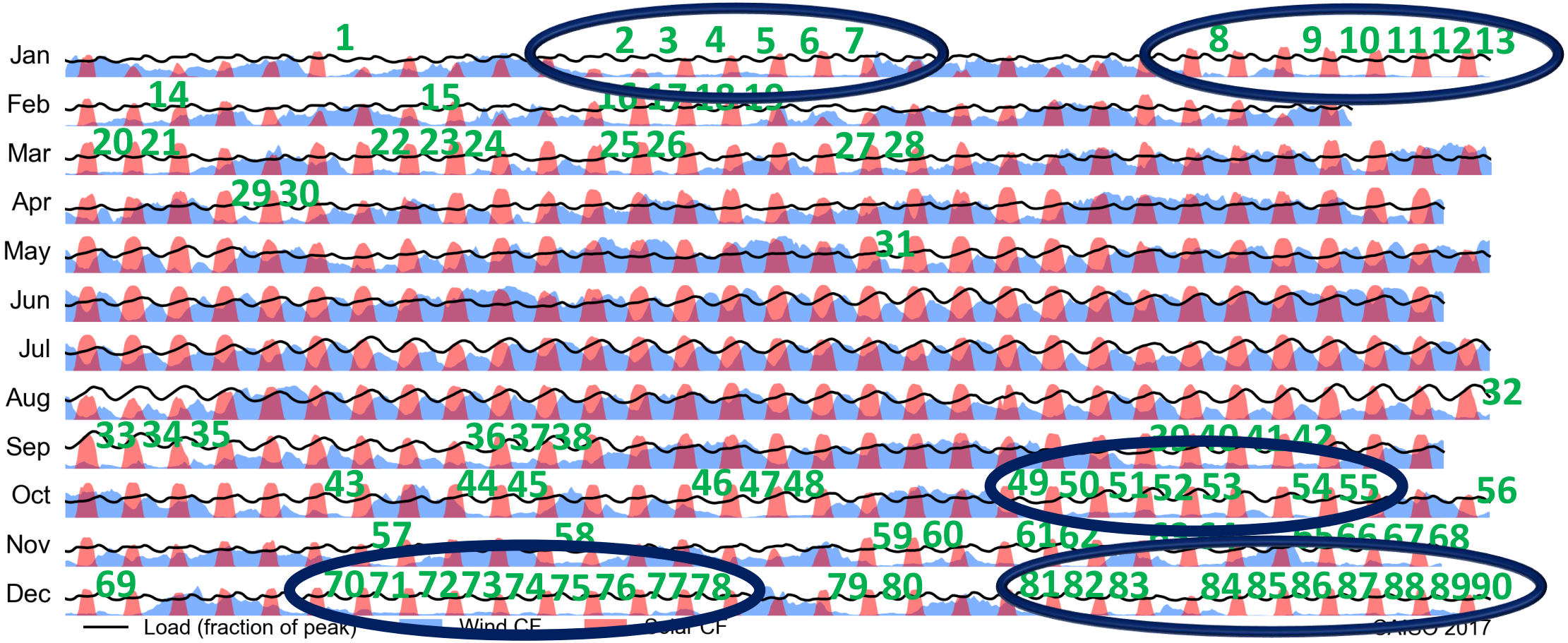
To meet 80% target, 242.9 MMT CO2e reductions -- 71% of total emissions in 2016 -- are needed from the most difficult to decarbonize sectors



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

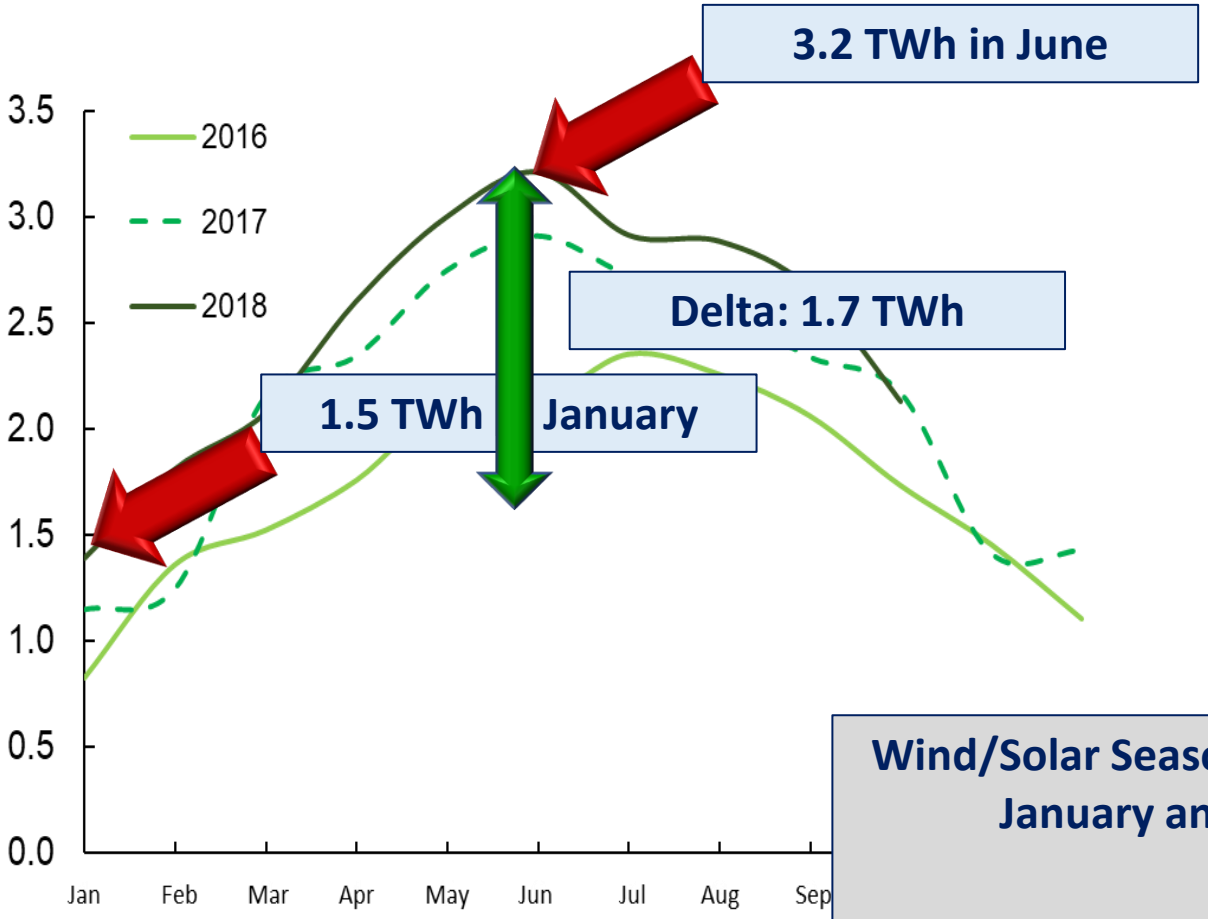


Hourly trends in solar and wind capacity factors in CA for 2017 aligned to normalized variation in hourly load relative to peak daily load

Source: CAISO data, EFI analysis

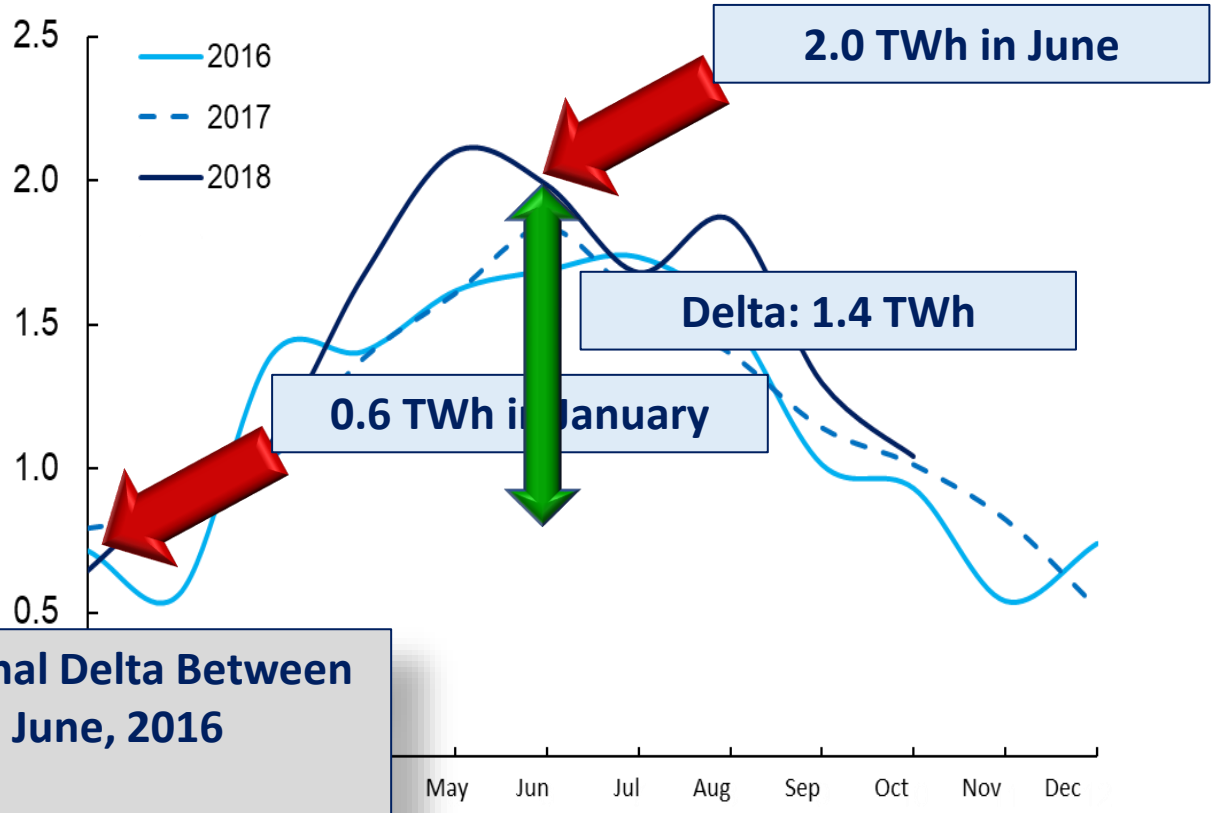
Seasonal Variation in Solar & Wind in CA, 2016

Metered Solar Generation



Source: EFI, compiled using data from CAISO

Wind Generation

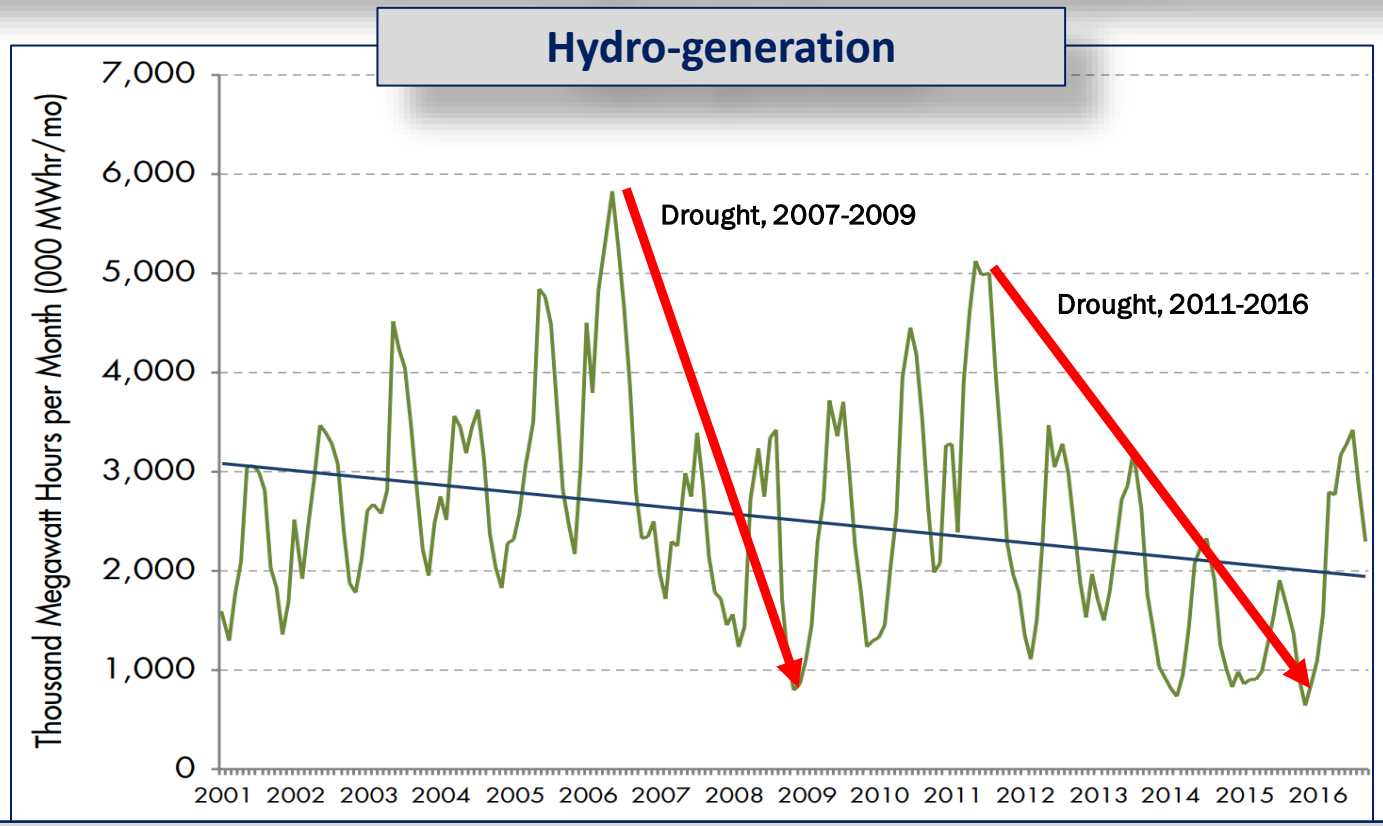


Wind/Solar Seasonal Delta Between January and June, 2016

3.1 TWh

California Study

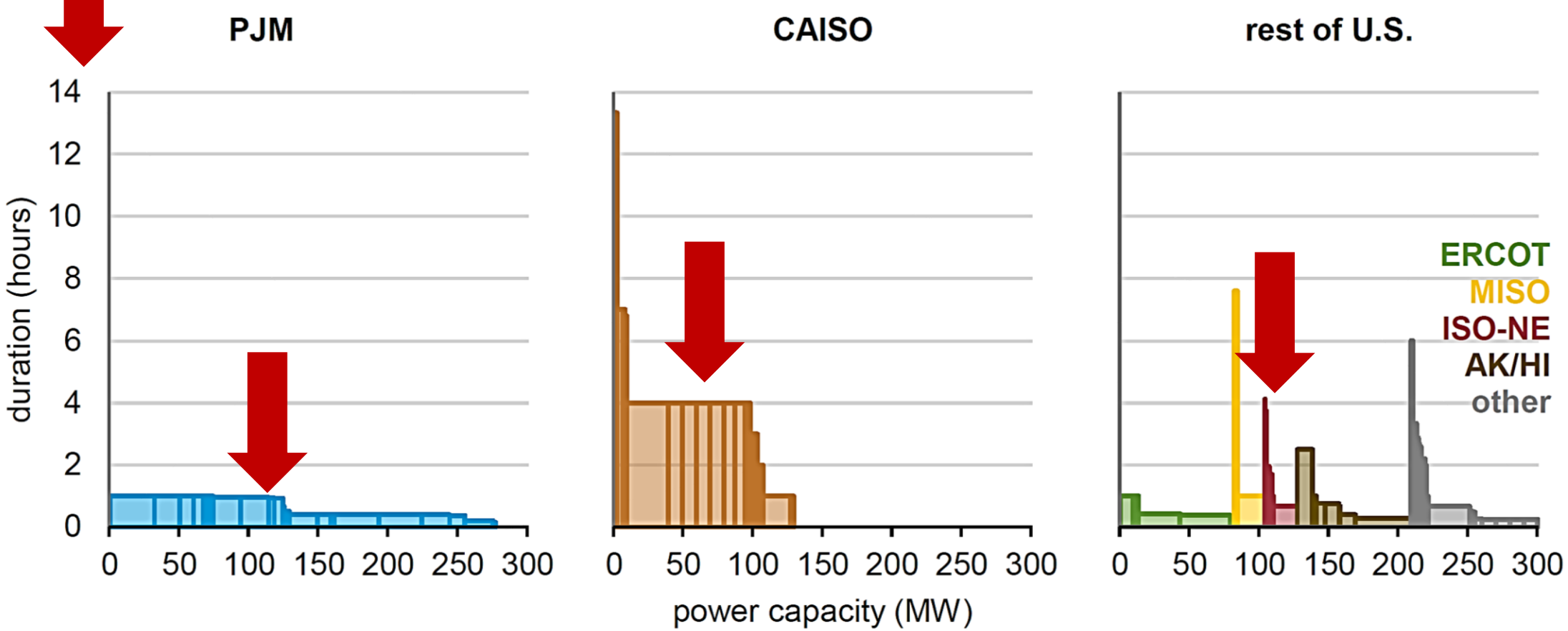
Impacts of Drought (and Climate Change) on Hydro Generation



…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

ENERGY FUTURES INITIATIVE

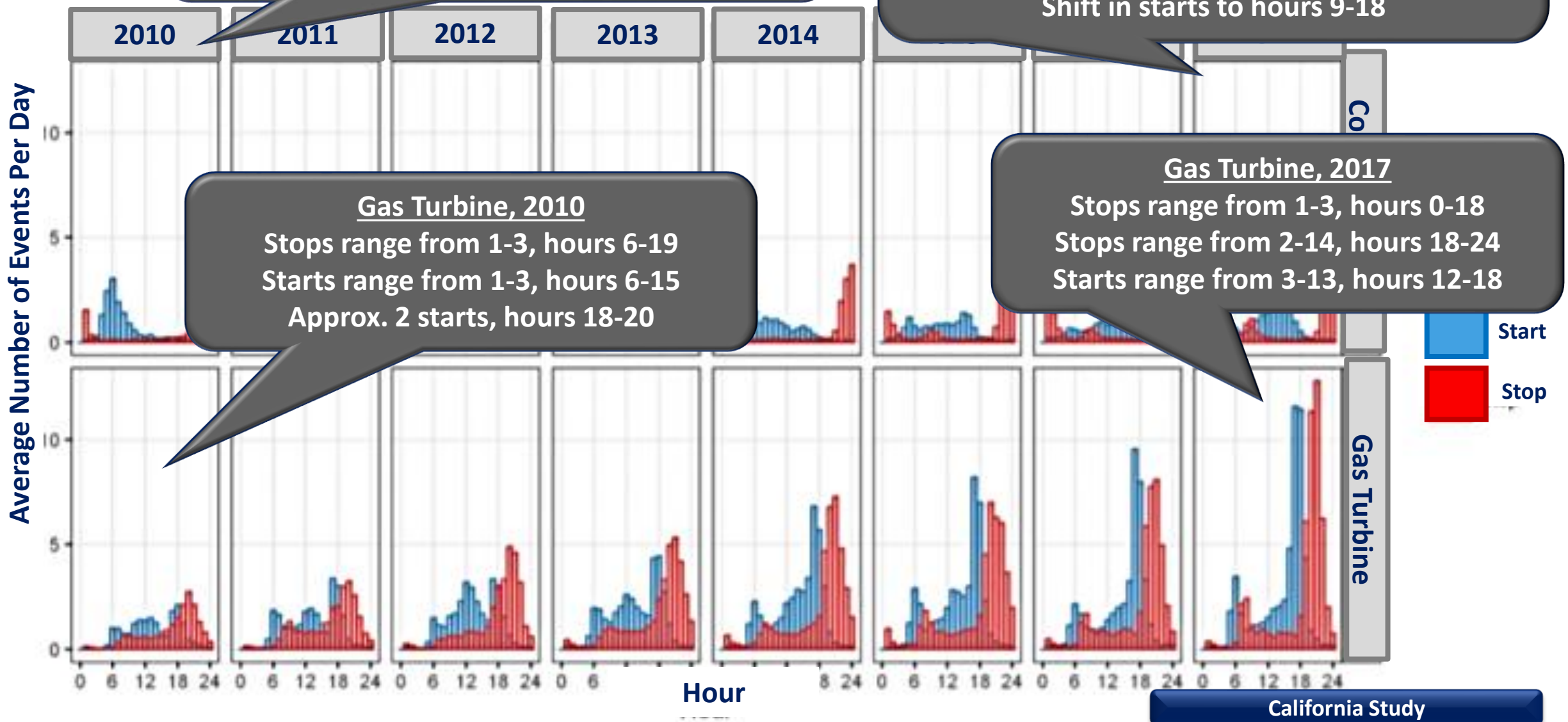
Hourly average start and st
showing CC unit starts shi
ups. Source: EFI, 2019. Co

