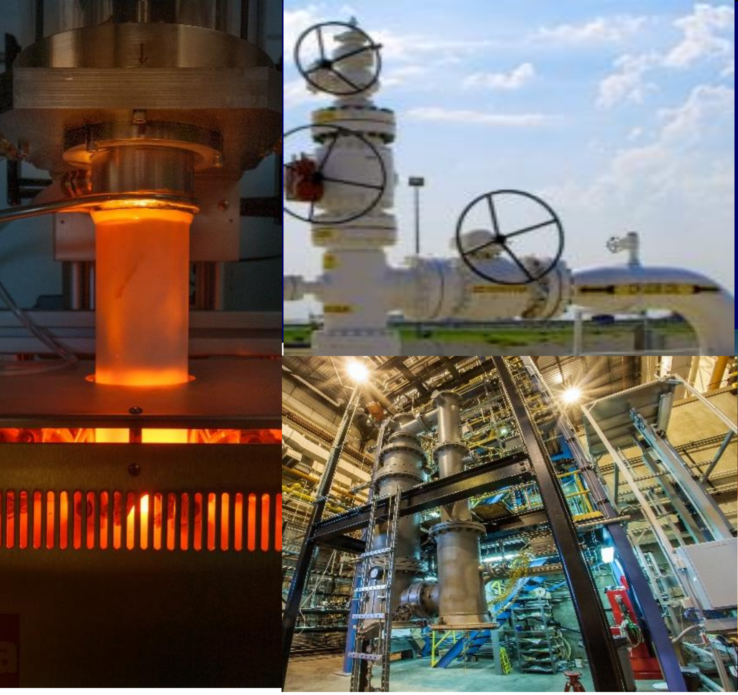

U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy

How To Ensure Energy Security Through Improved Reliability

Peter Balash, PhD
John Brewer
Ken Kern

National Energy Technology Laboratory

Western States Coal Strategies Forum | November 2019 | Moab, Utah

DECLINE OF FUEL-SECURE ELECTRICITY

Share of Coal and Nuclear Output and Capacity

Generation	2000	2005	2010	2015	2017
PJM ISO	95%	92%	86%	72%	67%
New York ISO	42%	40%	38%	32%	32%
New England ISO	55%	41%	41%	33%	32%
Midcontinent ISO	84%	80%	76%	64%	61%
Total Summer Capacity					
PJM ISO	77%	65%	64%	55%	50%
New York ISO	27%	23%	20%	17%	16%
New England ISO	35%	26%	27%	20%	17%
Midcontinent ISO	69%	55%	52%	49%	45%

Source:* *ABB Velocity Suite

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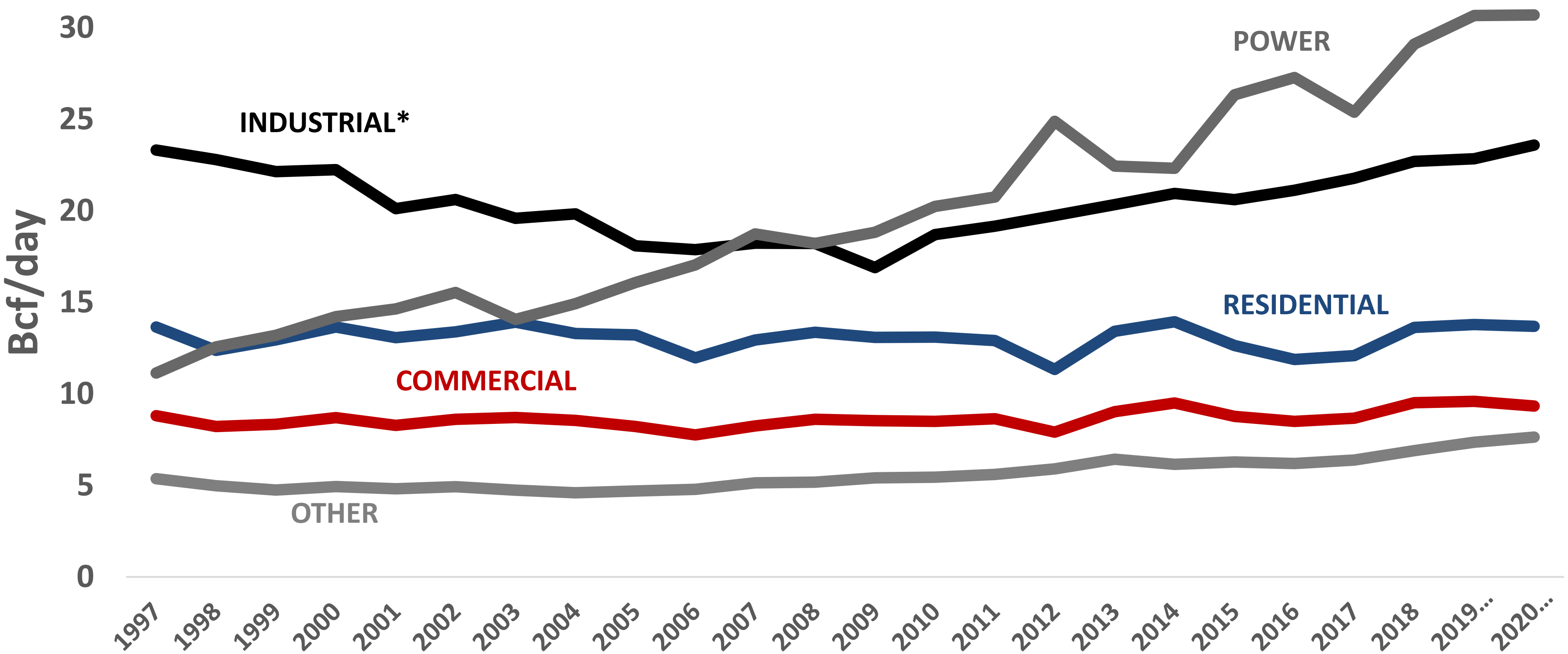
SECTORAL TRENDS IN U.S. NATURAL GAS CONSUMPTION