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

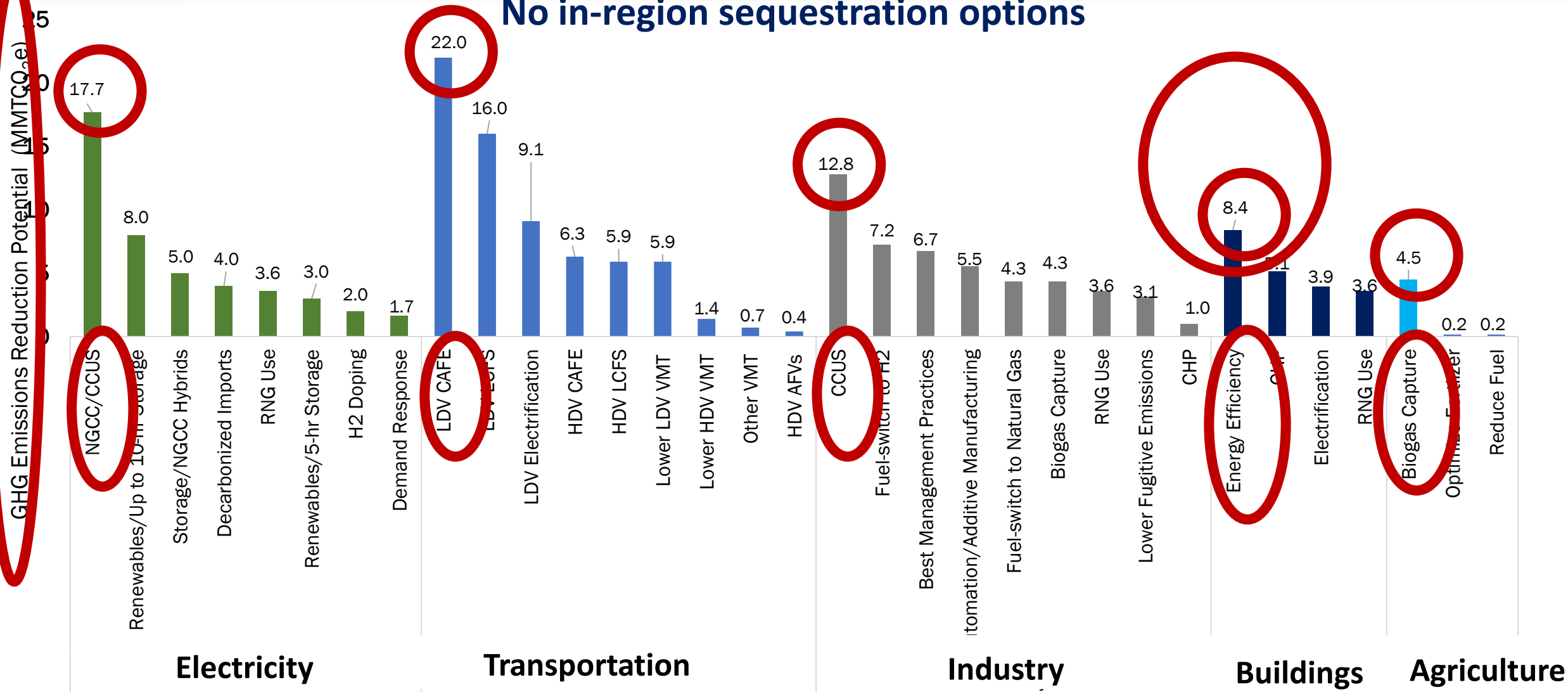
Gas Turbine, 2017
Stops range from 1-3, hours 0-18
Stops range from 2-14, hours 18-24
Starts range from 3-13, hours 12-18



California Study

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

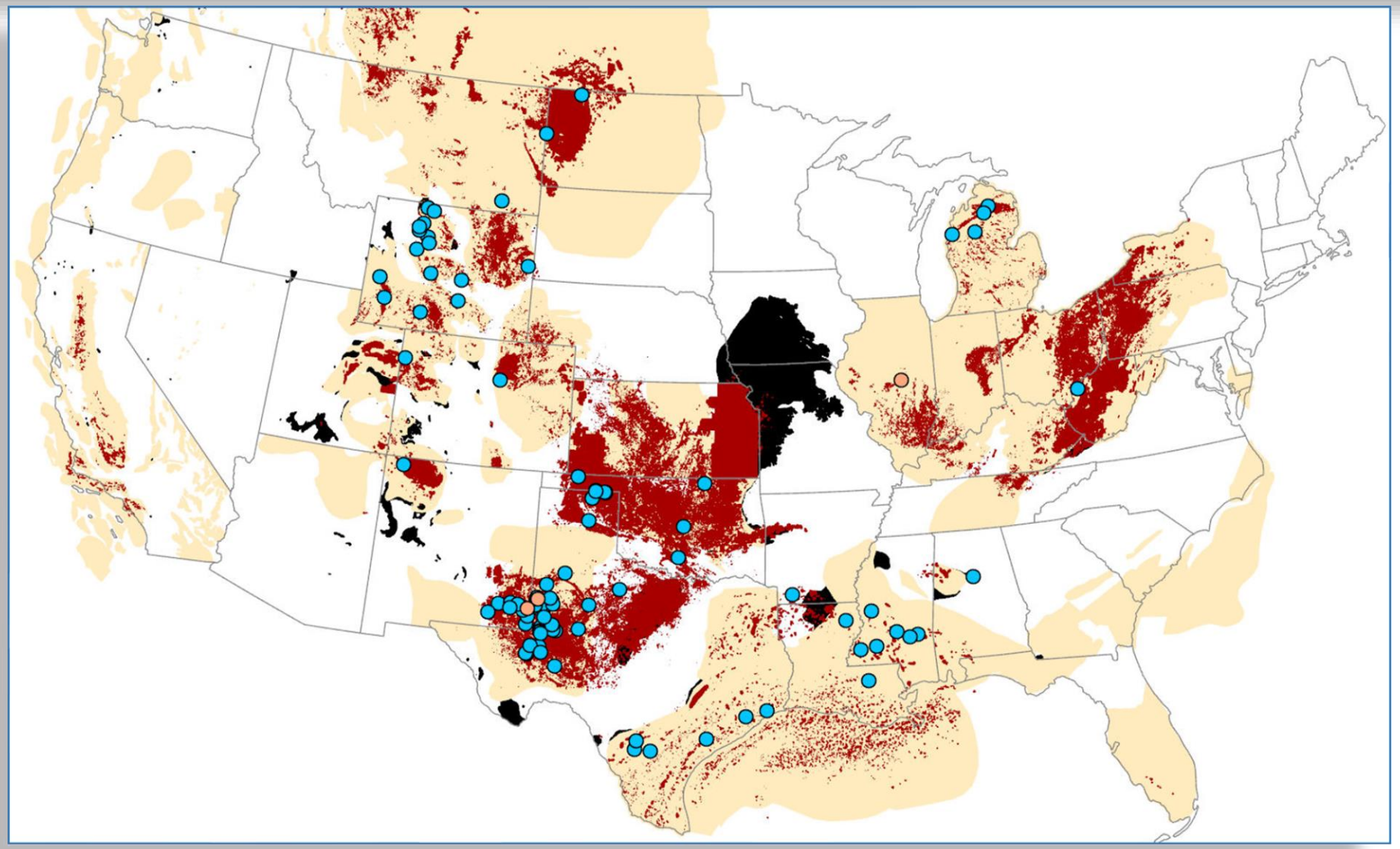
No in-region sequestration options



Source: EFI analysis

California Study

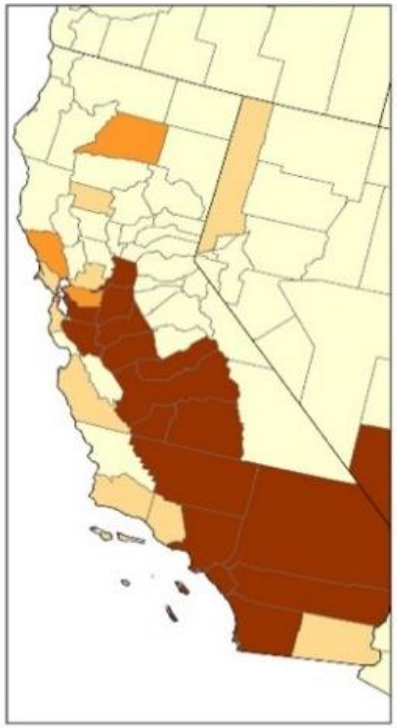
US Subsurface Sequestration Potential

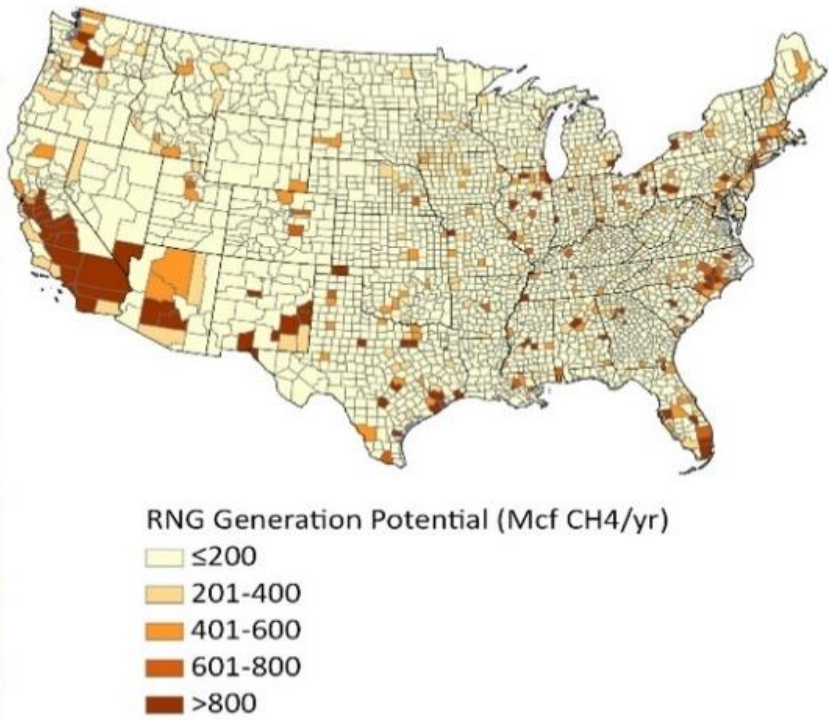


Source: EFI analysis

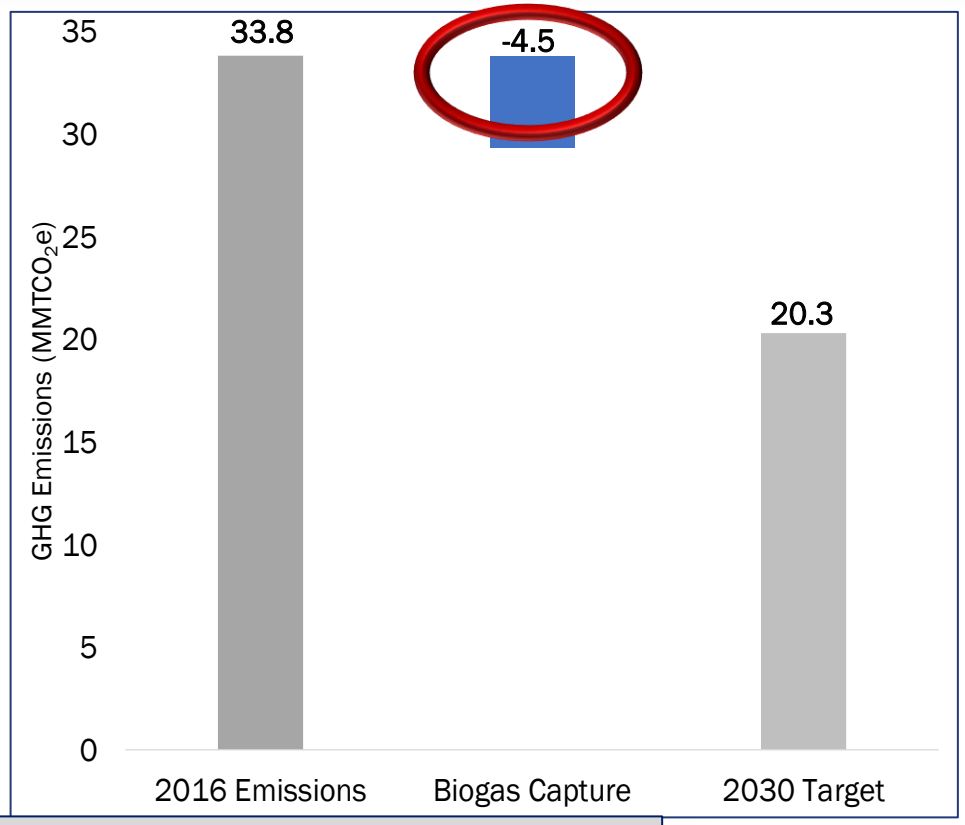
Biogas/Renewable Gas for Decarbonizing Agriculture Sector

RNG Generation Potential in California (Mcf CH_4/year)





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.

Source: EFI Analysis

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)

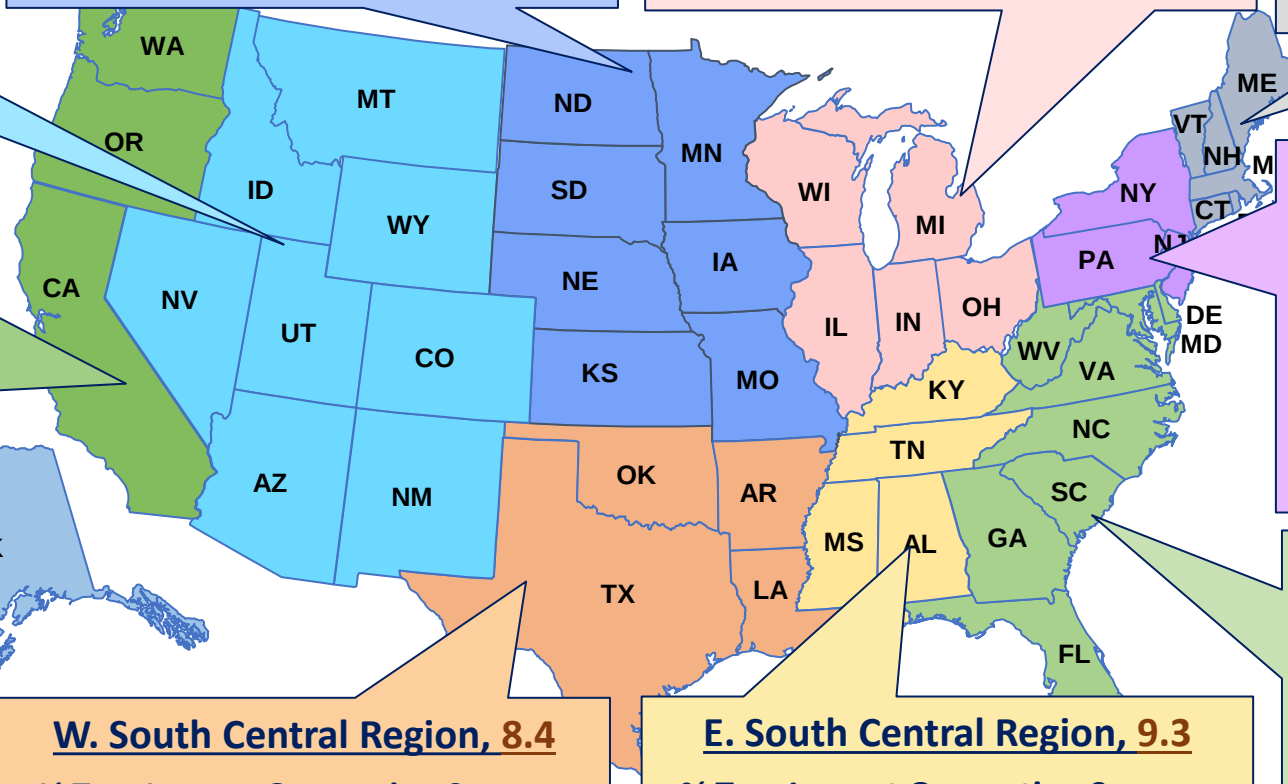
Pacific Contiguous, 13.8

% 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

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)

South-Atlantic Region, 9.9

% Two Largest Generation Sources

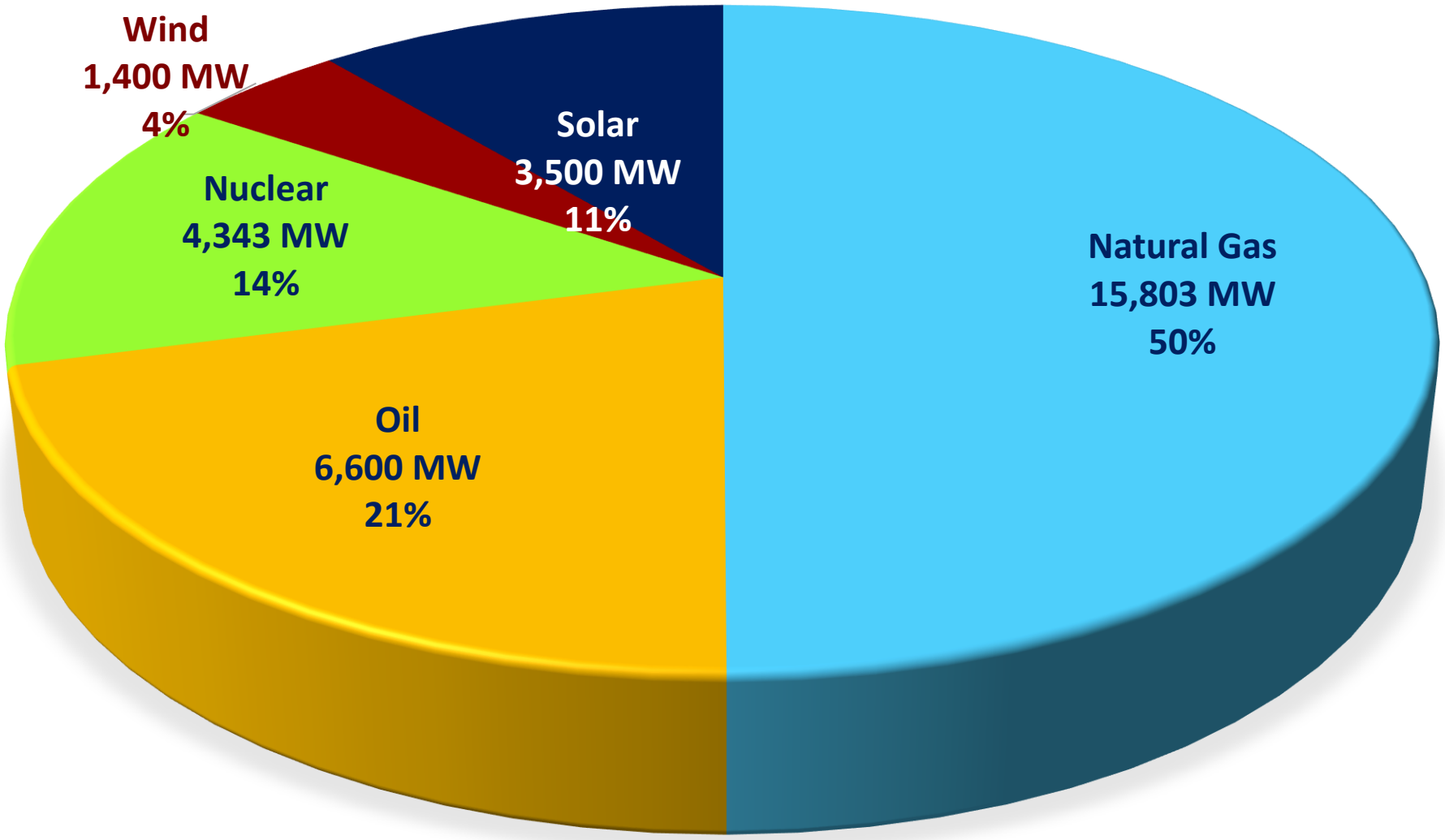
68.9% (N. Gas, 44.1, Nuclear, 24.7)

% Non-Hydro Renewables

4.4% (Wind, 0.3, Solar, 1.7)

New England Electric Grid

Installed Capacity in New England, 2019 (MW)