*Does not include Lease and Plant Fuel

Source: EIA, Short Term Energy Outlook

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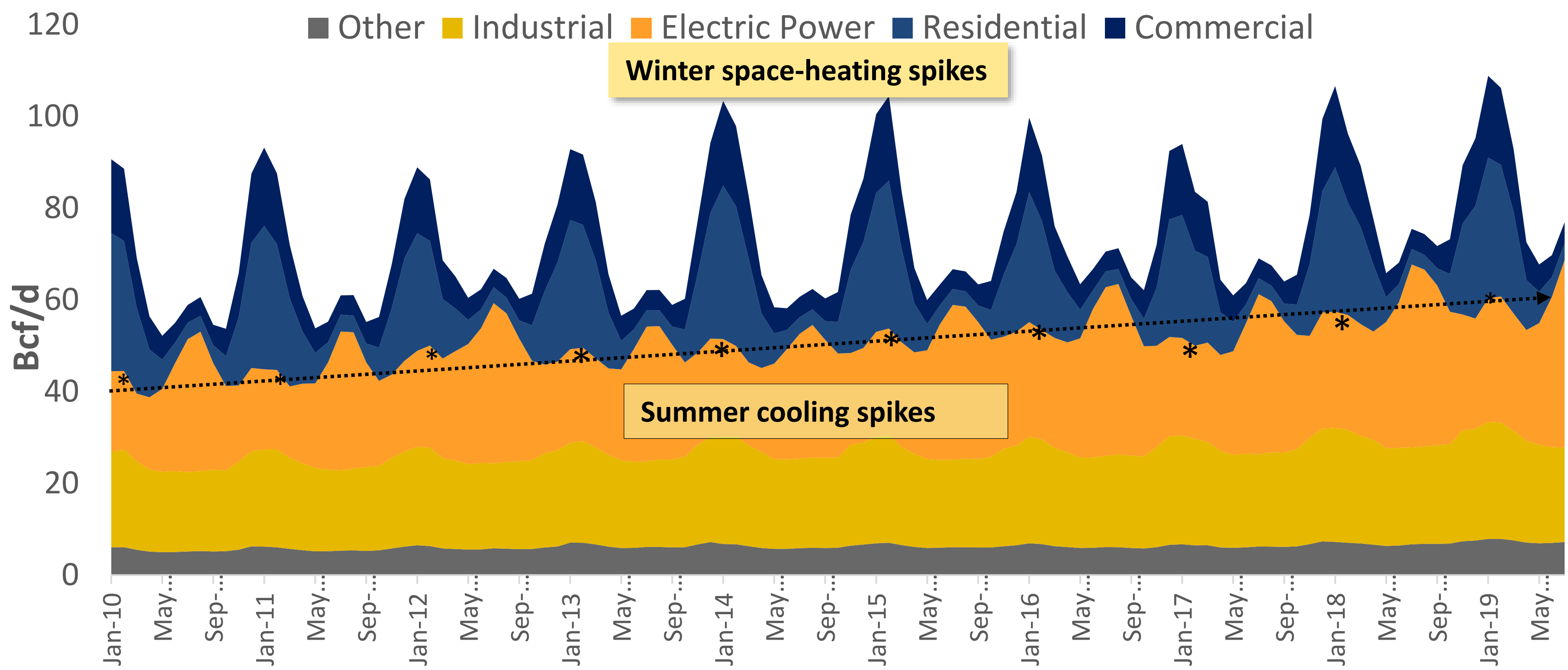
U.S. NATURAL GAS CONSUMPTION SEASONALITY

Rising winter PowerGen use exacerbating normal spike



Source: EIA, Short Term Energy Outlook (October 8, 2019 edition)

WHILE US GAS DEMAND FOR POWER HAS DOUBLED, STORAGE HAS CONTRACTED

Estimates of demonstrated peak and design capacity of underground working gas storage, November 2018
(billion cubic feet, unless otherwise noted)

	Demonstrated peak capacity[1]			Design capacity[2]			Demonstrated peak capacity share of design capacity[3]	
Region	(Dec 2012 - Nov 2017)	(Dec 2013 - Nov 2018)	percent change	Nov 2017	Nov 2018	percent change	Nov 2017	Nov 2018
East	990	983	0.6%	1,061	1,062	0.1%	93%	93%
Midwest	1,186	1,181	-0.4%	1,226	1,222	-0.3%	97%	97%
Mountain	270	261	-3.4%	466	471	0.9%	58%	55%
Pacific[4]	411	401	-2.5%	414	414	0.0%	99%	97%
South Central	1,460	1,437	-1.6%	1,558	1,543	-1.0%	94%	93%
Nonsalt	1,025	1,013	-1.2%	1,065	1,062	-0.3%	96%	95%
Salt	435	424	-2.5%	493	481	-2.4%	88%	88%
Lower 48	**4,317**	**4,263**	**-1.2%**	**4,725**	**4,712**	**-0.3%**	**91%**	**90%**

EIA Underground Natural Gas Working Storage Capacity

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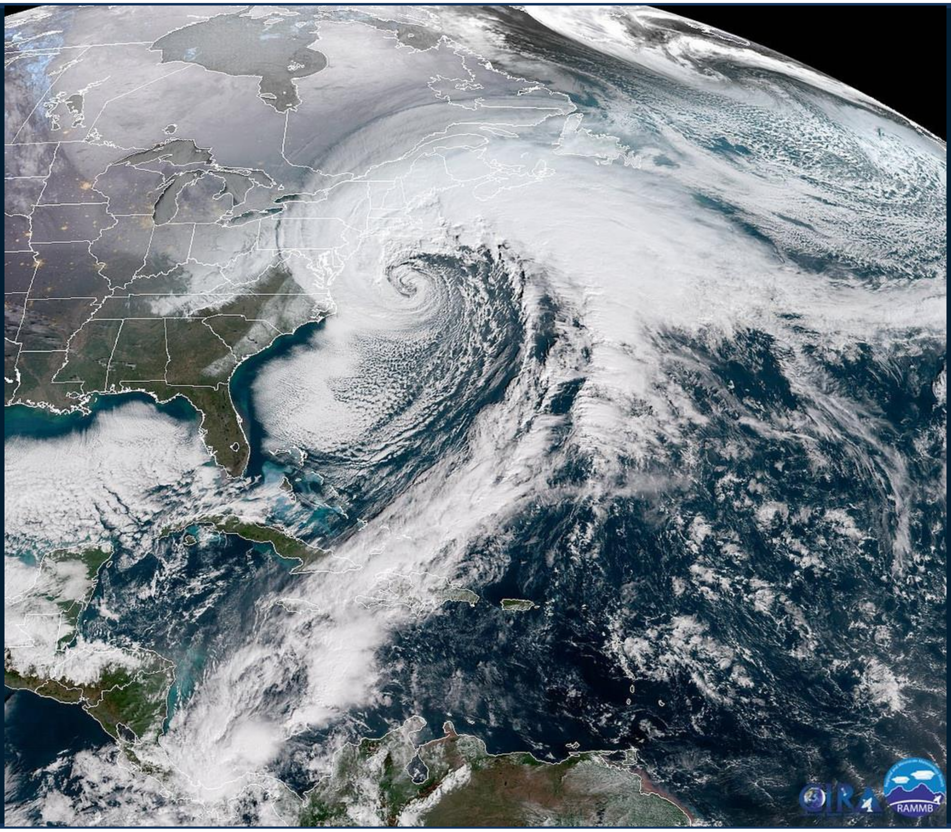
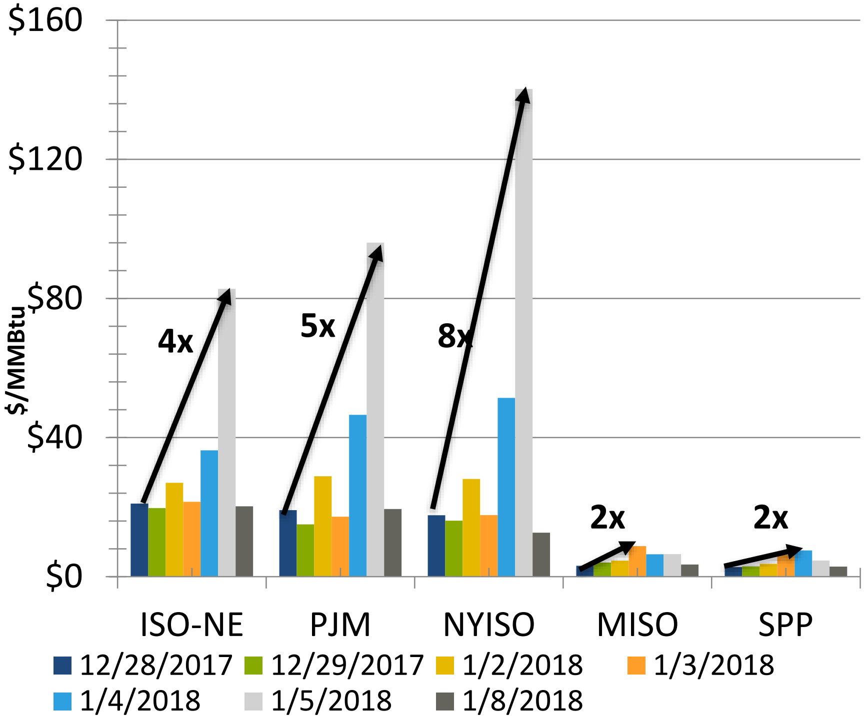
THE "BOMB CYCLONE"