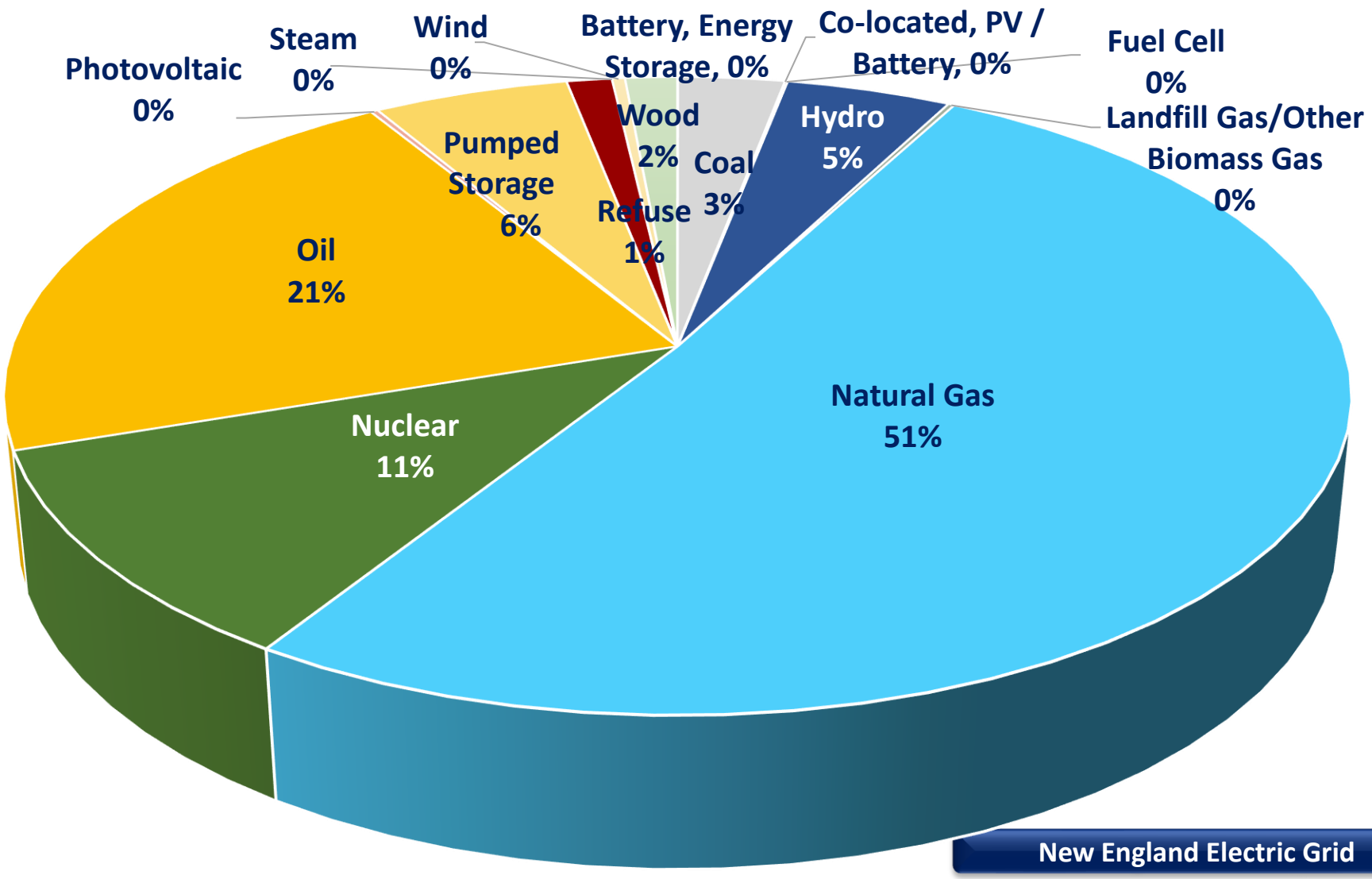
Sources: ISO-NE Website

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

Summer Capacity Supply, 2019 (MW)

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

New England Electric Grid

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

ENERGY FUTURES INITIATIVE

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

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**

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

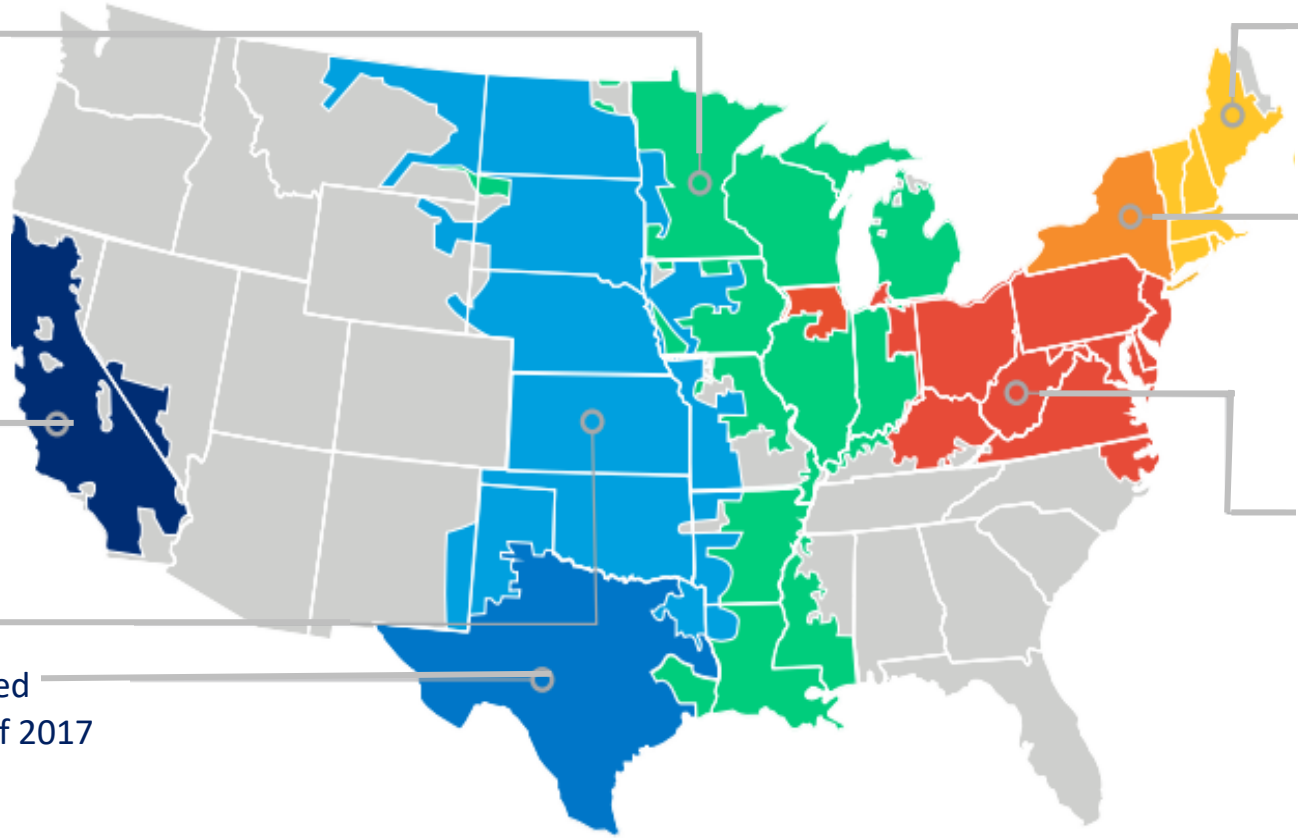
...we need an even greater focus on demand response

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

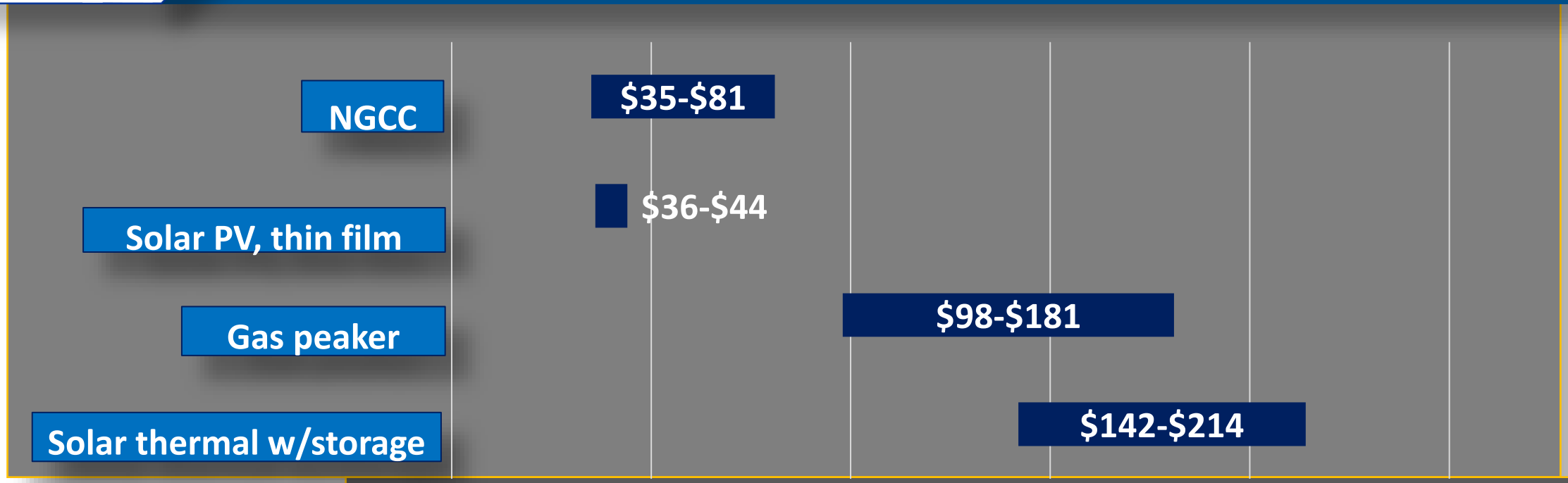
Offshore Wind → $138.0

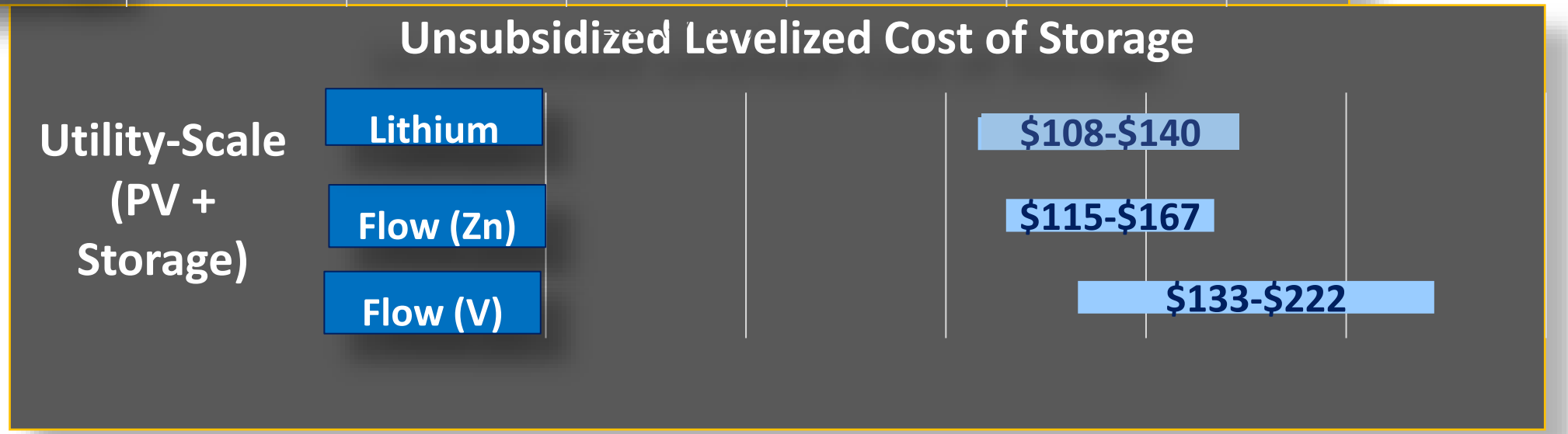
Solar Thermal → $165.1

LCOS ($/MWh)

LCOE Source: EIA

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



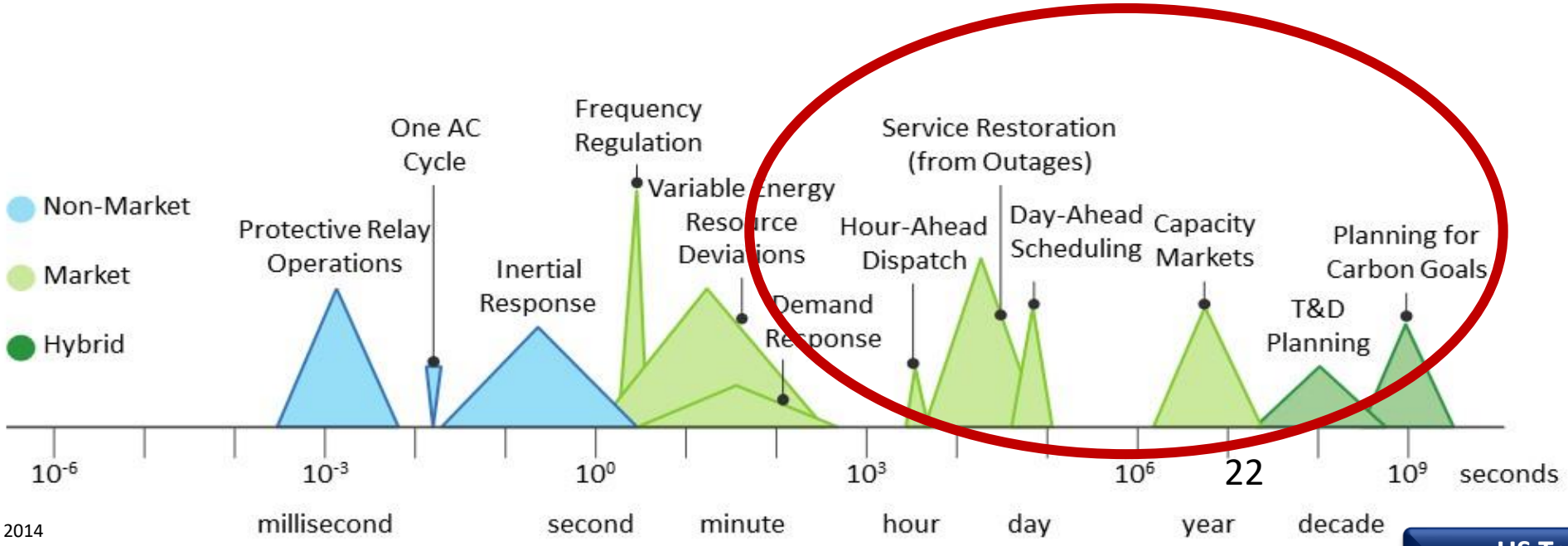


Source: Lazard, Levelized Cost of Energy Analysis, Version 4.0, 2018

Evolving Requirements for System Operations

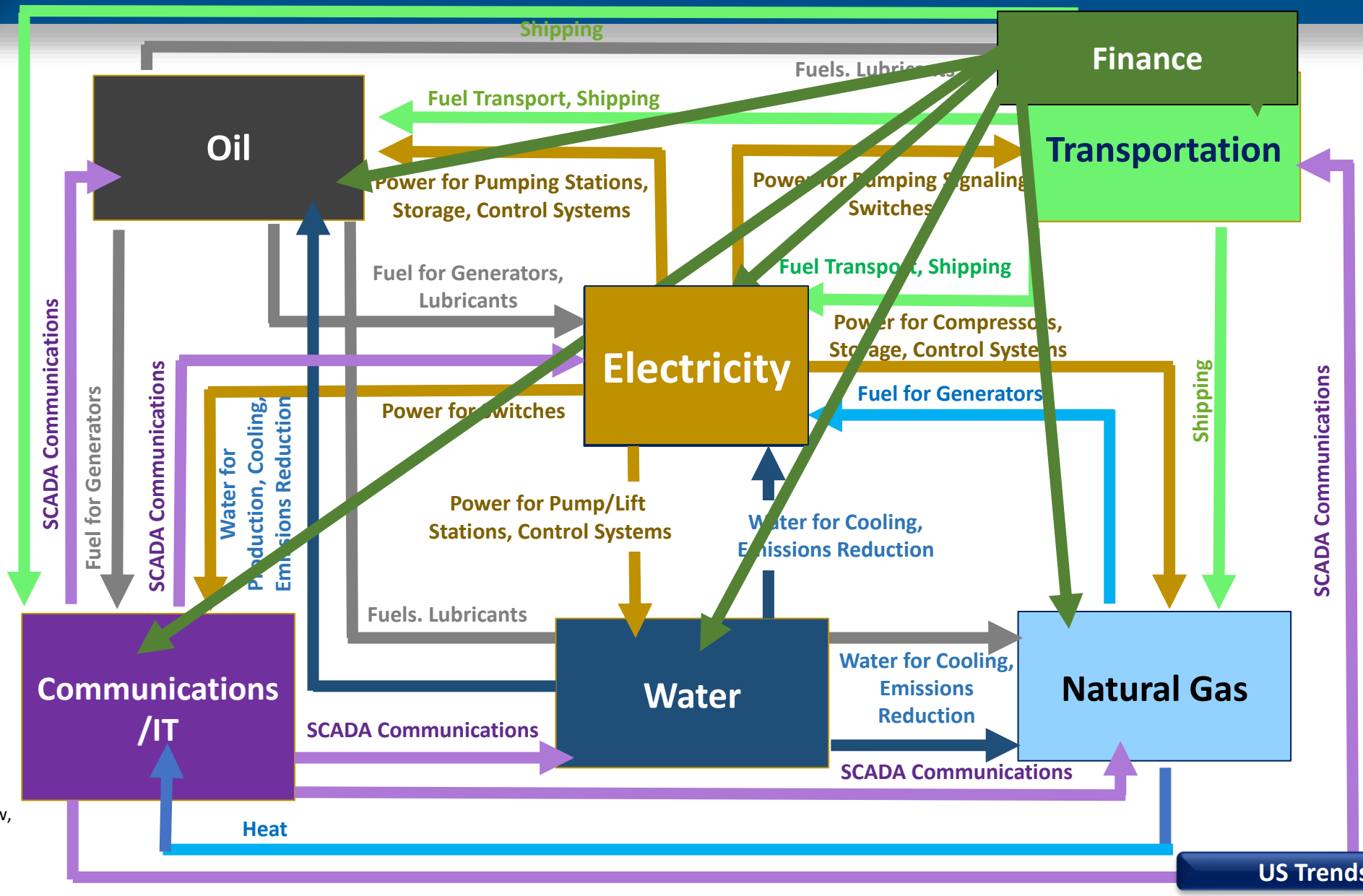
- The widespread integration of VERs at both utility scale and distributed across all consumer segments significantly expands the time dimensions in which grid operators must function and complicates operations.
- Dispatch effectiveness will require the integration of automated grid management with continuing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

System Reliability Depends on Managing Multiple Event Speeds



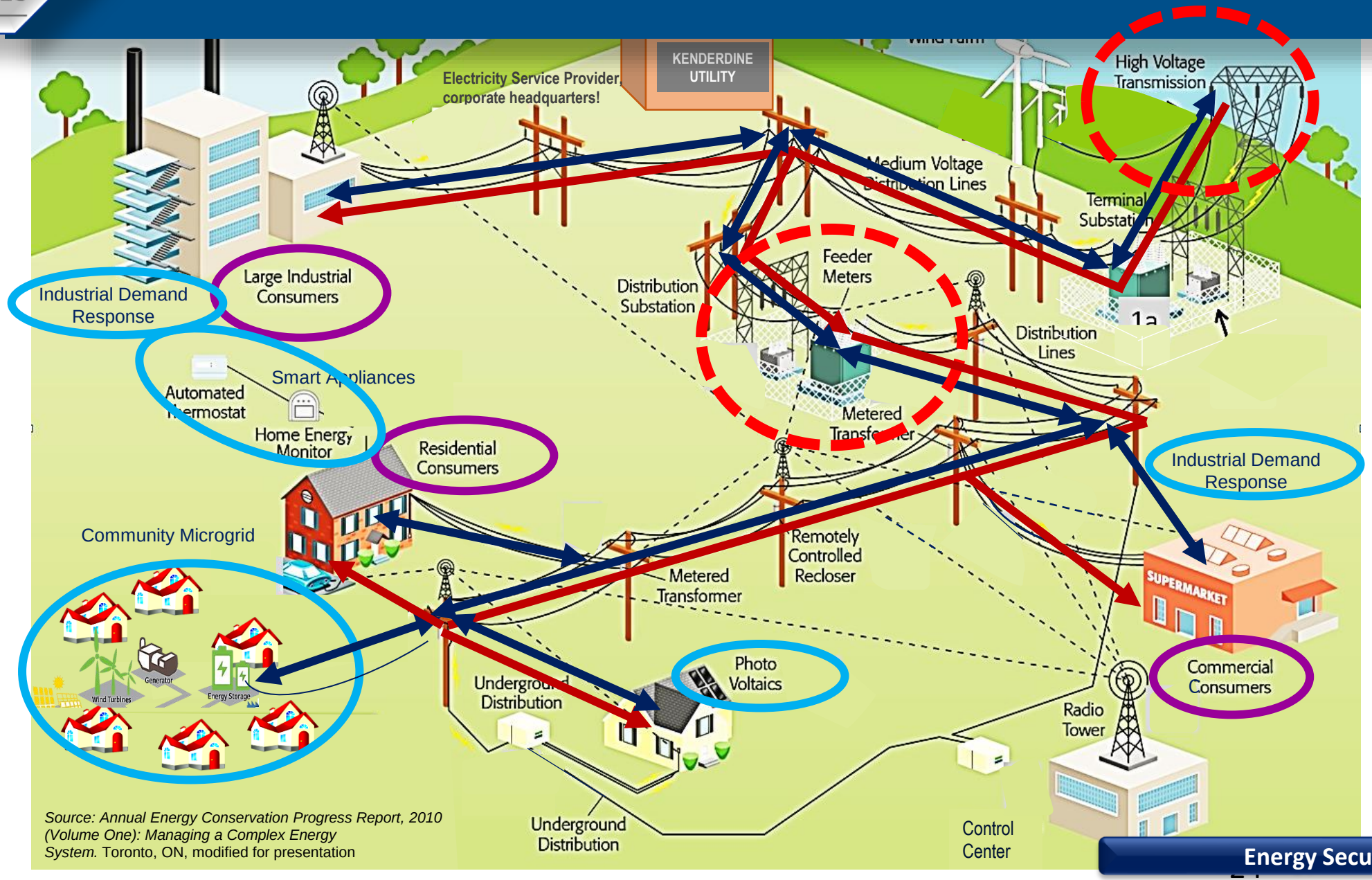
Source: von Meier, 2014

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

ENERGY FUTURES INITIATIVE

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-

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

ENERGY FUTURES INITIATIVE

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 2018[e]	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	6,800	[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 2018[e]	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 2018[e]	Reserves[8]
United States	22,100	19,000	110,000
[illegible]	129,000	120,000	[illegible]
Brazil	78,600	80,000	11,000,000
Canada	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
Guatemala	53,700	49,000	[illegible]
Indonesia	345,000	560,000	21,000,000
Madagascar	41,700	30,000	1,000,000
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

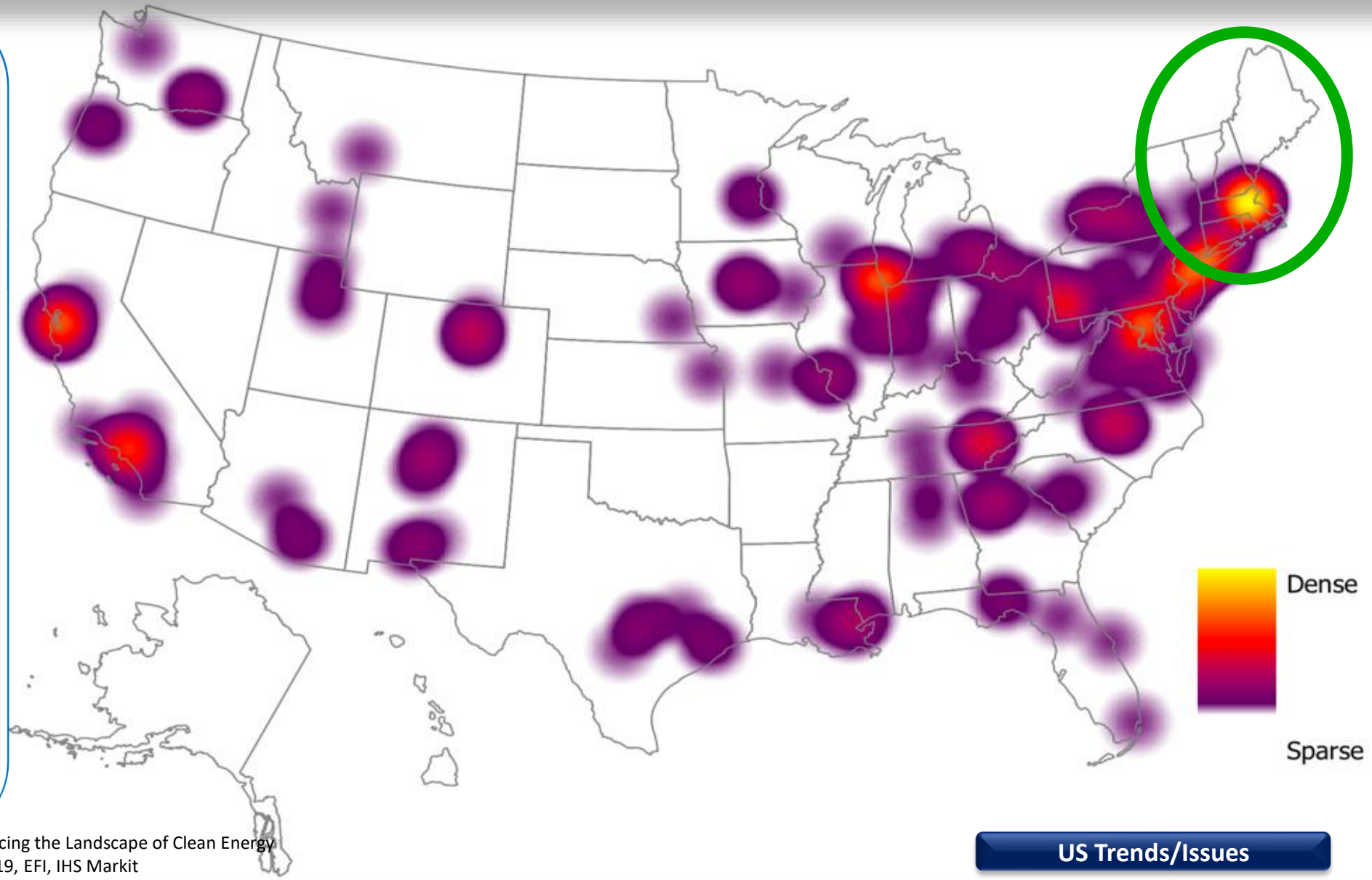
Source: USGS, 2019

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

EFI Clean Energy Innovation Index

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

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.

ENERGY FUTURES INITIATIVE

MELANIE KENDERDINE

Managing Principal

Melanie Kenderdine is a Principal of Energy Futures Initiative (EFI) and a non-resident Senior Fellow at the Atlantic Council. She is also currently a Visiting Fellow at the Energy Policy Institute at the University of Chicago (EPIC), and a Principal of EJM Associates, LLC.

She worked in the Administration of President Barack Obama at the Department of Energy from May 2013–January 2017 as the Energy Counselor to the Secretary and concurrently was the Director of DOE's Office of Energy Policy and Systems Analysis. Her 100-person office was responsible for analysis and policy development in areas that included: DOE's role in the annual review of the Renewable Fuel Standard Program requirements, energy innovation, and climate change. Her office produced two installments of the Quadrennial Energy Review and helped conceive and develop the Energy Security Principles adopted by G-7 leaders in 2014. In her capacity as Energy Counselor to the Secretary, Kenderdine helped create Mission Innovation, now a 24-country/European Union initiative that supports transformational clean energy RD&D; North American grid integration and security; and the modernization of the Strategic Petroleum Reserve.

Prior to her service at DOE, Kenderdine helped establish the MIT Energy Initiative (MITEI) and served there as Executive Director. During her six-year tenure at MITEI, she managed a large research and administrative staff, was a key contributor MIT's Future of Natural Gas Study, the MITEI Symposium Report on Alternative Fuels and Vehicles and edited the MIT Future of the Electric Grid study. Kenderdine also started the C3E Symposium series, a joint MIT-DOE program to support the careers of women in clean energy with cash prizes; she still serves as a DOE C3E Ambassador.

Before joining MITEI, she was Vice President of Washington Operations for the Gas Technology Institute (GTI) from 2001 to 2007. While at GTI, Kenderdine established a separate not-for-profit company, the Research Partnership to Secure Energy for America (RPSEA). As RPSEA's first CEO, she transformed it from an MOU between GTI and one university, to an industry/academic unconventional natural gas research consortium of 26 universities and 30 industry partners. Concurrently, she was a key architect of the Royalty Trust Fund, the only federal trust fund dedicated to energy R&D.

From 1993 to 2001, Kenderdine was an appointee in President Bill Clinton's administration, where she served in several key posts at DOE, including Senior Policy Advisor to the Secretary, Bill Richardson, Director of the Office of Policy, and Deputy Assistant Secretary for Congressional and Intergovernmental Affairs.

She was a primary architect of the SPR oil exchange of 2000, the creation of the Northeast Home Heating Oil Reserve, and the return of the Naval Oil Shale Reserve No. 2 to the Ute tribe in Utah, the largest land transfer back to Native Americans in the lower 48 in over 100 years. Prior to joining DOE, Kenderdine was Chief of Staff and Legislative Director for then-New Mexico Congressman Richardson.

Kenderdine is currently on the Board of Our Energy Policy.Org , the Alliance to Save Energy, and the American Council for an Energy Efficient Economy . She is also a non-resident Senior Fellow at the Atlantic Council and currently serves as Board Chair of the Alliance of Hope, a nation-wide support network for survivors of suicide. She is a graduate of the University of New Mexico, has homes in New Mexico and Hawaii, and is an avid global traveler and enthusiast of fly fishing.

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BPS Reliability Perspectives for 2050

Jim Robb, President and Chief Executive Officer
New England Power Pool
June 24, 2020

RELIABILITY | RESILIENCE | SECURITY




About NERC

Mission: To assure the effective and efficient reduction of risks to the reliability and security of the North American bulk power system

- Develop and enforce reliability standards for users, owners, and operators of the bulk power system
- Assess current and future reliability
- Analyze system events and recommend improved practices
- Encourage active participation by all stakeholders
- Facilitate information sharing on security matters
- Accountable to FERC and Canadian government entities

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Electric Reliability is Complicated

Grid 1.0
Isolated Systems

Late 1800s - 1940s

- Urban area focus
- Largely self-contained utilities

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Electric Reliability is Complicated

Grid 1.0
Isolated Systems

Grid 2.0
Interconnected Systems

Late 1800s - 1940s

- Urban area focus
- Largely self-contained utilities

Post World War II

- Large, central station generation
- Long lines to support interconnected flows/ resource sharing
- Instantaneous load/resource balancing
- Significant coordination needs (incidents at speed of light)

And Getting More So …

Grid 1.0 Isolated Systems	*Grid 2.0 Interconnected Systems*	***Grid 3.0 Integrated Systems***
Late 1800s - 1940s	***Post World War II***	***Now - Future***

• Urban area focus
• Largely self-contained utilities
	• Large central station generation
	• Long lines to support interconnected flows/ resource sharing
	• Instantaneous load/resource balancing
	• Significant coordination needs (incidents at speed of light)
		• More load variability
		• Shift in fuel mix
		  ▪ Just in time gas
		  ▪ Variable wind /solar
		  ▪ Solid fuel retirement
		• Expansion of digital controls/ “behind meter devices”
		• Future:
		  ▪ Battery deployment
		  ▪ Deep electrification

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Where Could We Be In 30 Years?

In 30 years, technology issues can be assumed away

- Battery storage could be economical **and** scaleable
  - Grid scale
  - Distributed/end use
- Off shore wind could be a major generation source in New England
- Small/modular nuclear reactors could be deployable
- Hydrogen and fuel cells?

That said, a reliable electric system will have a number of "physics-based" characteristics

- Maintain frequency and voltage within narrow parameters
- Adequate flexibility to follow loads and minimize system disturbances
- Adequate capacity and *adequate fuel* to serve load

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Key Technology Bets – Next 30 years

Smart Inverters

- As we replace MWs from conventional generation, we also need to replace the essential reliability services needed to maintain system reliability
- Inverters and new electronic controllers can:
  - Mimic physical inertial properties
  - Provide near instantaneous response to support grid stability
  - Optimize and manage charging cycles on batteries based on grid needs
  - Work in aggregate to achieve the same objectives as conventional generation
- But …
  - They are not “plug and play”
  - Much more difficult to model
  - Less reliance on physics, and more reliance on software code
  - Need performance incentives/rules to support reliable behavior

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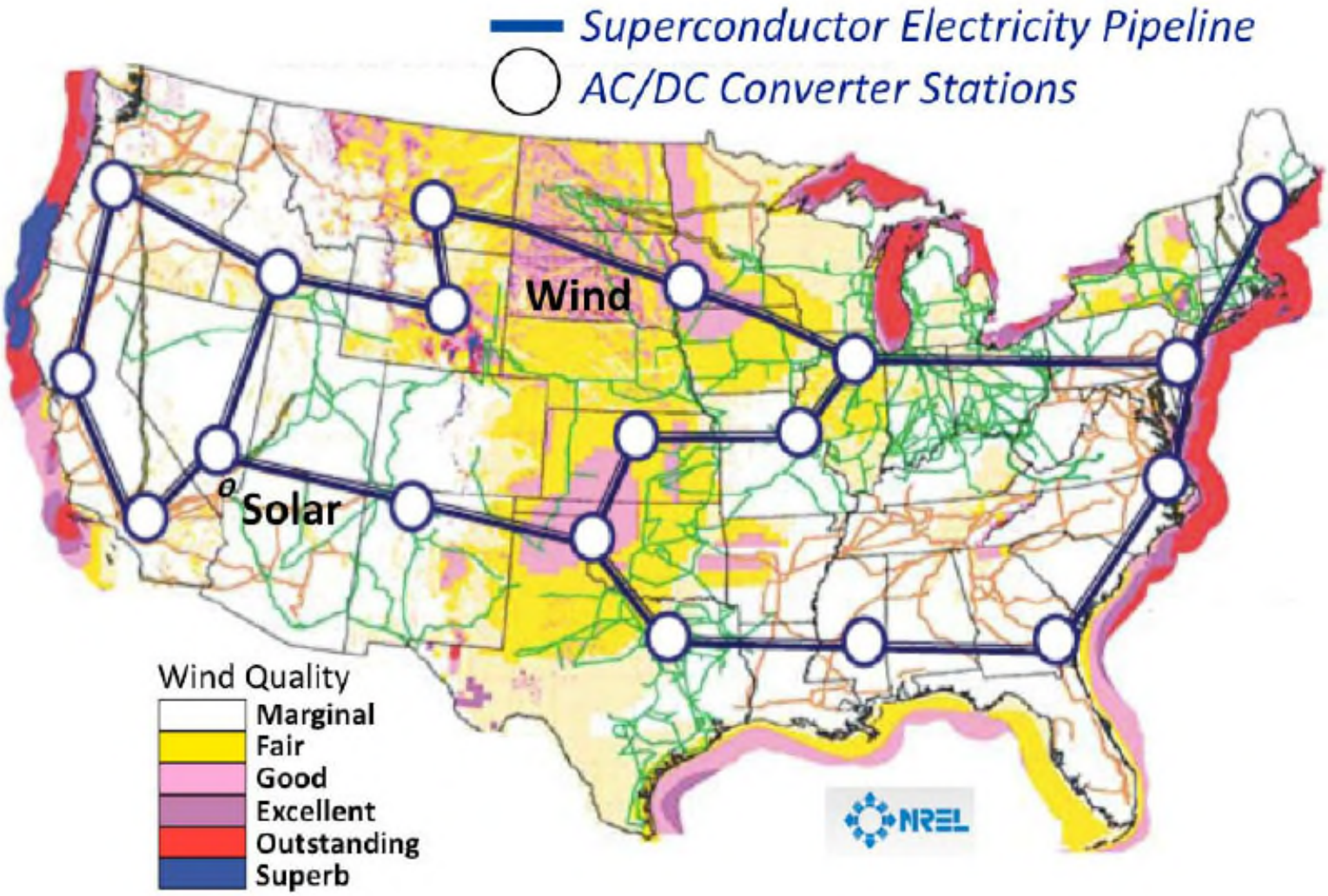
Role of Transmission System:
Bulk Power System as a Super Highway



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Until Then – Gas Remains a Critical Fuel

1980s	*1990s-2000s*	*Foreseeable Future*
An Economic Choice	An Environmental/ Efficiency Opportunity	A Reliability Requirement
• Easy to modify steam plants to burn gas • Gas prices often favorable to bunker fuel • Utilities developed switching capabilities • Gas and electric customers benefit	• Gas emissions substantially lower than fuel oil • Combined cycle technology substantially reduced heat rates • "Dual fuel" capability eliminated in many jurisdictions	• Public policy focus on clean resources, especially solar • Key dispatchable and flexible resource to balance variable generation • Substantial changes to BPS power plant operations profiles due to "duck curve" and ramp rate impact • Declining volumes but substantial peak needs result in an economic/pricing problem and create a key vulnerability

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Transitional Reliability and Energy Policy:
Bridging the Gap on an Evolving System

Key Issues

- Timing of technology development and deployment, especially batteries
- Pace of "deep" electrification
- Gas ratemaking/ regulatory treatment

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Getting to the "End State"

- **Substantial investment in technology (especially batteries) and transmission**
- **New planning and operating tools**
  - Much more dynamic and stochastic – opportunity for AI?
  - Focus on fuel and energy adequacy, not just capacity/resource adequacy
  - Less centralized resource planning; more focus on enabling resource access
- **Improved situation awareness and visibility**
  - Real underlying loads
  - Real generation capability
- **Integrated cyber defenses**
  - "Design in" vs. "bolt on"
  - Understanding and securing new attack vectors and attack surfaces across a more distributed system

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Questions and Answers

James B. Robb

President and Chief Executive Officer

James B. Robb assumed the role of president and chief executive officer of NERC in April 2018.

Mr. Robb oversees NERC's mission of assuring the reliability and security of the North American bulk power system. As president and CEO, Mr. Robb directs key programs affecting more than 1,400 bulk power system owners, operators, and users, including mandatory NERC Reliability Standards, compliance monitoring, enforcement, situational awareness, event and risk analysis, reliability assessments and forecasting, cyber and physical security, and government relations. Mr. Robb also oversees the operations of the Regional Entities who support the reliability mission across North America.

From 2014 to 2018, Mr. Robb served as president and CEO of the Western Electricity Coordinating Council (WECC) where he was responsible for the strategic direction and leadership of all of WECC's activities.

Mr. Robb has more than 30 years of experience in the energy sector as an engineer, a consultant, and a senior executive. Prior to becoming WECC's CEO in 2014, he held three major leadership roles in the industry at Northeast Utilities (now Eversource Energy) as senior vice president of Enterprise Planning and Development; at Reliant Energy (now part of NRG Energy) where he served as senior vice president of Retail Marketing for the competitive retail business in Texas and the Northeast; and at McKinsey & Company where he was a partner and the leader of the West Coast's Energy and Natural Resource Practice. During his 15-year career at McKinsey, he worked closely with prominent electric power companies in California, western Canada, the Pacific Northwest, and the Rocky Mountain states, as well as with some of the region's largest energy consumers.

Mr. Robb earned a bachelor's degree in Chemical Engineering from Purdue University in Indiana and a master's degree in Business Administration from the Wharton School of Business at the University of Pennsylvania, Philadelphia, PA.

Panel II: **10:35 AM – 12:30 PM**

POTENTIAL FUTURE PATHWAYS AND THEIR IMPLICATIONS

WHAT PATHWAYS HAVE OTHERS CHOSEN OR ARE THEY CONSIDERING?

Presenter: ***Frank Felder, PhD***, Director of the Center for Energy, Economic and Environmental Policy (CEEEP) at Rutgers University and Director of the Rutgers Energy Institute (REI).

Dr. Felder, who teaches students from around the world on various electric energy market structures, will begin Panel II describing various market frameworks and how those frameworks contemplate and are compatible with the implementation of state energy and environmental laws, consistent with reliable power system operations.

INVESTING IN THE FUTURE

Presenter: ***Scott Kushner***, Managing Director, John Hancock Infrastructure Investments

Based on the morning's discussions, Mr. Kushner will explore the considerations involved with deciding where to invest, either debt or equity, given the various market structures identified and discussed. He will discuss how changing public policy affects those decisions. John Hancock is a major investor in the electric power industry across a broad range of debt and equity instruments, from utility first mortgage bonds to debt and equity investments in renewable technologies on its own behalf and through private equity funds that it manages. Mr. Kushner leads teams of investment professionals in evaluating, structuring, negotiating and closing those investments.

Questions, Comments and Discussions Among Stakeholders

End Session **12:30 PM**

RUTGERS UNIVERSITY
Edward J. Bloustein School
of Planning and Public Policy

NEPOOL Participants Committee
Summer Meeting

What Pathways Have Others Chosen Or Are Considering

Frank A. Felder

ffelder@ejb.rutgers.edu

National Science Foundation Award: CMMI 1825225

June 24, 2020
Updated

Summary

Review and analysis of different policy and design choices of the electric power sector (EPS) outside of New England to explore the range of possibilities, their interactions, and implications to inform New England's Transition to the Future Grid project.