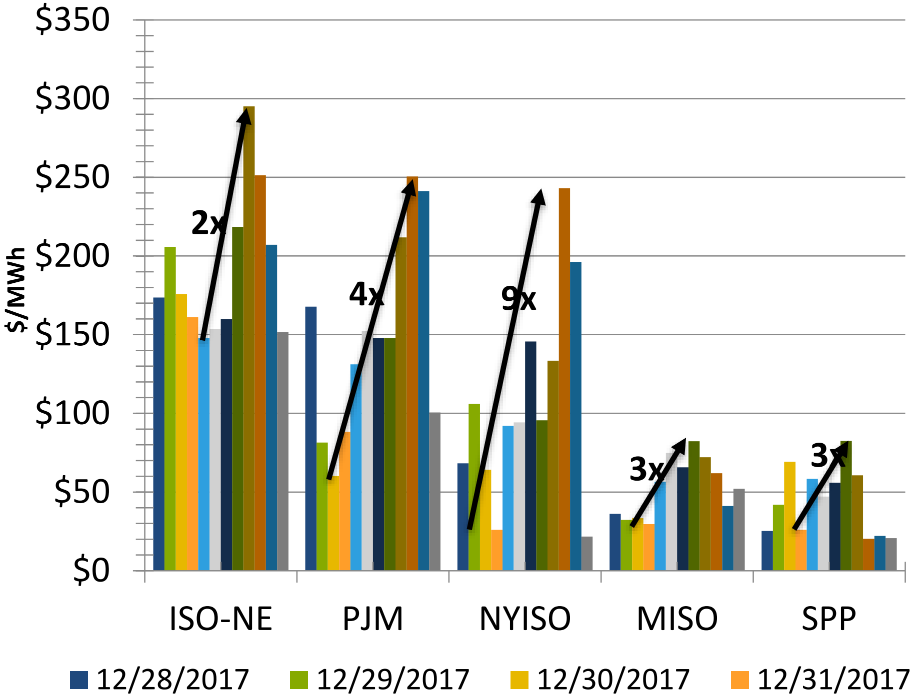
NOAA's GOES-16 (GOES-East) satellite caught a dramatic view of the bomb cyclone moving up the East Coast on January 4, 2018.

GAS AND POWER PRICE SPIKES

Regional natural gas spot prices, December 28, 2017–January 8, 2018



Daily load weighted average marginal electricity price, December 28, 2017–January 8, 2018



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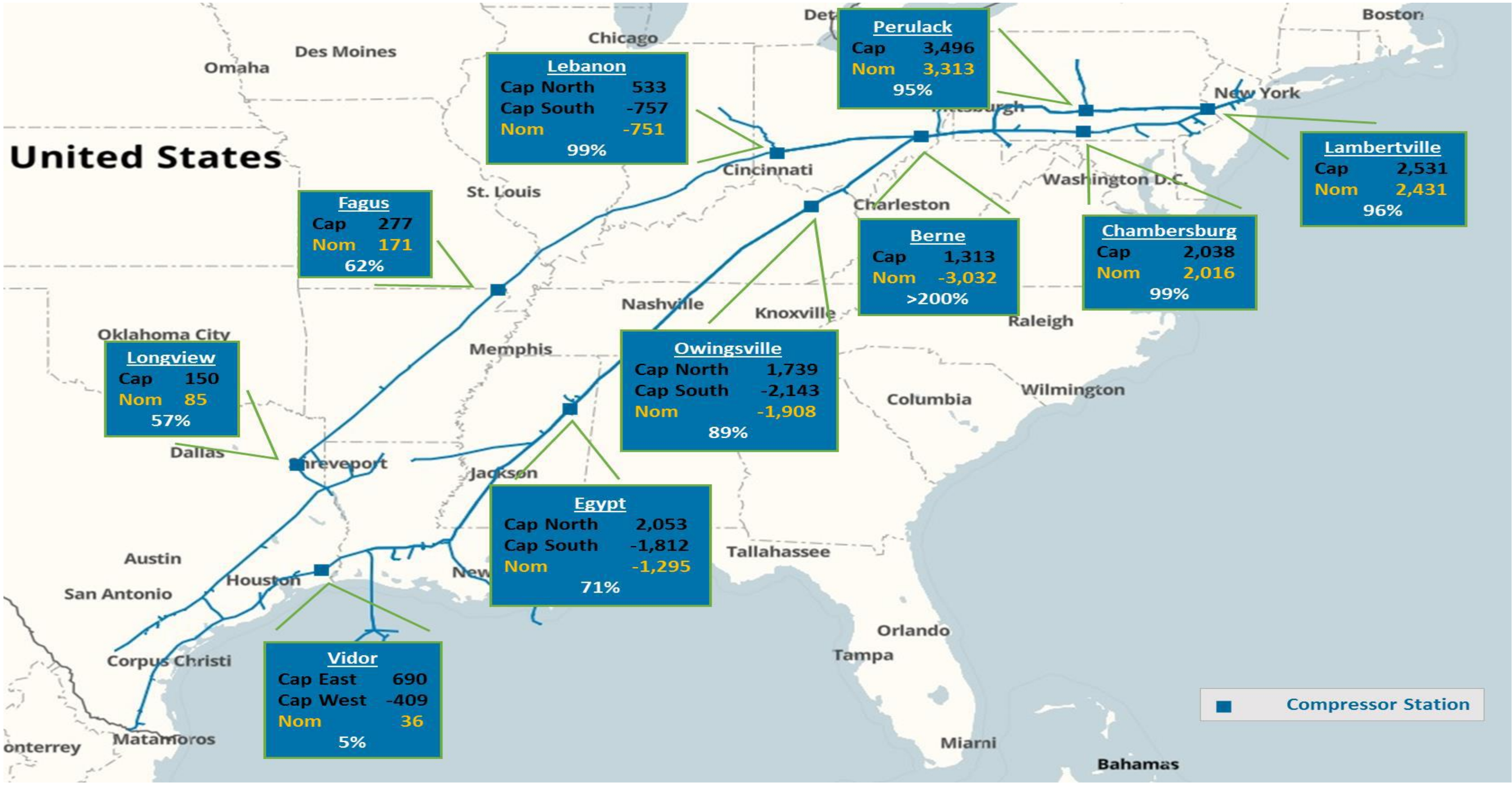
DELIVERABILITY CONSTRAINTS 1/7/18



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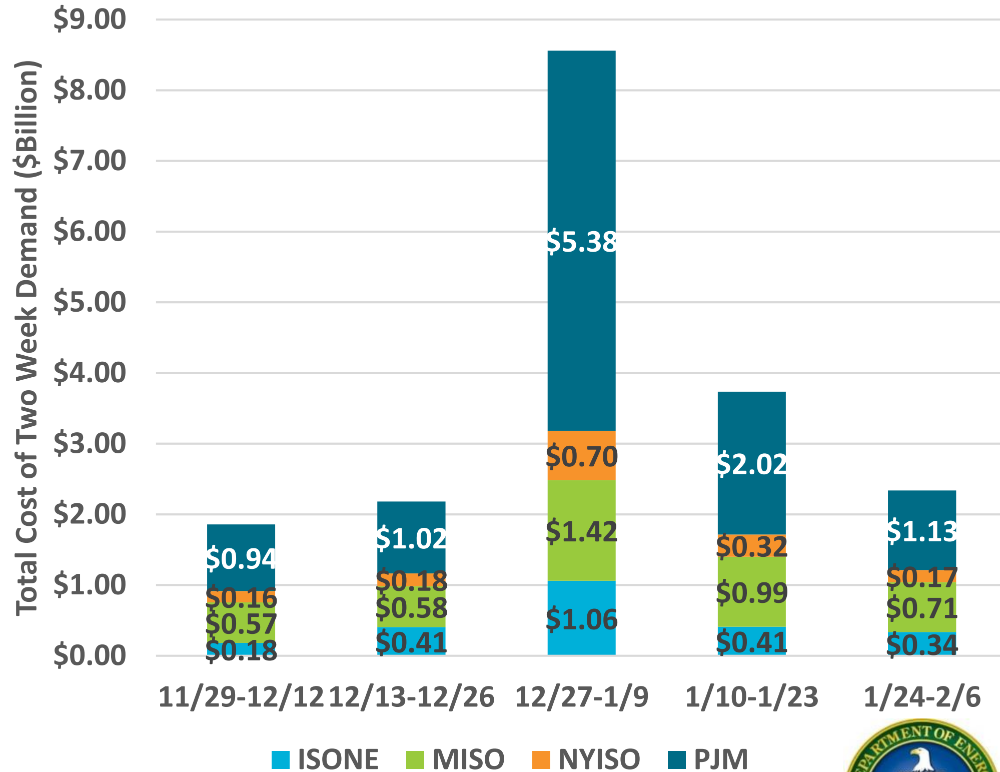
Cost of Serving Load

Electricity Costs for Three Winters with Extreme Events

		Billings ($B)	Delta from 2013-18 Average Quarter ($B)
PJM (9)	Q1 2014	$19.6	$9.4
	Q1 2015	$12.3	$2.1
	Q1 2018	$12.3	$2.1
	Regional Total	$44.2	$13.6
NYISO (10)	Q1 2014	$6.3	$4.4
	Q1 2015	$3.4	$1.4
	Q1 2018	$2.4	$0.4
	Regional Total	$12.1	$6.2
ISO-NE (11)	Winter 2014	$5.0	$3.5
	Winter 2015	$2.9	$1.3
	Winter 2018	$2.7	$1.1
	Regional Total	$10.6	$5.9
MISO (12)	Q1 2014	$3.7	$1.7
	Q1 2015	$2.0	$0.1
	Q1 2018	$2.1	$0.1
	Regional Total	$7.8	$1.9
Northeast U.S. three extreme winter event total cost			$27.6 Billion

PJM, ISO-NE and New York, NETL calculates that natural gas price "excursions" led to electricity price increases that cost consumers, ultimately, over $25 billion since 2014.



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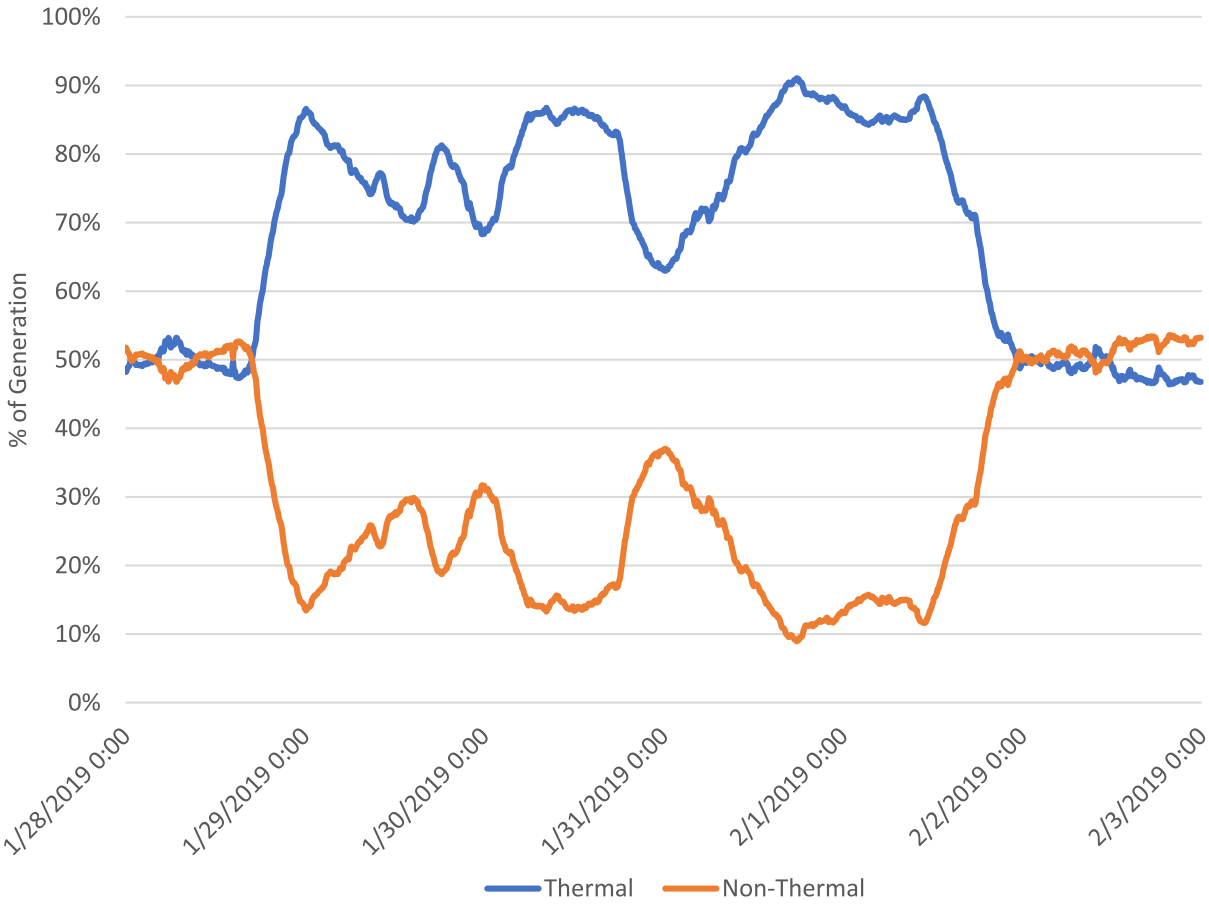
RESOURCE DRIVEN INDUCED POWER SUPPLY VOLATILITY