Context for Presentation

1. Deep decarbonization of EPS by 2050 and use of electricity for transportation and heating
2. Large geographical region with multiple jurisdictions encompassing multiple generation and transmission companies
3. Focus is on the bulk power system design given the trends in the industry

Deep Decarbonization: Summary of Some U.S. & International Practices

Public Engagement re: Transmission Siting	Planning	Markets & System Flexibility	Diverse Resources	System Operations
TX: 18.5 GW of wind integration with new transmission Germany: Priority to extra-HV transmission projects & shorter planning process CA: Established renewable energy generation and transmission siting steering committee	TX: Centralized planning and Competitive Renewable Energy Zones with risk borne by ratepayers Australia: National rather than regional development based upon market-based cost differentials	TX: Demand response for frequency regulation Australia: 5 min. dispatch and negative prices Denmark: CHP required to participate in the spot power market Germany: substantial incentives for energy storage	Ireland: regional expansion and major interconnection expansion U.S. West: energy imbalance market and reserve sharing	Australia: Market forecast model integrates forecasts from variety of sources Denmark: uses multiple forecasts Spain: Wind farms > 10 MW and solar > 2 MW provide reactive power & most wind farms have fault-ride through capability

Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience, Summary for Policymakers, Cochran et al, April 2012, https://www.nrel.gov/docs/fy12osti/53730.pdf

Deep Decarbonization: Some U.S. & International Practices

Public Engagement re: Transmission Siting	Planning	Markets & System Flexibility	Diverse Resources	System Operations
TX: 18.5 GW of wind integration with new transmission Germany: Priority to extra-HV transmission projects & shortens planning process CA: Established renewable energy generation and transmission siting steering committee	TX: Centralized pla Co Re Zo bo rat Au rat re de based upon market-based cost differentials	TX: Demand spot power market Germany: substantial incentives for energy storage	Ireland: regional y t ng	Australia: Market forecast model integrates forecasts from variety of sources Denmark: uses multiple forecasts used Spain: Wind farms > 10 MW and solar > 2 MW provide reactive power & most wind farms have fault-ride through capability

- Practices span planning and operations
- Multiple practices are used
- No single set of practices are common among regions

Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience, Summary for Policymakers, Cochran et al, April 2012, https://www.nrel.gov/docs/fy12osti/53730.pdf

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Analysis Set-up: Problems and Timeline

	Cycles/Sec	5 minutes	Day-ahead	Months	Years
Political Economy Problem					Decarbonization, Economic development Coalition building, Political ideology, Equity, Multiple Jurisdictions (Years)
Economic/ Regulatory Problem		Economic efficiency, Incentive alignment, Strategic behavior/rent seeking: asymmetric information, market power, externalities, and public goods (Minutes to Years)			
Engineering Problem	System Control	*Economic Dispatch*	*Unit Commitment*	*Operational Planning*	*Expansion Planning*

Optimization

	Cycles/Sec	5 minutes	Day-ahead	Months	Years	Time

Major Overall Findings

1. Each of the three types of problems: political economy, economic/regulatory, and engineering must be addressed
2. These three problems may be solved inconsistently or incompletely and compounded by multiple and overlapping jurisdictions
3. Unless they are addressed in an integrated and consistent manner, political, economic, and reliability difficulties are likely to occur
4. Decisionmakers pursue their own strategic objectives
5. Important tradeoffs exist between different approaches

Analysis Set-up: Decisionmakers

Political Economy Problem	U.S. Context: Federal & State Regulators International: Individual countries, perhaps as part of a larger cross-national union
Economic/ Regulatory Problem	Federal Energy Regulators State Energy Regulators International and National Environmental Regulators Federal & State Environmental Regulators State Economic Development Agencies
Engineering Problem	Integrated utilities OR Merchant generators, transmission companies, system operator

Cycles/Sec → 5 minutes → Day-ahead → Months → Years → Time

Analysis Set-up: Design Variables

Political Economy Problem

Types of resources and their products
Air emission regulation
Cost-of-service, performance-based, market oriented
Regional scale definition

Economic/ Regulatory Problem

Extent of joint planning: generation and transmission
Extent of joint operations by generation and load
Extent of trading

Engineering Problem

Product and service definitions
Optimization period
Cost-based or bid/offer-based
Settlement/pricing mechanism

Cycles/Sec | 5 minutes | Day-ahead | Months | Years | Time

Presentation Organization, Part 1: Deep Decarbonization

Political Economy Problem

Decarbonization, Economic development Coalition building, Political ideology, Equity, Multiple jurisdictions

Economic/ Regulatory Problem

Economic efficiency, Incentive alignment, Strategic behavior/rent seeking: asymmetric information, market power, externalities, and public goods

Engineering Problem

Optimization

System Control	*Economic Dispatch*	*Unit Commitment*	*Operational Planning*	***Expansion Planning***

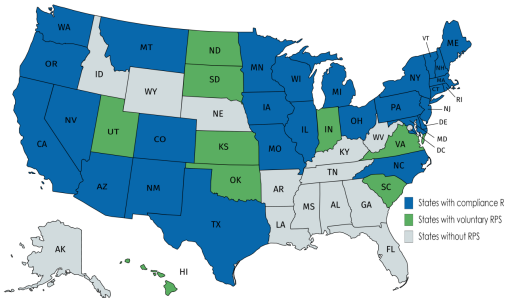
Cycles/Sec — 5 minutes — Day-ahead — Months — Years — Time

Deep Decarbonization: High-level Considerations

Political and Policy Objectives	Policy Development	Policy Options
Decarbonization & environmental co-benefits Economic development within a particular jurisdiction Political success	Political negotiation Legislative non-integrated resource planning Integrated resource planning	Ban/restrict fossil fuels Clean energy subsidies Feed-in tariffs Power Purchase Agreements Renewable portfolio standards Pricing greenhouse gases

Deep Decarbonization: Examples

Means	Some Examples
Ban/restrict fossil fuels	Countries in Europe and Asia banning fossil fueled cars; U.S. restrictions on air permits, pipeline developments
Clean energy subsidies	Many U.S. states both historically and currently; energy efficiency is a major example
Feed-in tariffs	Many European Countries, e.g., Germany
Power Purchase Agreements	Ubiquitous
Renewable portfolio standards	29 U.S. states and DC Multiple countries in Asia
Pricing greenhouse gases	Europe (economy wide), CA (economy wide), RGGI



Deep Decarbonization: Policy Supports, Asia

Asia and Pacific	Regulatory support				Economic support						
Country	Renewable energy law	Targets	Quotas/RPS	Auction schemes	Tradable green certificates	FIT/Feed-in premium	Capital grants and subsidies	Soft loans	Tax relief	Net metering	Carbon pricing
Australia	✔	●		■ ✓	✔	●	✔				✔
Bangladesh		✔		✔					✔		
India		✔✓	✔✓	✔✓	✔	✔	✓	✓	✔●	✔✓	✔
Indonesia		✔		●		●			✔		
Japan		●		■		●	✔		✔	✔	
Korea		✔	✔		✔	✓			✔		
Lao PDR*[1]		✔							✔		
Malaysia	✔	✔		●		●		✔	✔		
Mongolia	●	✔									
Myanmar		■							✔		
New Zealand		✔									✔
Pakistan		✔				●				⓪	
Philippines	✔	✔	⓪			●			✔	✔	
Singapore		✔					✔		✔		
Thailand		●		■		●	✔		✔		
Viet Nam		●				■		✔	✔		

Notes: ✔ = national-level policy; ✓ = state/provincial-level policy, ● = tendering suspended, or closed to new applicants, ⓪ = recently introduced, ■ – under review. For further information, refer to IEA/IRENA Policies and Measures Database for Renewable Energy: www.iea.org/policiesandmeasures/renewableenergy.

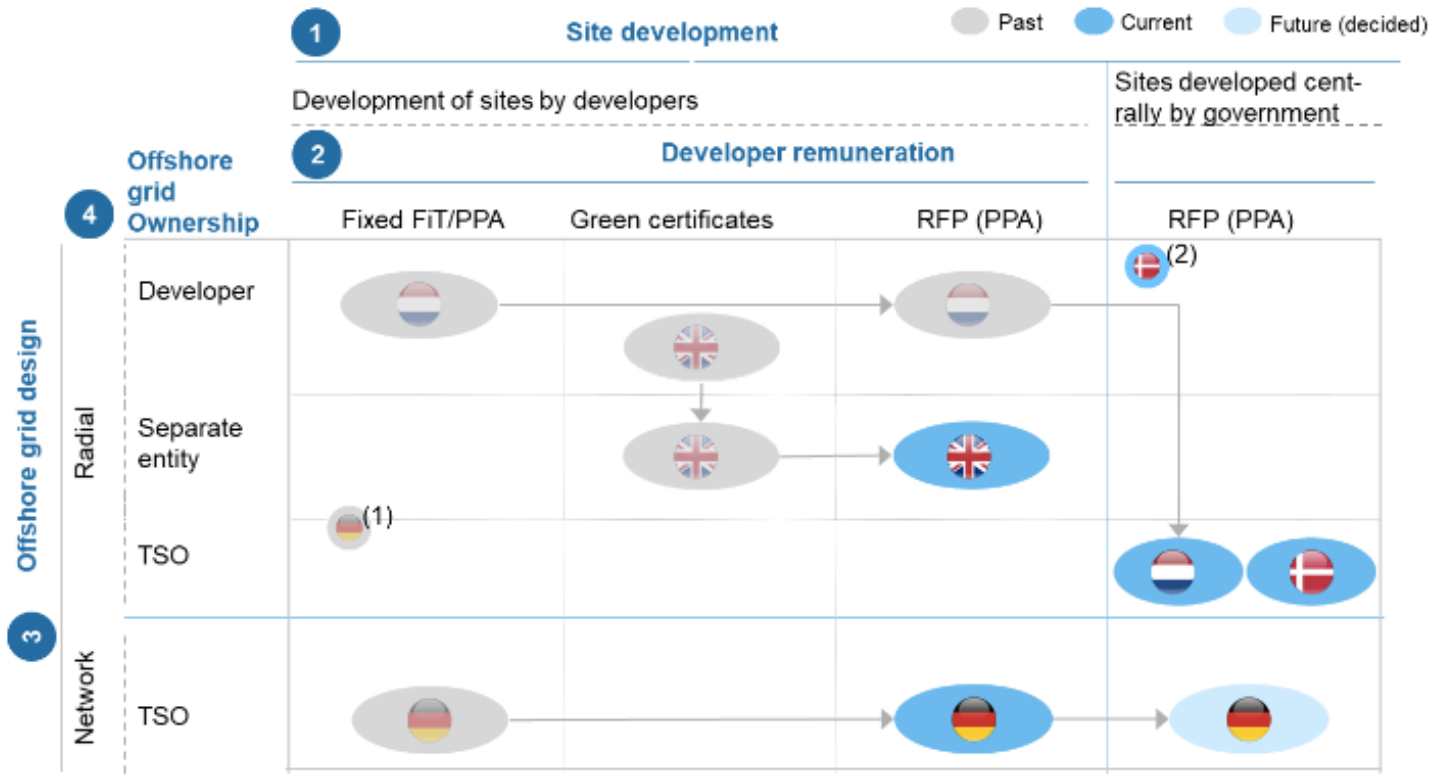
IEA Medium-Term Renewable Energy Market Report 2016, p. 267
https://webstore.iea.org/download/direct/424

Deep Decarbonization: Policy Supports, Europe

Europe	Regulatory support				Economic support						
Country	Renewable energy law	Targets	Quotas/RPS	Auction schemes	Tradable green certificates	FIT/Feed-in premium	Capital grants and subsidies	Soft loans	Tax relief	Net metering	Carbon pricing
Austria	✔	✔				✔	✔		✔		
Belgium		✔	✔✓		✔✓		✔✓			✓	
Denmark	✔	✔	✔	●		✔	✔	✔	✔	✔	
Estonia		✔		⓪		●	✔		✔		
Finland	✔	✔				●▶	✔				
France	✔	●		⓪		⓪	✔	✔	✔		
Germany	●	✔		⓪		●	●	●	✔		
Greece	■	✔		■		■	✔		✔	✔	
Hungary		✔		⓪		●	✔				
Ireland		✔				■			✔		
Italy	✔	✔		●		✔			✔	✔	
Netherlands		✔		⓪		●		✔	✔	✔	
Norway		●	▶		▶		✔				✔
Poland	⓪	✔	▶	⓪●	▶		●			⓪	
Portugal		✔									
Slovak Republic	✔	✔				✔	✔		✔		
Slovenia		✔				✔	✔	✔		⓪	
Spain		✔		⓪							
Sweden		✔	✔		✔		✔		✔		✔
Switzerland		✔				✔	✔				
Turkey	✔	✔				●					
United Kingdom		✔	▶	●	▶	■		✔	✔		✔

IEA Medium-Term Renewable Energy Market Report 2016, p. 268
https://webstore.iea.org/download/direct/424

Offshore Wind: Investment Instruments



1 Some parks in the North and Baltic Sea connected point-to-point such as Alpha Ventus, Riffgat, EnBW Baltic 1/2, Nordergründe 2 Nearshore projects

Source: Energinet; TenneT; National Grid; International Energy Agency

Exhibit 6: *Evolution of OSW support models in Europe*

NYPA, Offshore Wind A European Perspective, Aug. 2019
https://www.nypa.gov/-/media/nypa/documents/document-library/news/offshore-wind.pdf

Deep Decarbonization: Assessment of Policy Options

Means	Economic & Regulatory	Political Economy
Ban/restrict fossil fuels	Puts infinite price on fossil fuel externalities	Does not generate revenue or visibly contribute to economic development
Clean energy subsidies Feed-in tariffs	Due to information asymmetry, difficulty to set amount of subsidies Requires technology and project selection process Financial risk borne by ratepayers	Direct subsidies may quickly become too large to be politically supportable Can be tailored to further economic development goals
Renewable portfolio standards	If market-based, shifts risks to developers Selection of RPS may not be efficient Nascent & fractured markets: opaque & volatile pricing	
Pricing greenhouse gases	Efficient Financial risks borne by developers	Considered less politically viable Economic development disconnect Technically neutral; not know what investments will be made Raises revenue

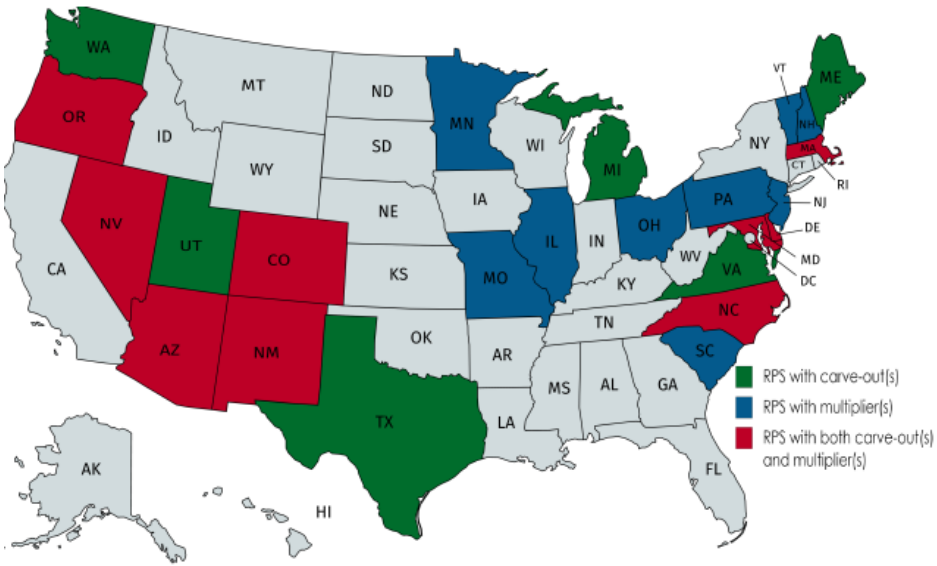
Deep Decarbonization: RPS and Generation Investment

Many States have RPS carve-outs and multipliers

Many types of xRECs:
RECs, SRECs, ORECs, ZECs

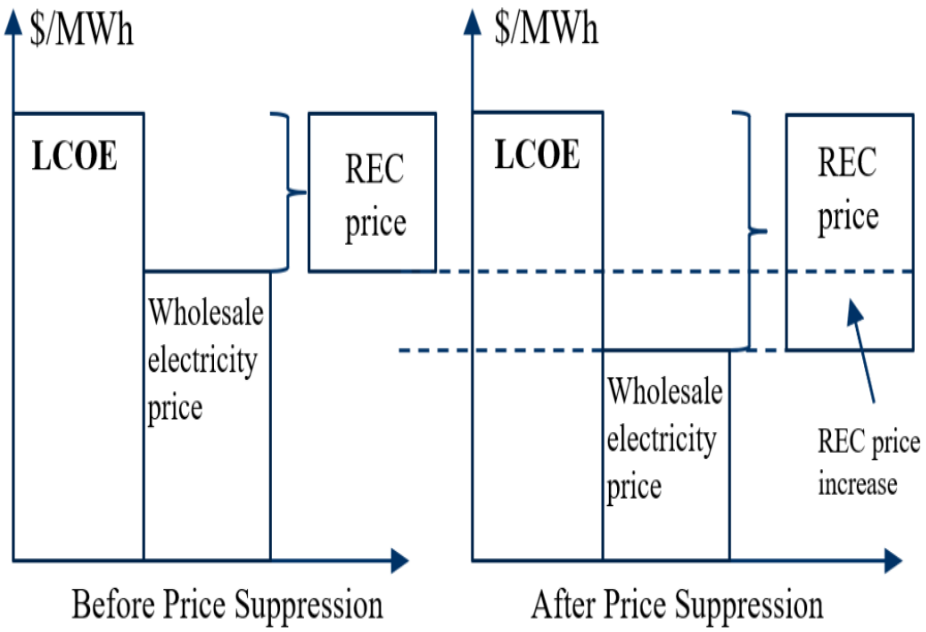
⇒ Partial explanation of these variations is states having different strategic goals

Note: RPS directly provide MWh, not inertia, regulation, ramping, or operating reserves



Deep Decarbonization: Out of Wholesale Electricity Market Payments

- Revenue stream of renewable energy generators comes from wholesale and REC markets
- Out of market payments not unique to RPS or nuclear resources
- Cost of RECs/ZECs amortized over all retail kWh
- Out of wholesale market payments suppress wholesale prices
- Multiple market failures



Deep Decarbonization: Generation and Transmission (and distribution)

Three important examples:

- Offshore wind: radial vs. backbone
- Energy storage
- Major regional and sub-national interconnections

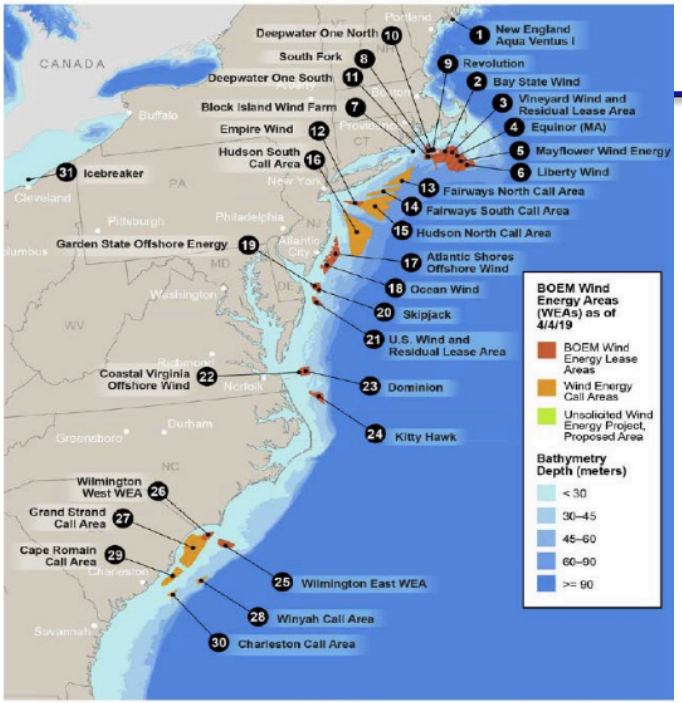


Figure 4. Locations of U.S. Atlantic Coast offshore wind pipeline activity and Call Areas as of March 2019.
Map provided by NREL

Smart Grid Solutions, https://www.renewableenergyworld.com/2018/02/13/unpacking-the-value-stack-the-challenge-facing-the-energy-storage-industry/#gref

Deep Decarbonization: Transmission Planning Options

Political and Policy Objectives	Policy Development	Policy Options
Federal/Regional Objectives: Reliability Economic efficiency State Objectives: Integrate renewables Lower electricity rates Shifting costs to another jurisdiction	Political negotiation Planning by transmission owners Planning by system operator	Integrated generation and transmission planning vs. sequential generation investment and transmission planning Types of transmission planning investments: • Public policy • Reliability • Economic Addressing uncertainty in transmission planning Cost allocation

Deep Decarbonization Investment: Examples of Three Major Tradeoffs

1. Long-term financing methods (e.g., cost-of-service regulation or long-term contracts) may reduce cost of capital but allocate risk to ratepayers

2. Wholesale markets shift risks to suppliers and may lower generation costs but may increase the costs of sequential generation and transmission planning

3. Commitments to long-term supply arrangements may address political economy objectives but restrict the ability to address operational requirements

BREAK FOR QUESTIONS AND COMMENTS

Presentation Organization, Part 2: Balancing Supply and Demand

Political Economy Problem

Decarbonization, Economic development Coalition building, Political ideology, Equity, Multiple jurisdictions

Economic/ Regulatory Problem

Economic efficiency, Incentive alignment, Strategic behavior/rent seeking: asymmetric information, market power, externalities, and public goods

Engineering Problem

Optimization

System Control	*Economic Dispatch*	*Unit Commitment*	*Operational Planning*	*Expansion Planning*