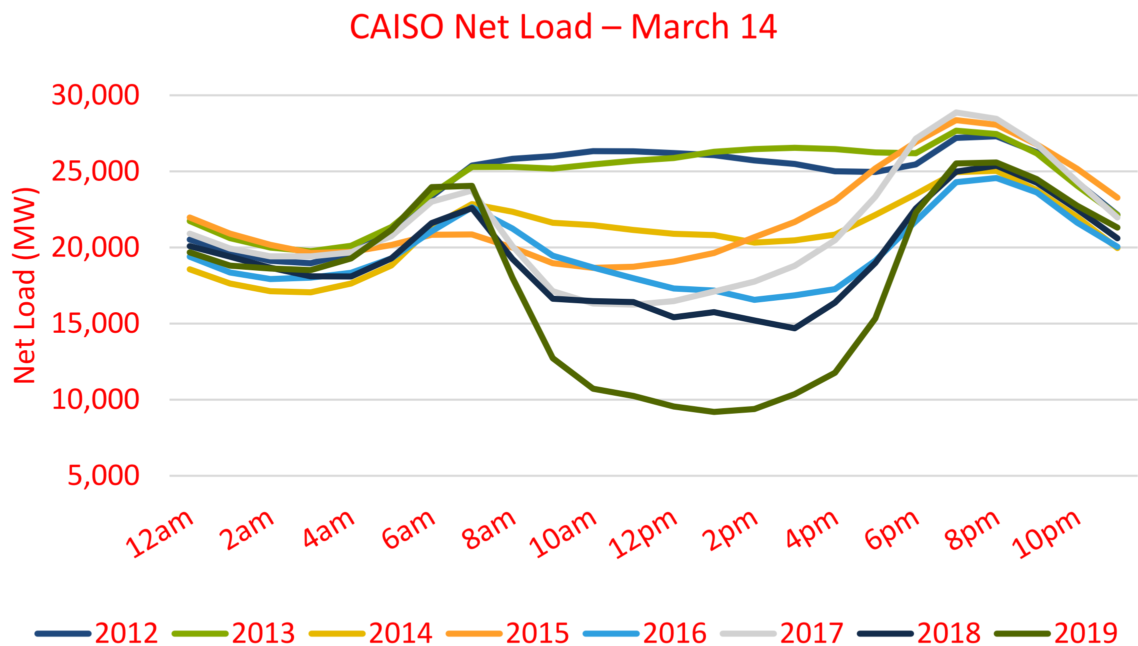
Variable resources sudden loss in generation led to a spike in thermal generation during 2019 winter storm in SPP



- **Non-thermal output fell from 50% to below 10% over 12-hour period**
- **Thermal resources in place made up for the sudden loss**
- **Future resources to cover such an event are in doubt**

OVERSUPPLY OF GENERATION THREATENS GRID STABILITY

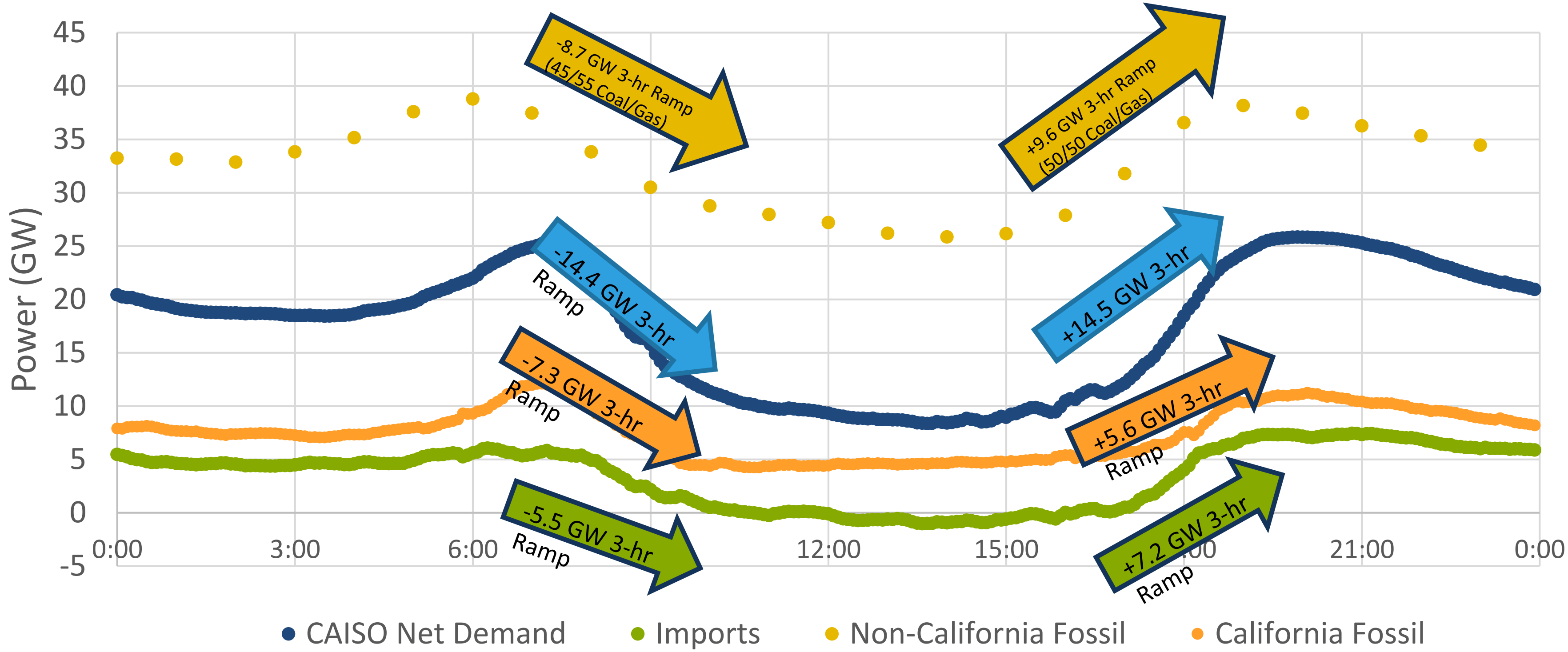
Oversupply of generation from intermittent renewable sources = "need" for flexible generation from elsewhere; is grid stability affected?