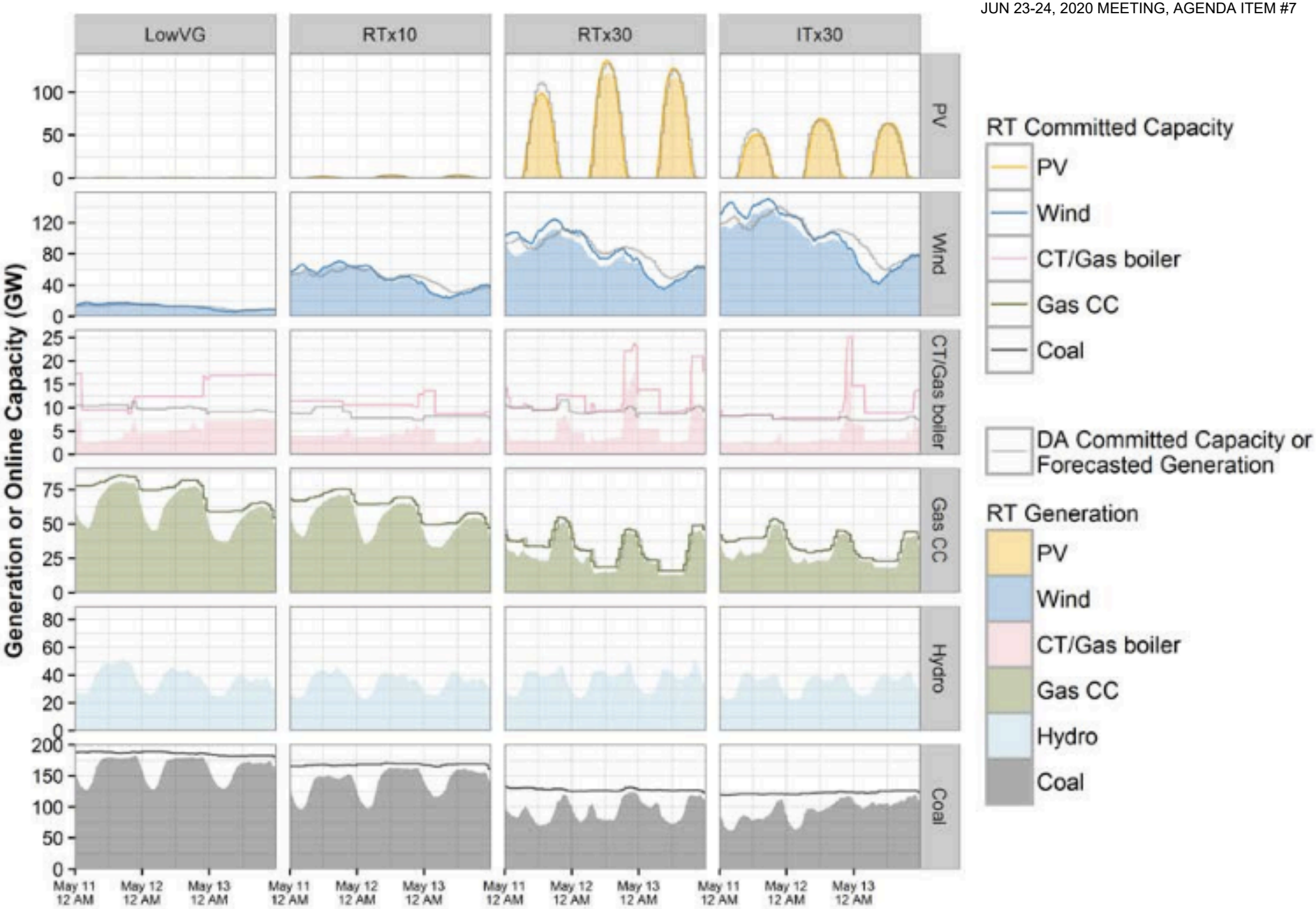
Cycles/Sec → 5 minutes → Day-ahead → Months → Years → Time

Generation Dispatch with Increasing Variable Energy Resources

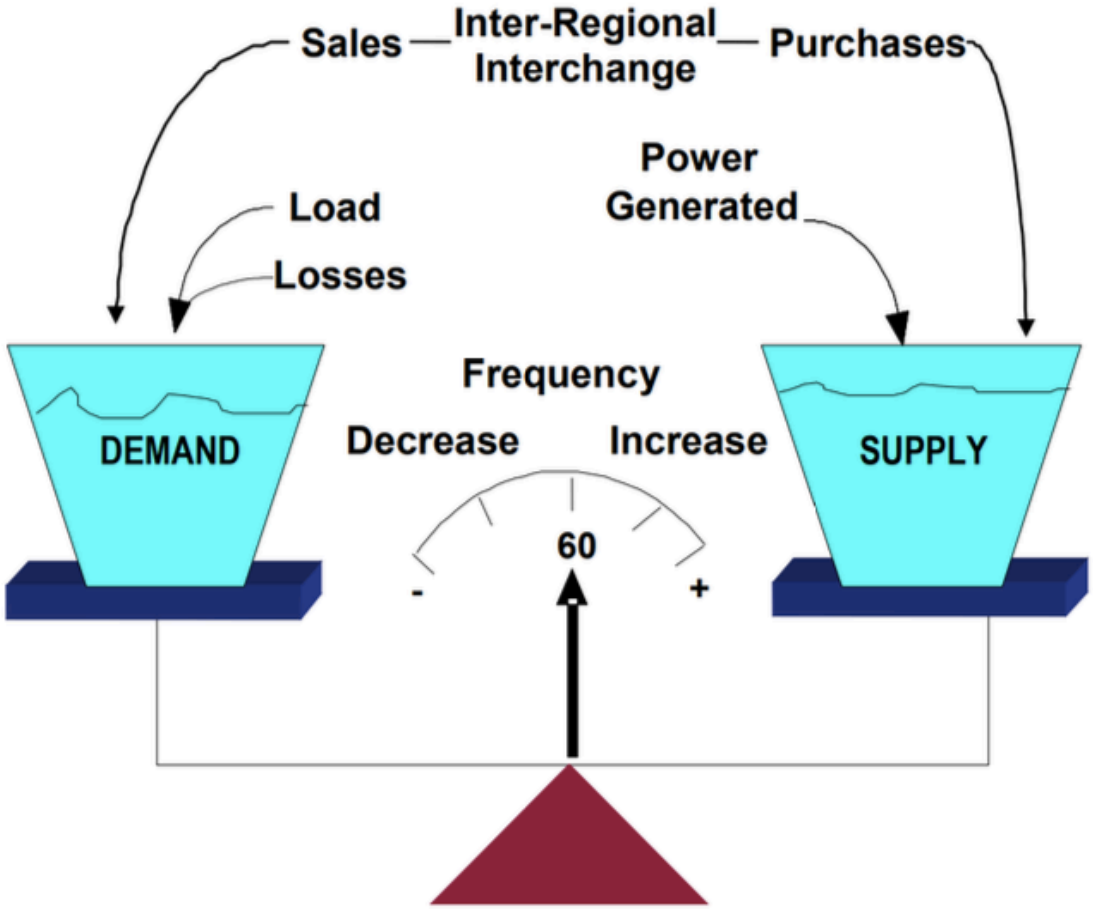
Table ES-1. ERGIS Includes Four Scenarios with Different Levels of Wind, PV, and Transmission Capacity Expansion

Scenario	Wind	PV	Total[a]	Attributes
LowVG	3%	0%	3%	• No new wind or PV generation installations after the year 2012. • Minimal transmission expansion.
RTx10 (Regional Transmission and ~10% VG)	12%	0.25 %	12%	• An approximately 10% VG penetration as reflected in state RPS and interconnection queues as of 2012.[b] • Intra-regional transmission expansion.
RTx30 (Regional Transmission and 30% VG)	20%	10%	30%	• Approximately 30% combined VG, with an emphasis on within-region wind and PV resources. • Identical transmission expansion to RTx10.
ITx30 (Inter-regional transmission and 30% VG)	25%	5%	30%	• Approximately 30% combined VG, with an emphasis on the best wind and PV resources in the U.S. EI. • Interregional transmission expansion with 6 large high-voltage direct current (HVDC) lines.

This slide and the next from NREL Eastern Renewable Generation Integration Study, 2016
https://www.nrel.gov/docs/fy16osti/64472-ES.pdf

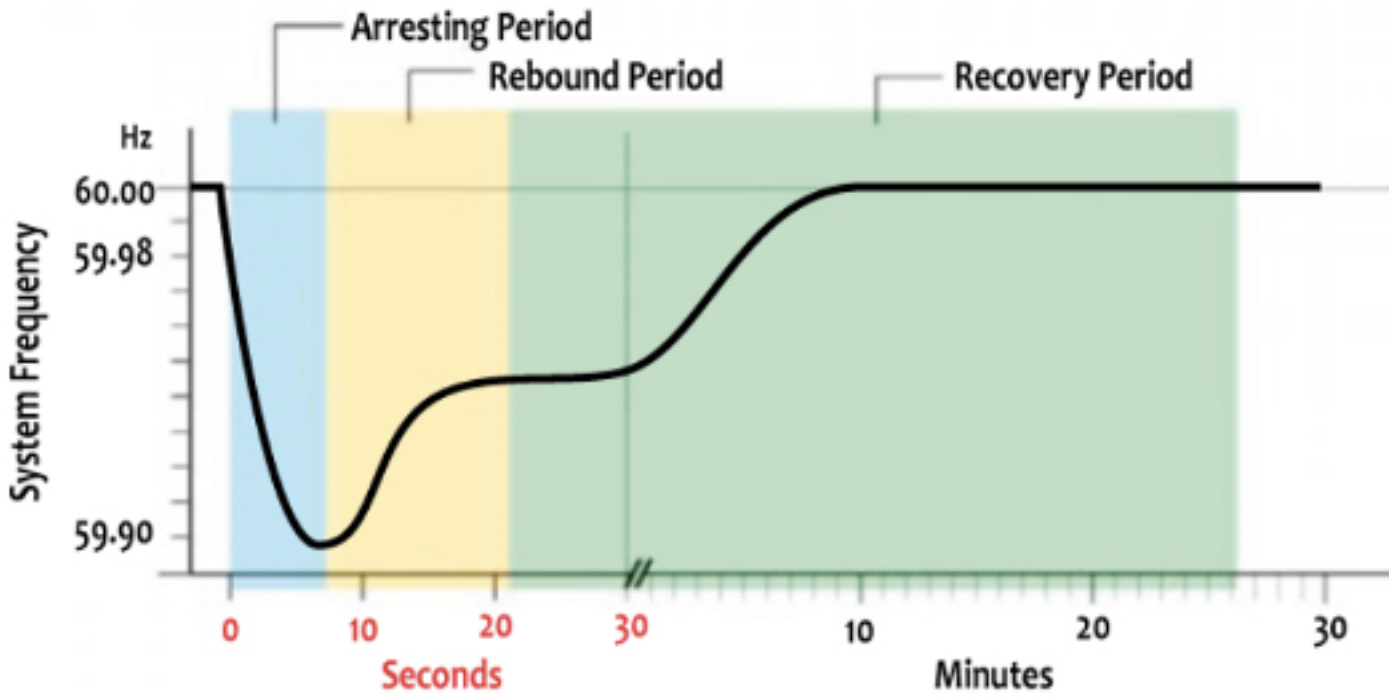

LowVG
RTx10
RTx30
ITx30
PV
Wind
CT/Gas boiler
Gas CC
Hydro
Coal
Generation or Online Capacity (GW)
May 11 12 AM
May 12 12 AM
May 13 12 AM
RT Committed Capacity
PV
Wind
CT/Gas boiler
Gas CC
Coal
DA Committed Capacity or Forecasted Generation
RT Generation
PV
Wind
CT/Gas boiler
Gas CC
Hydro
Coal

System Control: Normal Operations



Source: NERC *Balancing & Frequency Control*, January 2011

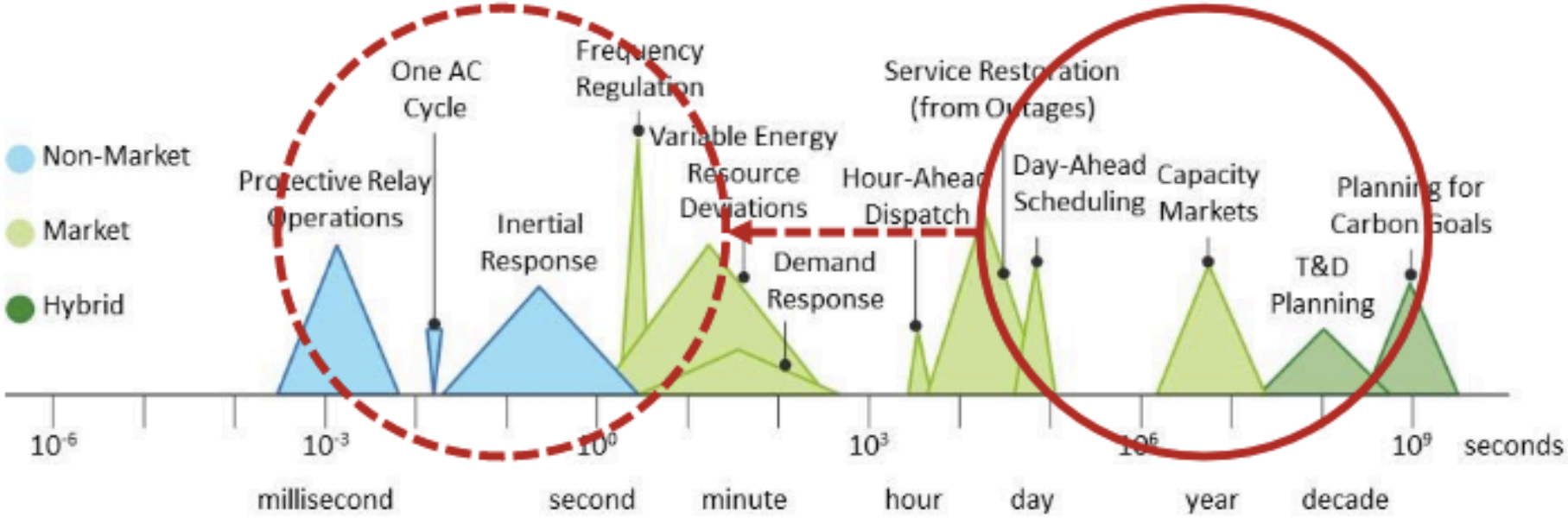
System Control: Contingency



Source: http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERS%20Abstract%20Report%20Final.pdf

System Control: Occurs Over Entire Timeline

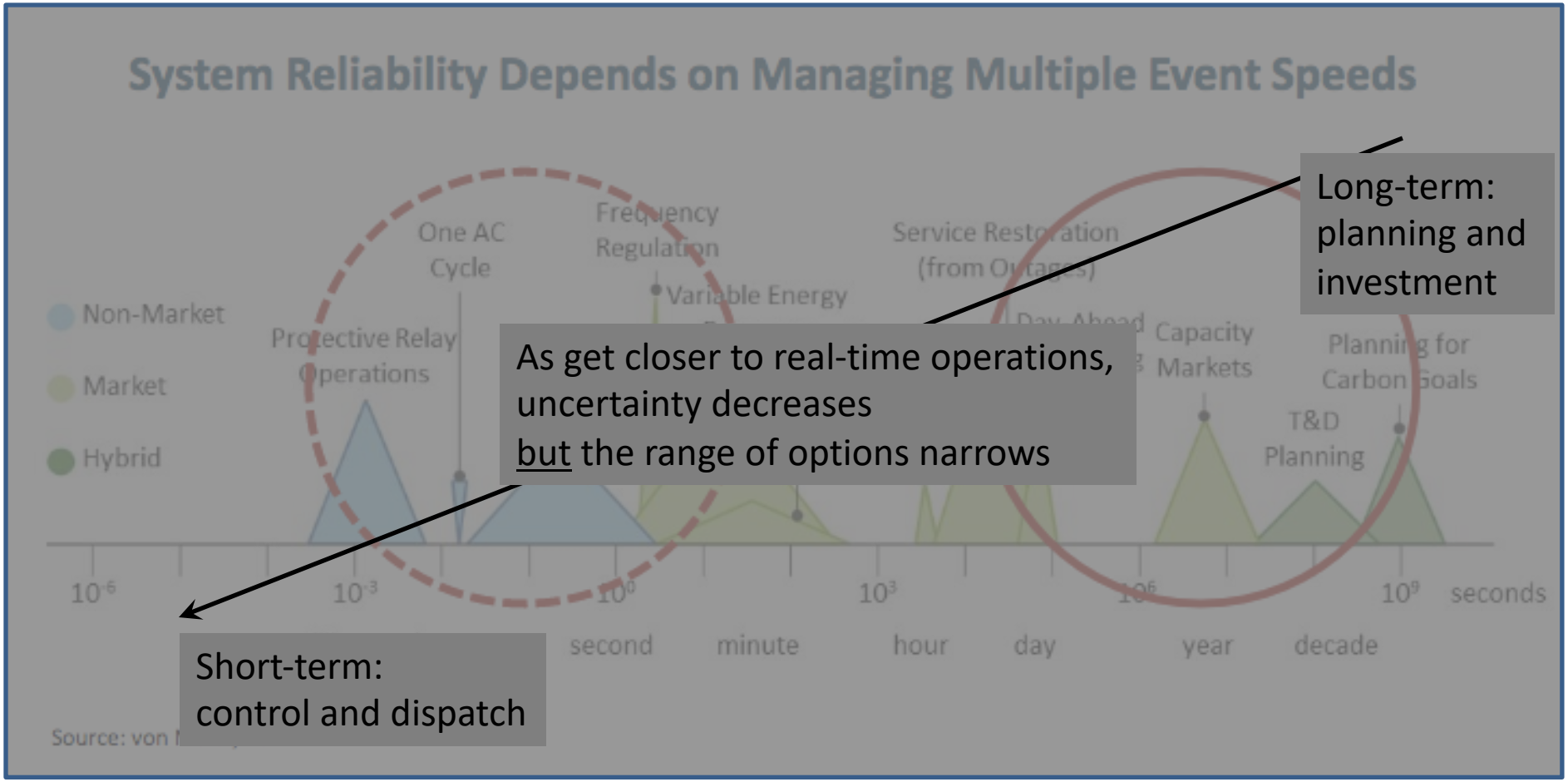
System Reliability Depends on Managing Multiple Event Speeds



Source: von Meier, 2014

http://energyoutlook.naseo.org/Data/Sites/13/media/presentations/Battershell--QER-1.2-Briefin.PDF

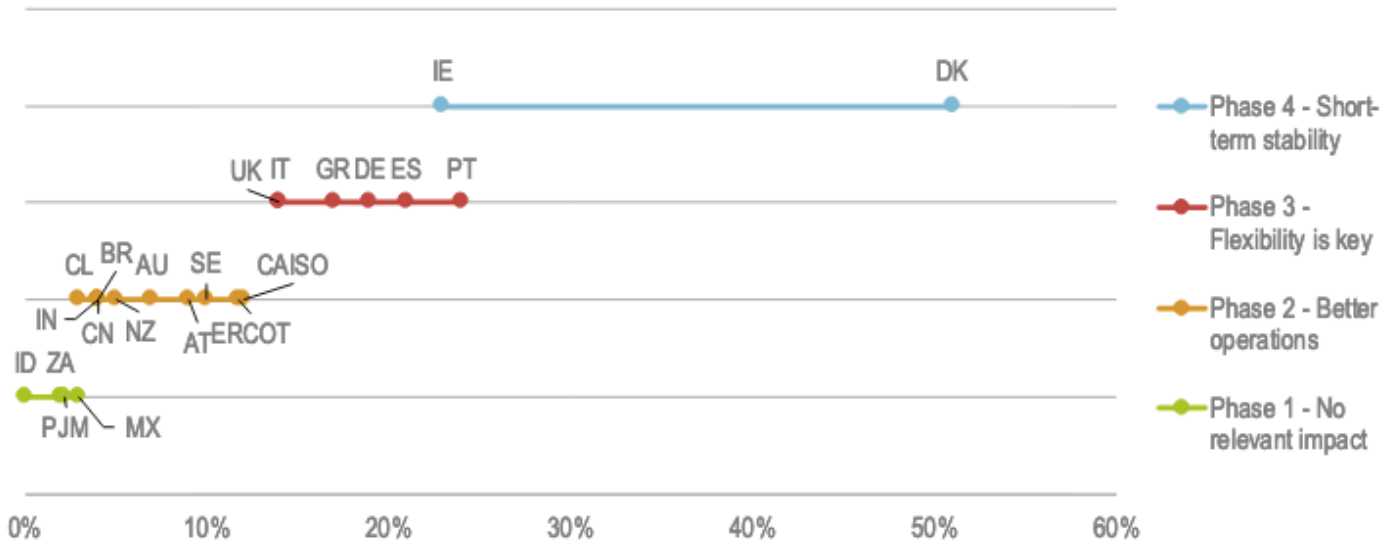
System Control: Relationship between Available Options and Uncertainty



http://energyoutlook.naseo.org/Data/Sites/13/media/presentations/Battershell--QER-1.2-Briefin.PDF

System Control: International Share of Variable Generation

Figure 3.2 • Annual VRE share of generation in selected countries and corresponding VRE phase, 2015



Notes: AT = Austria; AU = Australia; BR = Brazil; CL = Chile; CN = China; DE = Germany; DK = Denmark; ES = Spain; GR = Greece; ID = Indonesia; IE = Ireland; IN = India; IT = Italy; MX = Mexico; NZ = New Zealand; PT = Portugal; SE = Sweden; UK = the United Kingdom; ZA = South Africa. PJM, CAISO and ERCOT are US energy markets.