Data from CAISO via ABB Velocity Suite

AT CAISO'S DEEPEST DUCK CURVE OF 2019 (3/14)

Out of state fossil assets bore more than 50% of the ramp response with the balance provided by in-state fossil assets



California data from CAISO Today's Outlook archive
Non-California fossil generation data from EPA Air Markets Program Data (CEMS)

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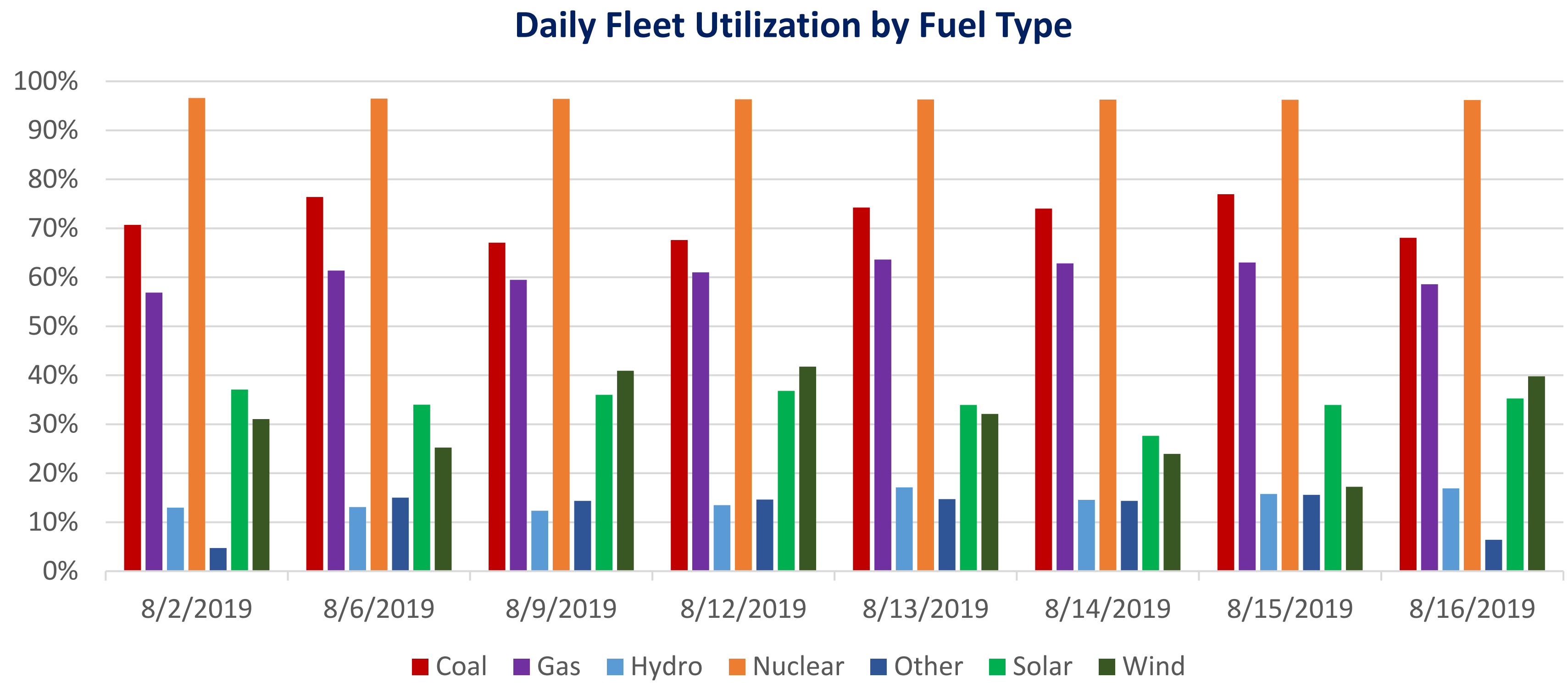
ERCOT RELIED HEAVILY ON FOSSIL FUELS DURING PEAK SUMMER 2019 DEMAND

Coal, nuclear and gas carried ERCOT during 2019 summer peak



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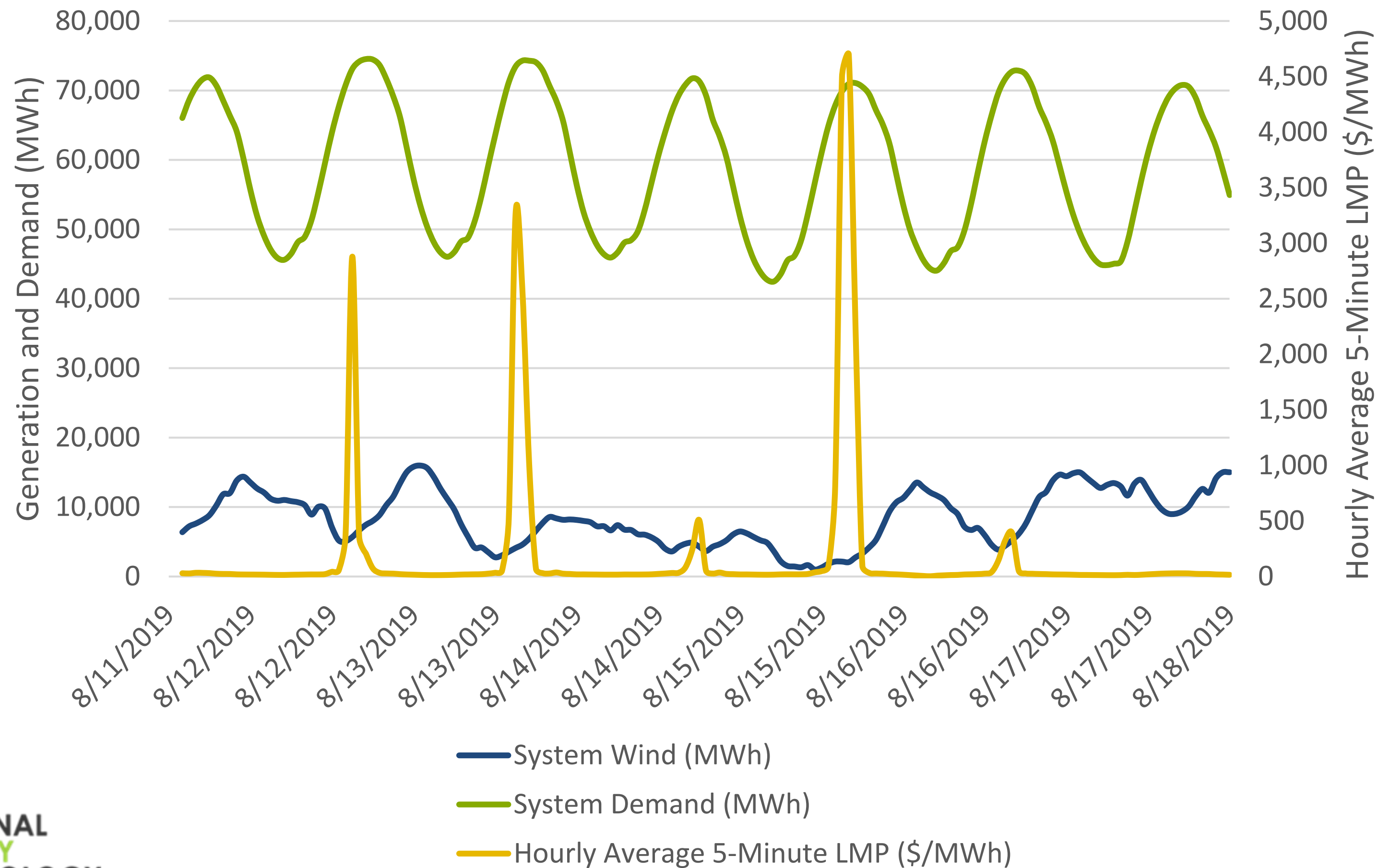
WIND GENERATION IN ERCOT WAS NOT RELIABLE DURING THE 2019 SUMMER PEAK