Source: Adapted from IEA (2016a), *Medium-Term Renewable Energy Market Report 2016.*

Key point • Each phase can span a wide range of VRE share of generation; there is no single point at which a new phase is entered.

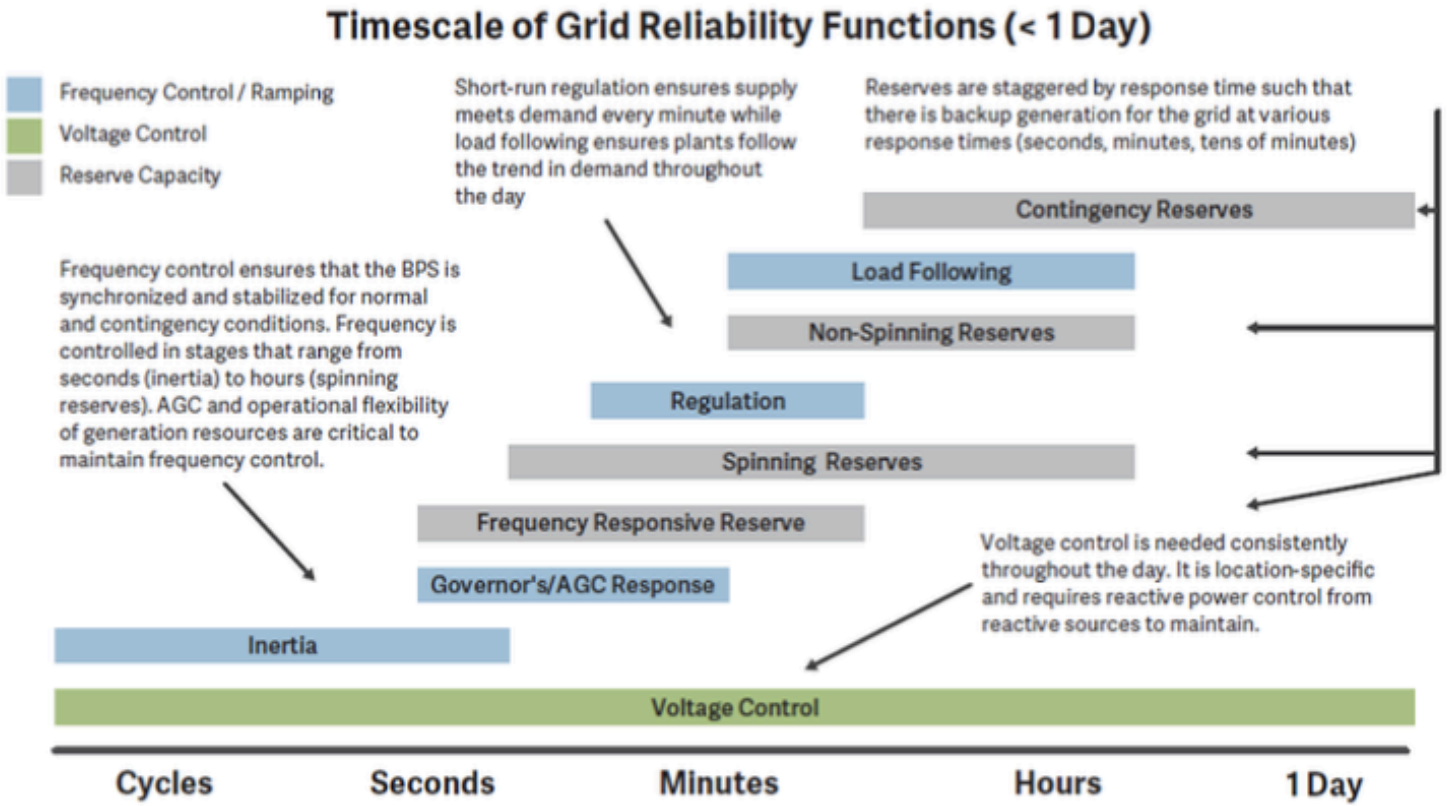
International Energy Agency, 2017, Status of Power System Transformation 2017:
System Integration and Local Grids, p. 37, https://webstore.iea.org/download/direct/298

See Kroposki et al, Achieving a 100% Renewable Grid, IEEE Power & Energy Magazine, March/April 2017, http://ipu.msu.edu/wp-content/uploads/2018/01/IEEE-Achieving-a-100-Renewable-Grid-2017.pdf for non-technical discussion of technical issues related to operating a 100% variable energy power system.

Findings: Ancillary Services

1. Ancillary service prices are volatile
2. Ancillary service costs are currently small total of wholesale costs but their share of costs is increasing
3. No consensus exists for the types and definitions of ancillary services
4. Ancillary services become more important as the percentage of renewable energy increases
5. The types of ancillary services are likely to increase and change with increasing variable energy resources
6. Renewable resources can provide many ancillary services
7. Some ancillary services are substitutes with other ancillary services
8. Co-optimization and opportunity cost pricing become more important with increasing variable energy resources

Balancing Supply and Demand: Ancillary Services (U.S. & International)



Notes and Sources:
[1] Adapted from Kirby, Brendan, "Potential New Ancillary Services: Developments of Interest to Generators," August 2014.
[2] NERC, "Special Report: Ancillary Service and Balancing Authority Area Solutions to Integrate Variable Generation," March 2011.
[3] Kirby, Brendan, "Ancillary Services: Technical and Commercial Insights," July 2007.

Source: Analysis Group, *Advancing Past "Baseload" to a Flexible Grid*, June 2017

From Electricity Ancillary Services Primer, Reishus Consulting, August 2017
http://nescoe.com/wp-content/uploads/2017/11/AnxSvcPrimer_Sep2017.pdf

System Control: U.S. Regulation Prices

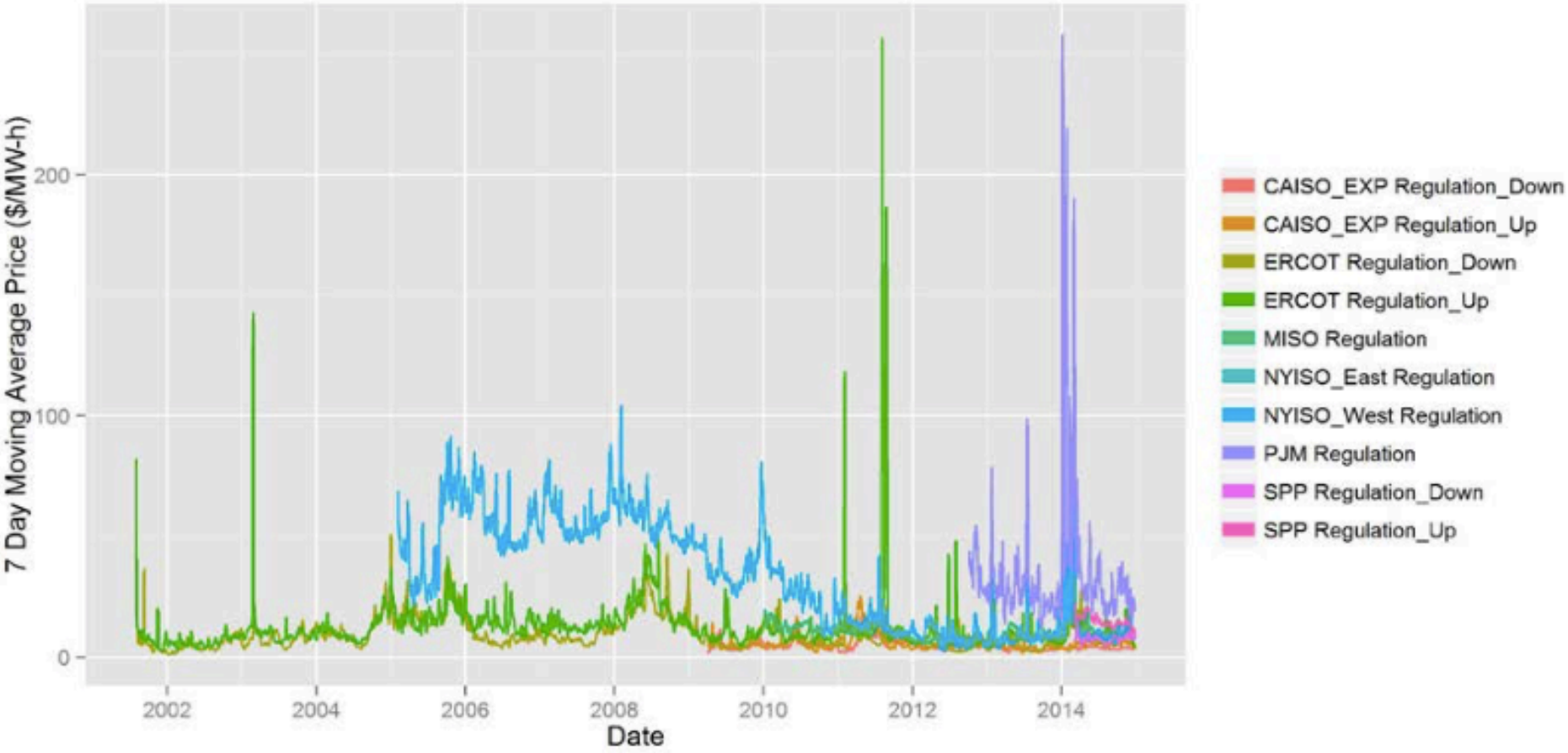


Figure 9-1 Seven-day moving average prices in each Regulation Reserves market

Argonne National Laboratory, Survey of U.S. Ancillary Services Markets, Jan. 2016
https://publications.anl.gov/anlpubs/2016/01/124217.pdf

System Control: U.S. Reserve Prices

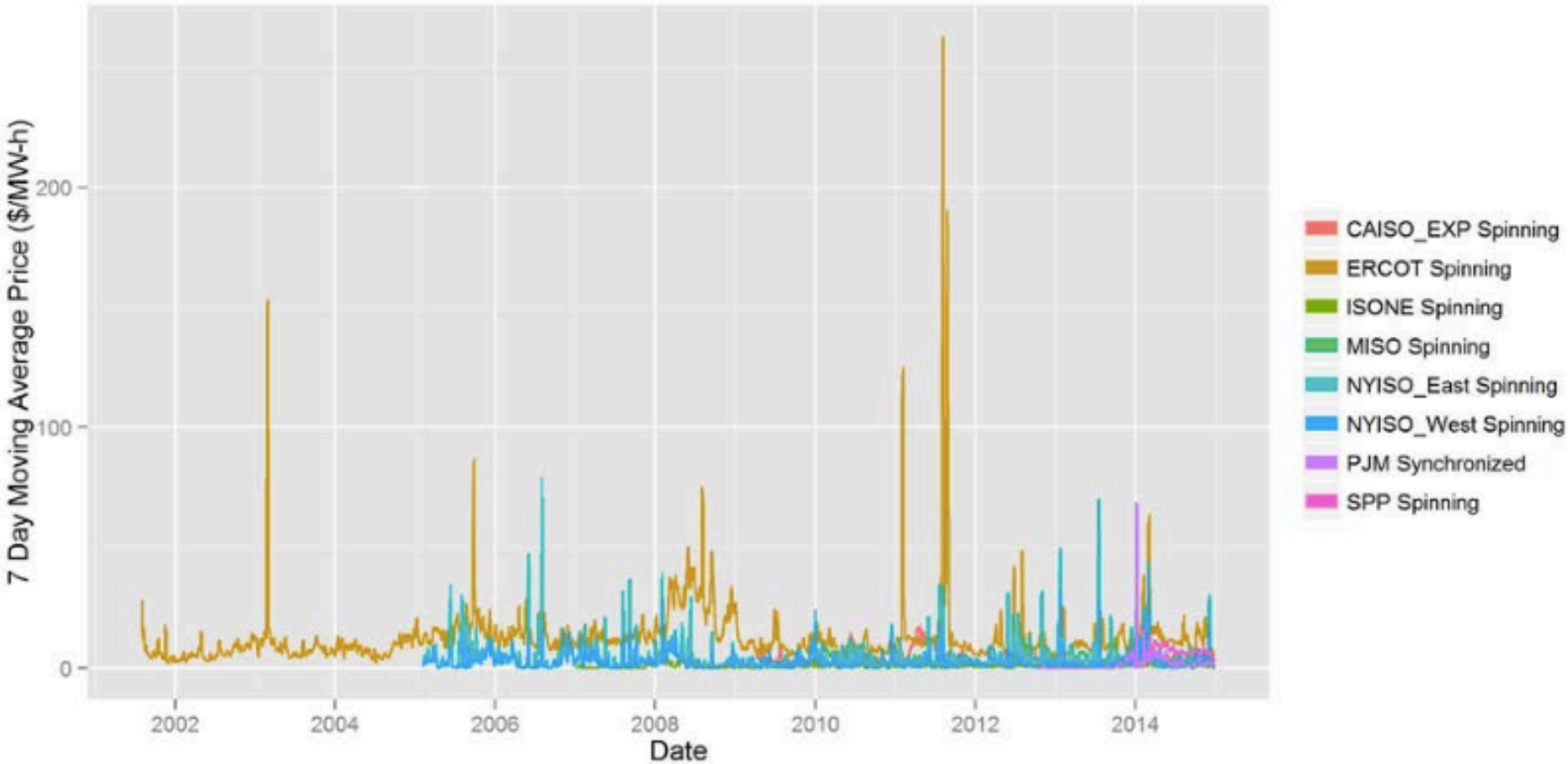


Figure 9-5 Seven-day moving average prices in each Spinning Reserves market

Argonne National Laboratory, Survey of U.S. Ancillary Services Markets, Jan. 2016
https://publications.anl.gov/anlpubs/2016/01/124217.pdf

Balancing Supply and Demand: Different Resources Provide Different Capabilities

● = Exhibits Attribute
◒ = Partially Exhibits Attribute
○ = Does Not Exhibit Attribute

Resource Type	Essential Reliability Services (Frequency, Voltage, Ramp Capability)					Fuel Assurance		Flexibility			Other		
	Frequency Response (Inertia & Primary)	Voltage Control	Ramp										
			Regulation	Contingency Reserve	Load Following	Not Fuel Limited (> 72 hours at Eco. Max Output)	On-site Fuel Inventory	Cycle	Short Min. Run Time (< 2 hrs.)/ Multiple Starts Per Day	Startup/ Notification Time < 30 Minutes	Black Start Capable	No Environmental Restrictions (That Would Limit Run Hours)	Equivalent Availability Factor
Hydro	●	●	●	●	●	○	◒	●	●	●	●	◒	●
Natural Gas - Combustion Turbine	●	●	◒	●	◒	●	○	●	●	●	●	◒	◒
Oil -Steam	●	●	●	●	●	●	●	●	○	○	○	○	◒
Coal - Steam	●	●	●	●	●	●	●	◒	○	○	○	◒	◒
Natural Gas - Steam	●	●	●	●	●	●	○	●	○	○	●	◒	◒
Oil/ Diesel - Combustion Turbine	●	●	○	●	○	○	●	●	●	●	●	○	◒
Nuclear	◒	●	○	○	◒	●	●	○	○	○	○	◒	●
Battery/ Storage	◒	◒	●	●	○	○	○	●	●	●	◒	●	●
Demand Response	○	○	◒	◒	◒	◒	◒	●	●	◒	○	●	●
Solar	◒	◒	○	○	◒	○	○	●	●	●	○	●	●
Wind	◒	◒	○	○	◒	○	○	●	●	●	○	◒	●

From Electricity Ancillary Services Primer, Reishus Consulting, August 2017 citing PJM Evolving Resource Mix and System Reliability, 2017
http://nescoe.com/wp-content/uploads/2017/11/AnxSvcPrimer_Sep2017.pdf

Balancing Supply and Demand: High-level Considerations

Political and Policy Objectives	Policy Development	Policy Options
Reliability Efficient grid operations Rapid deployment of renewable resources	Political negotiation with stakeholders (including system operator) Governance of system operator	Resource adequacy policy (prices or quantities) Operational planning Security constrained unit commitment Security constrained economic dispatch Ancillary services Co-Optimization and Opportunity Cost Pricing

Balancing Supply and Demand: International Examples

Means	Description
Flexible resources	Need sufficient incentives or regulatory approaches to ensure sufficient flexible are available when needed
Grid codes	Requirements for performance standards; needs to be enforced and resources tested for compliance
Demand response	Real-time demand response requires proper metering and information systems
Unit commitment/scheduling intervals	Include variable energy resources forecasting in unit commitment; submission of schedules closer to real-time; seamless integration of Supervisory Control and Data Acquisition (SCADA) and Energy Management System (EMS) systems

Operating and Planning Electricity Grids with Variable Renewable Generation, Madrigal and Porter, World Bank, 2013
https://openknowledge.worldbank.org/bitstream/handle/10986/13103/757310PUB0EPI0001300pubdate02023013.pdf?sequence=1&isAllowed=y

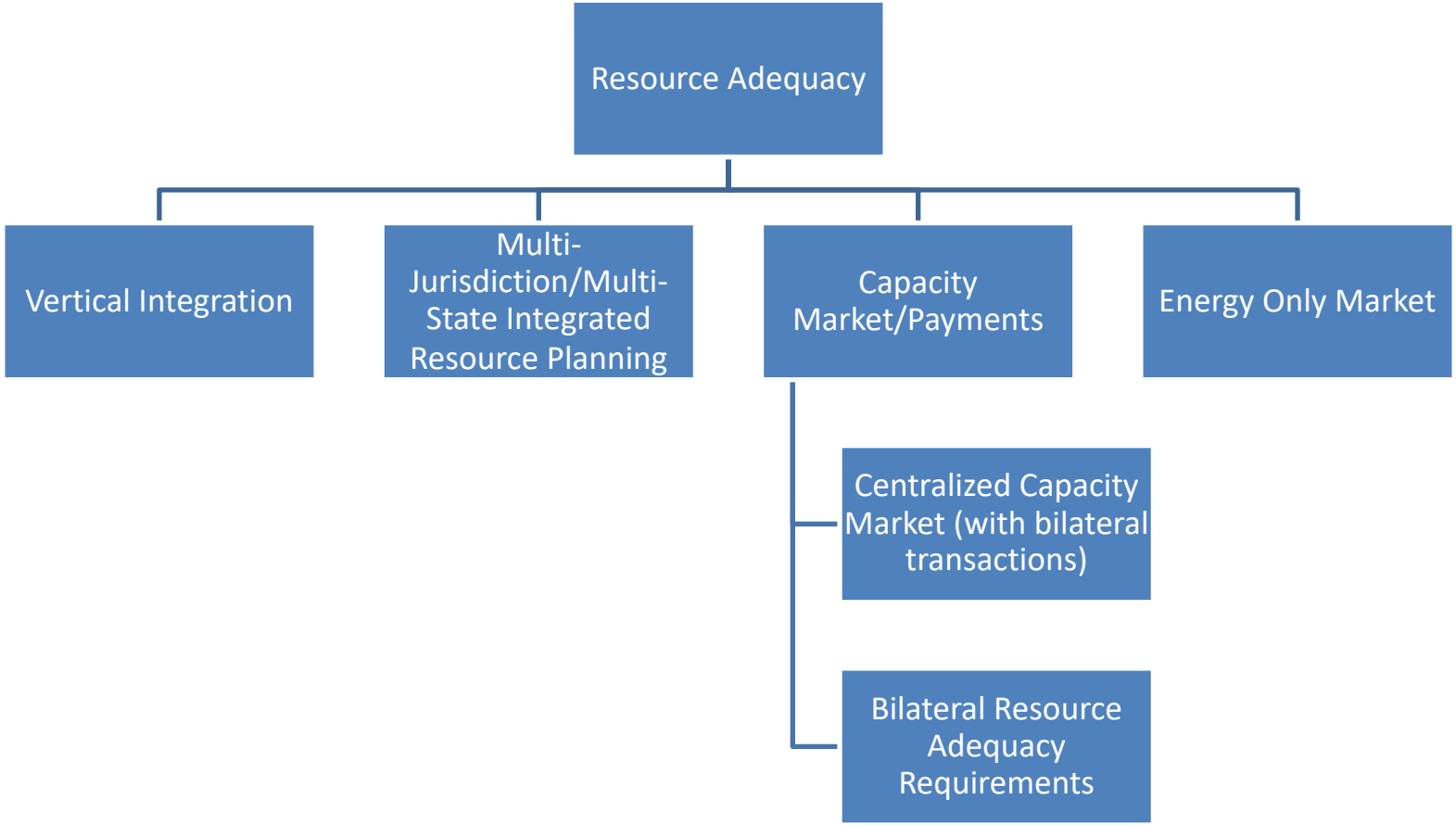
Based upon detailed case studies of China, Germany & Spain

Balancing Supply and Demand: International Examples, con't

Means	Description
Transmission planning for renewables	Proper planning and cost allocation needed so that the best combination of transmission and renewables are developed first
Improved planning practices for transmission and supply adequacy	Development of cost-effective solutions and probabilistic planning analyses and criteria
Renewable energy curtailments	Proper definition of the rules and conditions under which variable energy resources will be curtailed as part of the grid code; renewable energy contracts need to be designed to account for curtailments and payment implications
Advances in variable energy resources	Track and incorporate technological advances that variable energy resources can provide ancillary services

Operating and Planning Electricity Grids with Variable Renewable Generation, Madrigal and Porter, World Bank, 2013
https://openknowledge.worldbank.org/bitstream/handle/10986/13103/757310PUB0EPI0001300pubdate02023013.pdf?sequence=1&isAllowed=y

Balancing Supply and Demand: Resource Adequacy



From Capacity Markets at a Crossroads, Bushnell, Flagg & Mansur, April 2017, with modifications
https://hepg.hks.harvard.edu/files/hepg/files/wp278updated.pdf

Balancing Supply and Demand: Resource Adequacy

ISO	Procurement Structure	RA Requirement	Timeline	Price Formation	Market Power Mitigation	Resource Obligations	Performance Incentives
ERCOT	**Energy-only market** that primarily relies on scarcity pricing mechanisms.	No requirement. 'Target' reserve margin is 13.75%	n/a	Operating Reserve Demand Curve adder and Reliability Deployment Adder. Use LOLE[16] and value of lost load.	System offer cap set to $9,000/MWh. Mechanism in place to reduce offer cap if costs become excessive.	n/a	n/a
CAISO	**Bilateral RA Requirement:** met through **bilateral contracts and self-supply**.	System requirements set by LRAs (most at 15% reserve margin). Local and flexible requirements determined by ISO.	Yearly and monthly requirements.	Largely unknown. Backstop capacity procured by ISO via auction, paid as bid.	n/a Backstop procurement auction subject to soft-offer cap.	Must-offer obligations vary by capacity type but involve scheduling and bidding in Day-Ahead and Real-Time markets.	**Average.** Incentive mechanism assesses adherence to must-offer obligation. No established performance criteria.
SPP	**Bilateral RA Requirement:** Procurement is through bilateral contracts and self-supplied.	Planning reserve margin set at 12%.	Peak summer season.	Unknown.	n/a	None.	None.
MISO	**Bilateral RA Requirement:** LSEs may use bilateral contracts, *or* procure through a voluntary centralized ***Planning Resource Auction (PRA)***	System-wide and zonal requirements set with LOLE study. The 2015 required reserve margin set to 14.7%	Auction held immediately prior to delivery year. Proposal for 3-yr forward auction for competitive retail states.	Currently demand curve is vertical at RA requirement. Proposal for sloped demand curve for competitive retail states.	Participants may self-schedule or submit $0 offers in PRA. Offer cap set at 2.7*zonal CONE.[17]	Must offer in Day-Ahead Energy and Reserve markets and first post Day-Ahead RAC process every hour.	**Weak.** MISO monitors must offer obligation but no formal incentive structure. Forced outages will reduce capacity counted.
ISO-NE	**Centralized capacity market:** called the *Forward Capacity Auctions (FCA)* Centralized capacity Market	System and local requirements set with LOLE study.	3-years in advance with additional auctions held annually and monthly.	Sloped demand curve, uses LOLE and CONE.	Minimum competitive offer prices. Requests to exit reviewed by market monitor.	Must offer into energy market and schedule maintenance with ISO	**Strong.** New pay-for-performance design integrates performance into capacity payment.
NYISO	**Centralized capacity market:** called the *Installed Capacity Auctions.*	System and local requirements set with LOLE study. Current reserve margin is roughly 17%.	Auctions held immediately prior to and during 6 month capability period.	Sloped demand curve, uses capacity requirement and CONE.	Market power tests determine when to impose offer floors and caps	Must schedule or bid in Day-Ahead market.	**Weak.** No performance mechanism but forced outages reduce capacity counted.
PJM	**Centralized capacity market:** called the *Reliability Pricing Model (PRM)*	System and local requirements set with LOLE study.	Base auction 3-years in advance. Incremental auctions held up to delivery year.	Slopped Demand Curve, based on requirement, net-CONE & demand reservation prices.	Minimum offer price set at net asset class CONE.	Must offer into Day-Ahead market.	**Strong.** New Capacity Performance product focuses on emergency events.

Capacity Markets at a Crossroads, Bushnell, Flagg & Mansur, April 2017, Table 3
https://hepg.hks.harvard.edu/files/hepg/files/wp278updated.pdf

Balancing Supply and Demand: Resource Adequacy

ISO	Procurement Structure	RA Requirement	Timeline	Price Formation	Market Power Mitigation	Resource Obligations	Performance Incentives
ERCOT	**Energy-only market** that primarily relies on scarcity pricing mechanisms.	No requirement. 'Target' reserve margin is 13.75%	n/a	Operating Reserve Demand Curve adder and Reliability Deployment Adder. Use LOLE[16] and value of lost load.	System offer cap set to $9,000/MWh. Mechanism in place to reduce offer cap if costs become excessive.	n/a	n/a
CAISO	**Bilateral RA Requirement:** met through **bilateral contracts and self-supply**.	System requirements set by LRAs (most at 15% reserve margin). Local and flexible requirements determined by ISO.	Yearly and monthly requirements.	Largely unknown. Backstop capacity procured by ISO via auction, paid as bid.	n/a Backstop procurement auction subject to soft-offer cap.	Must-offer obligations vary by capacity type but involve scheduling and bidding in Day-Ahead and Real-Time markets.	**Average.** Incentive mechanism assesses adherence to must-offer obligation. No established performance criteria.
SPP	**Bilateral RA Requirement:** Procurement is through bilateral contracts and self-supplied.						None.
MISO	**Bilateral RA Requirement:** LSEs may use bilateral contracts, *or* procure through a voluntary centralized ***Planning Resource Auction (PRA)***					Day-Ahead eserve irst post Day- rocess every	**Weak.** MISO monitors must offer obligation but no formal incentive structure. Forced outages will reduce capacity counted.
ISO-NE	**Centralized capacity market:** called the *Forward Capacity Auctions (FCA)* Centralized capacity Market	System and local requirements set with LOLE study.	3-years in advance with additional auctions held annually and monthly.	Sloped demand curve, uses LOLE and CONE.	Minimum competitive offer prices. Requests to exit reviewed by market monitor.	Must offer into energy market and schedule maintenance with ISO	**Strong.** New pay-for-performance design integrates performance into capacity payment.
NYISO	**Centralized capacity market:** called the *Installed Capacity Auctions.*	System and local requirements set with LOLE study. Current reserve margin is roughly 17%.	Auctions held immediately prior to and during 6 month capability period.	Sloped demand curve, uses capacity requirement and CONE.	Market power tests determine when to impose offer floors and caps	Must schedule or bid in Day-Ahead market.	**Weak.** No performance mechanism but forced outages reduce capacity counted.
PJM	**Centralized capacity market:** called the *Reliability Pricing Model (PRM)*	System and local requirements set with LOLE study.	Base auction 3-years in advance. Incremental auctions held up to delivery year.	Slopped Demand Curve, based on requirement, net-CONE & demand reservation prices.	Minimum offer price set at net asset class CONE.	Must offer into Day-Ahead market.	**Strong.** New Capacity Performance product focuses on emergency events.

Resource adequacy requirements and market structure affect the amount and flexibility of resources and load that are available to balance supply and demand

Capacity Markets at a Crossroads, Bushnell, Flagg & Mansur, April 2017, Table 3
https://hepg.hks.harvard.edu/files/hepg/files/wp278updated.pdf

Balancing Supply and Demand: Scarcity Pricing, Today

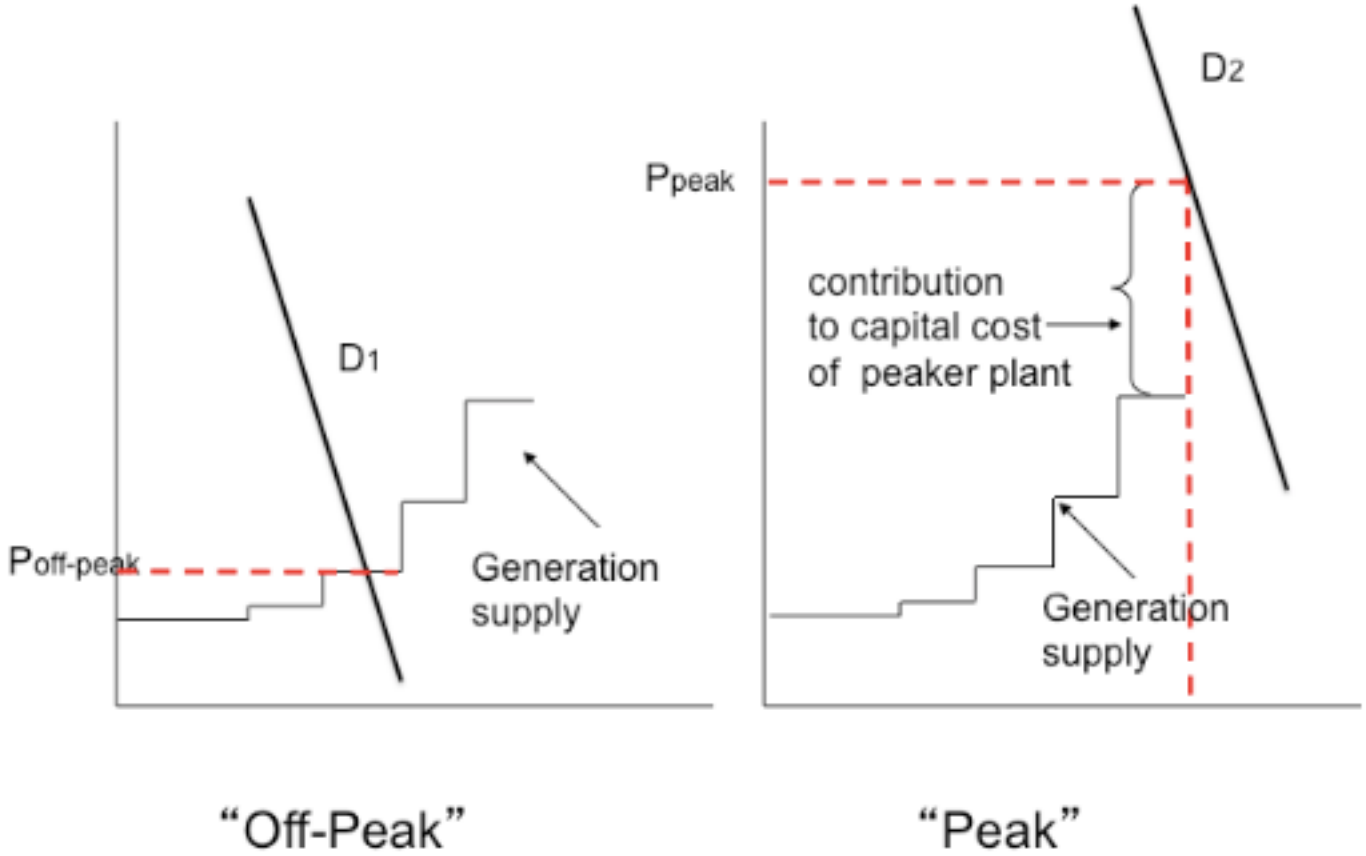
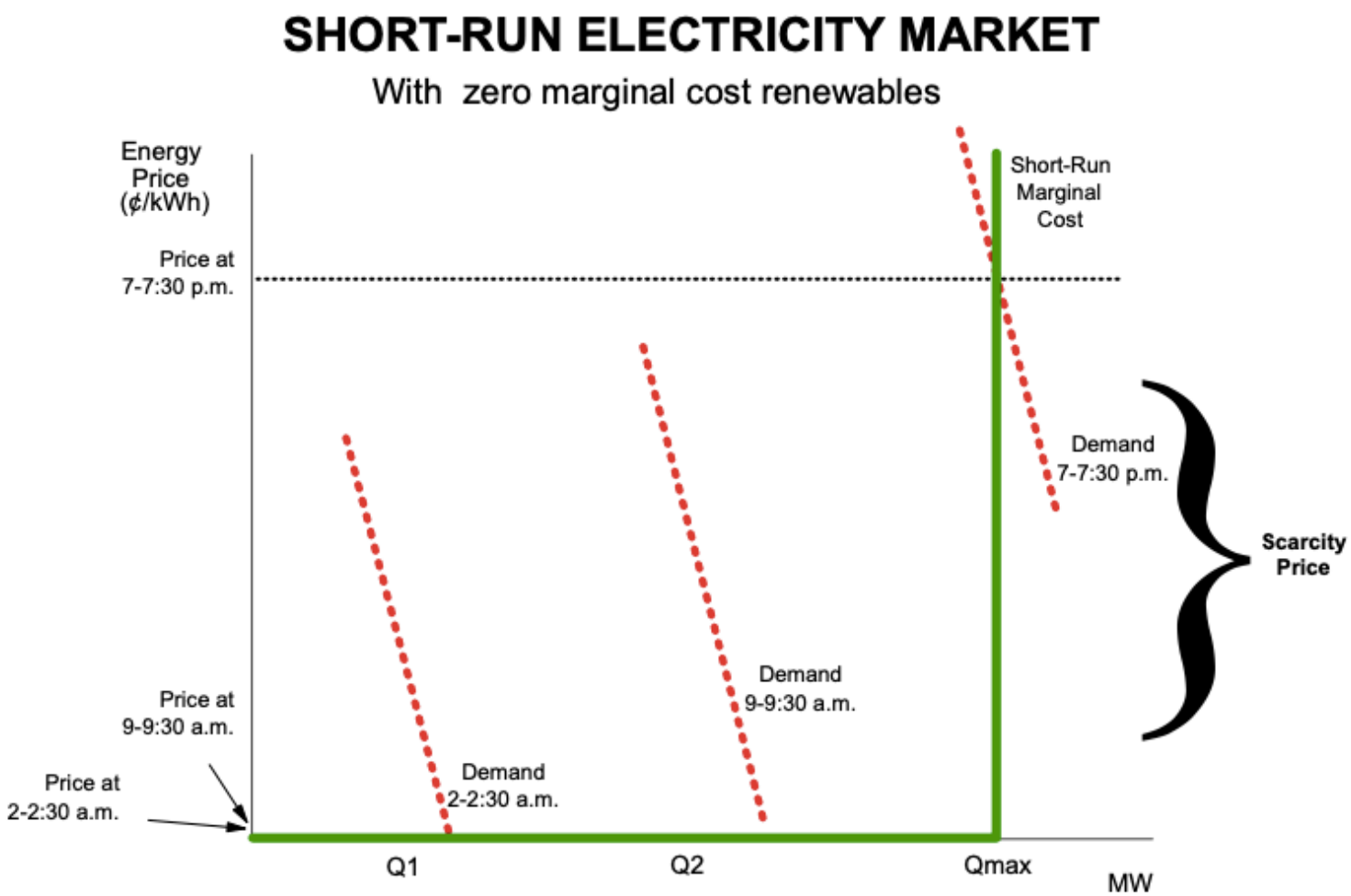


Figure 2: Scarcity Pricing Example

Capacity Markets at a Crossroads, Bushnell, Flagg & Mansur, April 2017
https://hepg.hks.harvard.edu/files/hepg/files/wp278updated.pdf

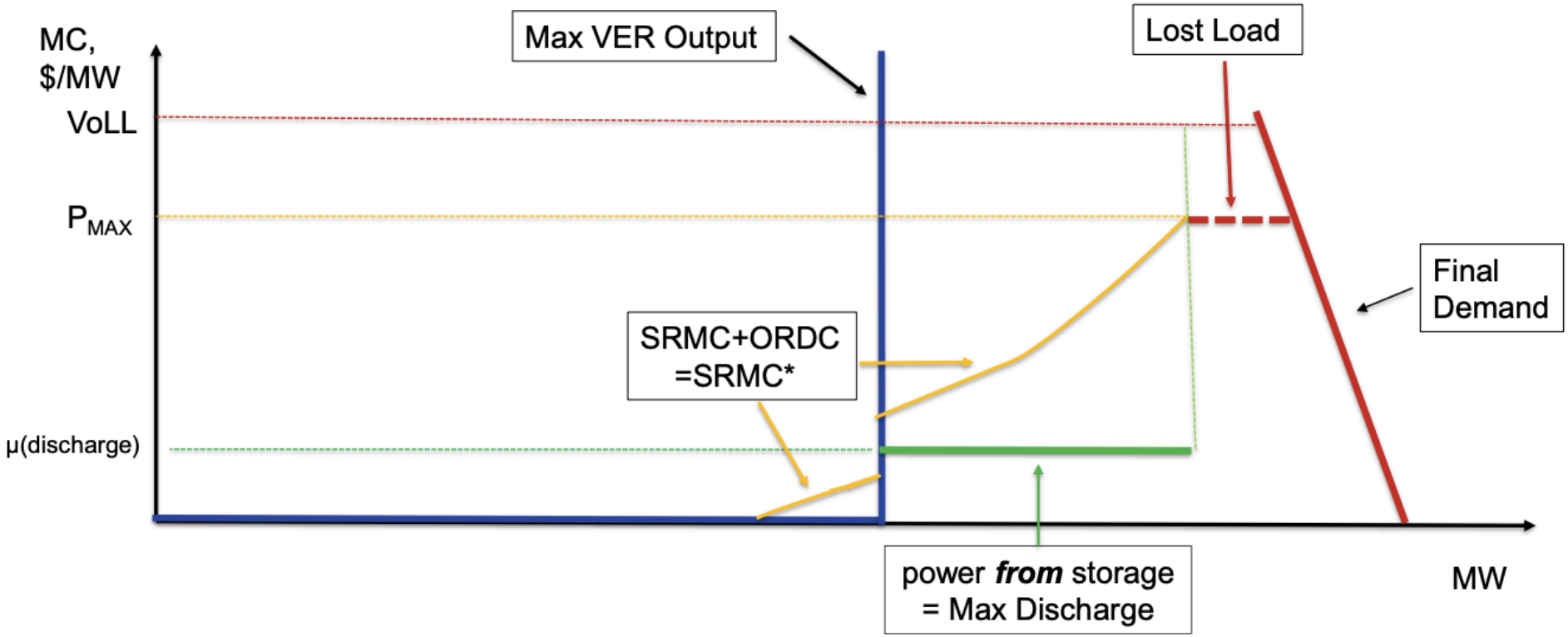
Balancing Supply and Demand: Pricing with Variable Energy Resources



Electricity Market Design and the Green Agenda, William Hogan, June 12, 2018
http://iaee2018.com/wp-content/uploads/2018/09/P2Hogan2018ppt.pdf

Balancing Supply and Demand: Pricing with Variable Energy Resources, Storage & Shortage

Very High Stress Equilbrium, P = P_{MAX}



R. Schmalensee, Decarbonized Electric Power Systems: Some Preliminary Results, Feb. 10, 2020
https://www.belfercenter.org/sites/default/files/Decarbonized_Electric_Power_Systems.pdf

Balancing Supply & Demand: Examples of Tradeoffs

1. Prescribing ancillary capabilities of variable energy resources provides more grid flexibility but allocates costs to ratepayers and may require changes to renewable procurement mechanisms

2. Separate mechanisms for resources adequacy and variable energy resources allow for different decisionmakers to achieve their objectives but risks inconsistency and incompatibility in actual operations

3. High energy prices may balance supply and demand but cause both political concerns, operational challenges and pricing issues

In Summary

1. Each of the three types of problems: political economy, economic/regulatory, and engineering must be addressed
2. These three problems may be solved inconsistently or incompletely and compounded by multiple and overlapping jurisdictions
3. Unless they are addressed in an integrated and consistent manner, political, economic, and reliability difficulties are likely to occur
4. Decisionmakers pursue their own strategic objectives
5. Important tradeoffs exist between different approaches
6. Much other work needs to be done to improve the electric power sector in conjunction with decarbonization efforts

QUESTIONS AND COMMENTS

Annotated References

Below is an annotated list of some of the references used in this presentation.

International Energy Agency, 2017, Status of Power System Transformation 2017: System Integration and Local Grids, https://webstore.iea.org/download/direct/298 Covers many countries and includes case studies of Australia, Indonesia, Mexico and South Africa.

Kroposki et al, Achieving a 100% Renewable Grid, IEEE Power & Energy Magazine, March/April 2017, http://ipu.msu.edu/wp-content/uploads/2018/01/IEEE-Achieving-a-100-Renewable-Grid-2017.pdf This article provides a non-technical description of the technical issues of operating a grid with 100% renewables.

NREL, Eastern Renewable Generation Integration Study, August 2016, https://www.nrel.gov/docs/fy16osti/64472.pdf Detailed study of up to 30% renewable generation in the eastern interconnection.

Reishus Consulitng LLC, Electricity Ancillary Services Primer, August 2017, http://nescoe.com/wp-content/uploads/2017/11/AnxSvcPrimer_Sep2017.pdf Prepared for the New England States Committee on Electricity (NESCOE).

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