Lowest wind output at highest system demand



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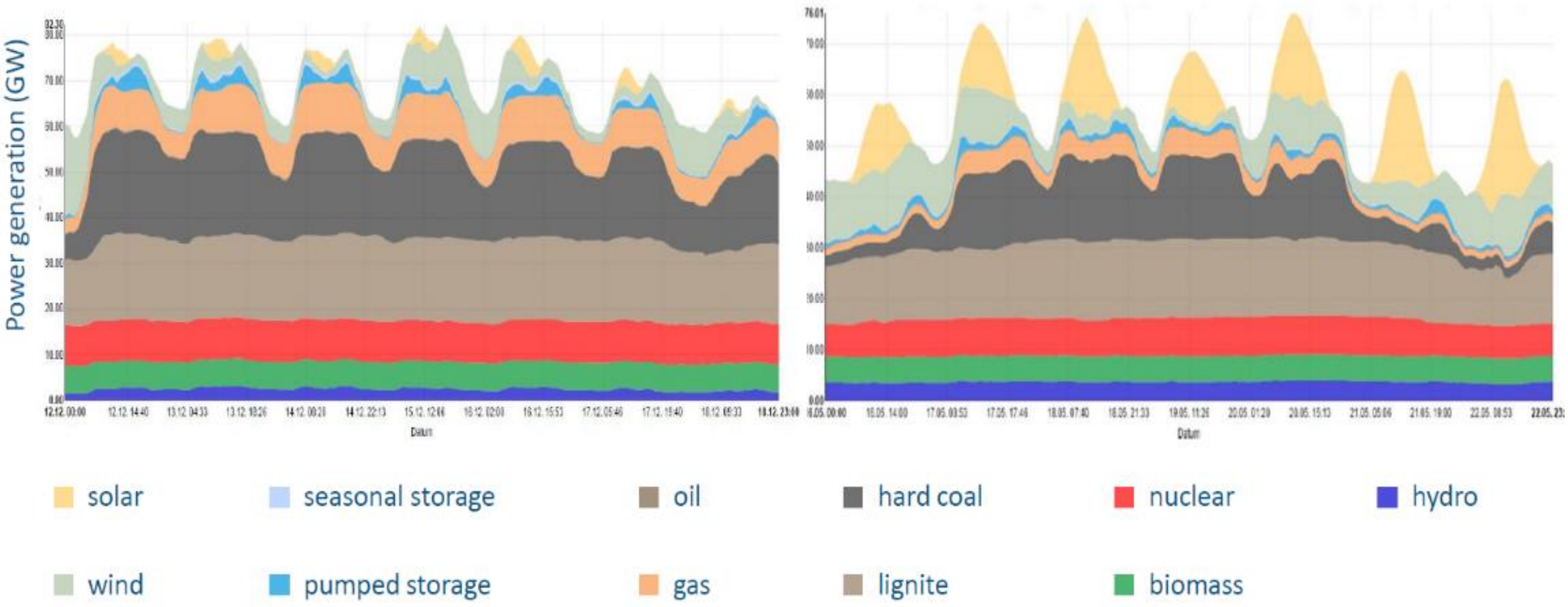
Germany – Renewable fluctuation and Gas/Coal backup

Winter 2016
week no. 50 (December)

Summer 2016
week no. 20 (May)



Source: Energie Wende

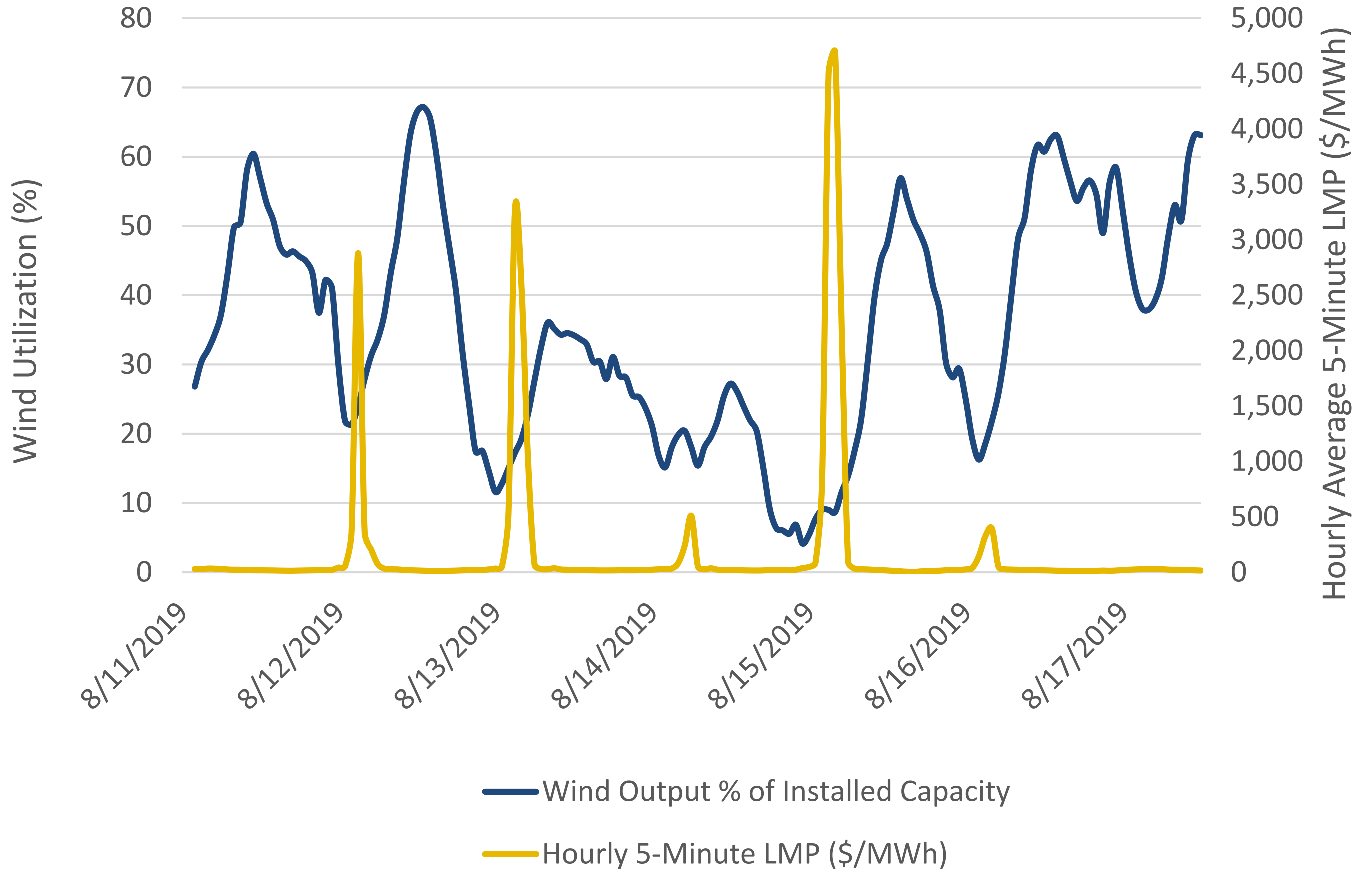
Questions?

U.S. DEPARTMENT OF ENERGY | Office of Fossil Energy

Angelos.Kokkinos@hq.doe.gov

WIND GENERATION IN ERCOT WAS NOT RELIABLE DURING THE 2019 SUMMER PEAK

Wind output and price inversely correlated



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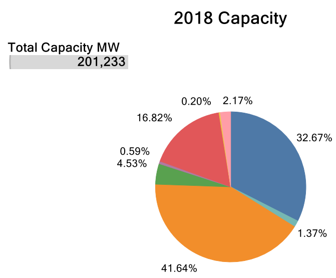
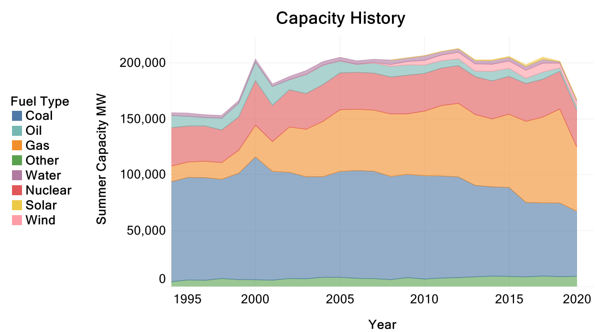
PJM and MISO have seen significant reductions in coal and nuclear generating capacity

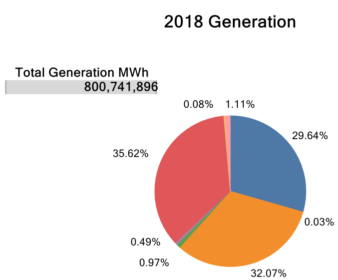
In PJM, lost coal replaced mainly by natural gas, adding significant pressure on just-in-time delivery and pipeline capacity.

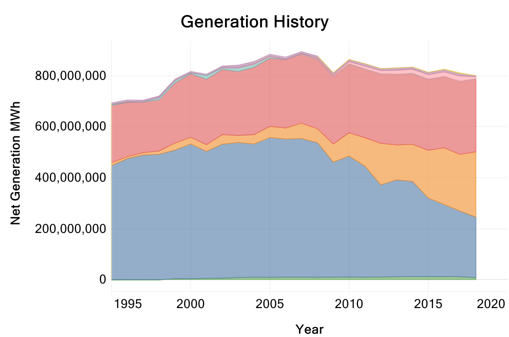


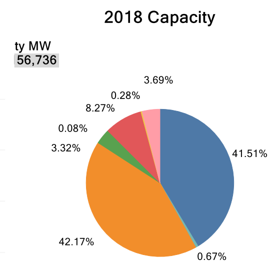


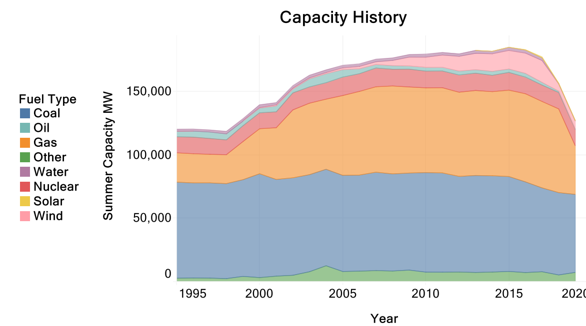
Similarly for MISO but with additional generation coming from wind power.

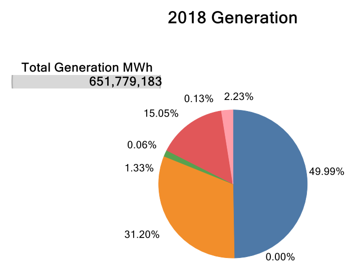
Coal and nuclear generate electricity at a higher percentage of their capacity than gas, wind and solar

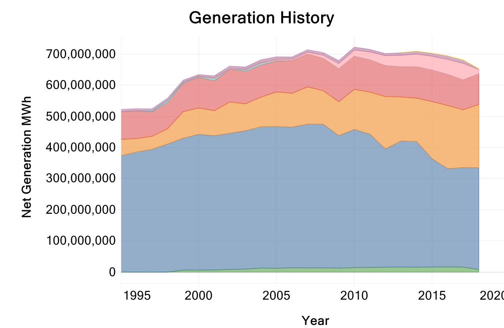








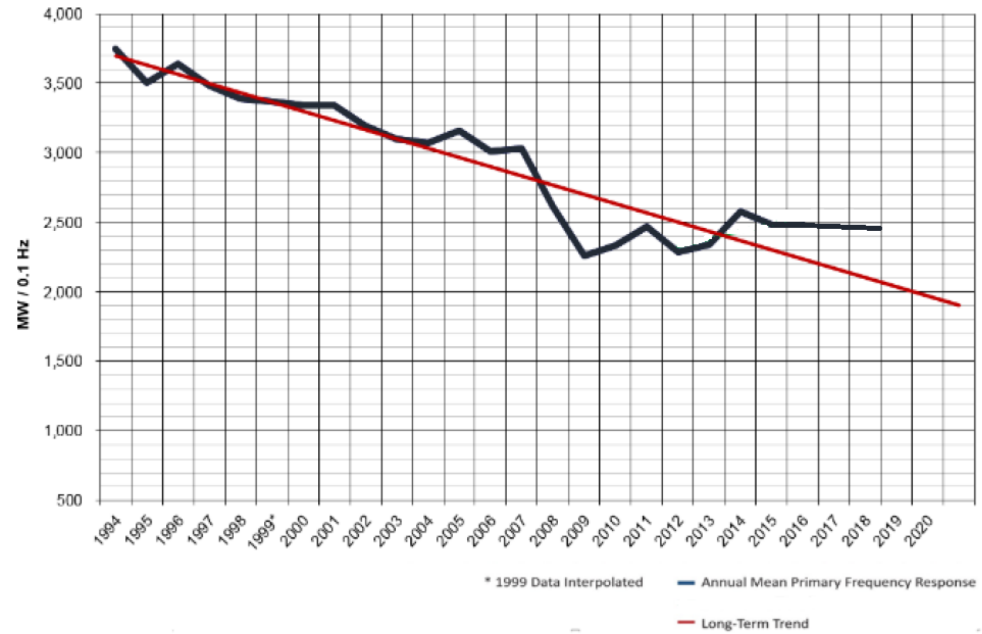




Increased intermittent generation increases the need for frequency response

- **Over the past several decades, NERC has observed the development of frequency stability issues**
- **Several causes of this trend have been identified, including load types, system moments of inertia, generation control practices, types and availability of reserves, and monitoring/regulating practices.**
- **As the generation fleet transitions to smaller intermittent and distributed generation, the system will have less kinetic energy (system inertia) available to mitigate frequency disruptions, potentially leading to BPS instabilities.**

Eastern Interconnection frequency response trend



Frequency values from NERC State of Reliability and Frequency Response Annual Analyses.

Yearly number of frequency events

Interconnection	2009	2010	2011	2012	2013	2014	2015	2016	2017
Eastern	25	29	25	12	32	34	36	61	81
Western	44	49	65	28	13	17	21	47	41
ERCOT	51	67	65	63	40	33	34	50	49
Quebec	-	-	20	28	35	33	29	47	73

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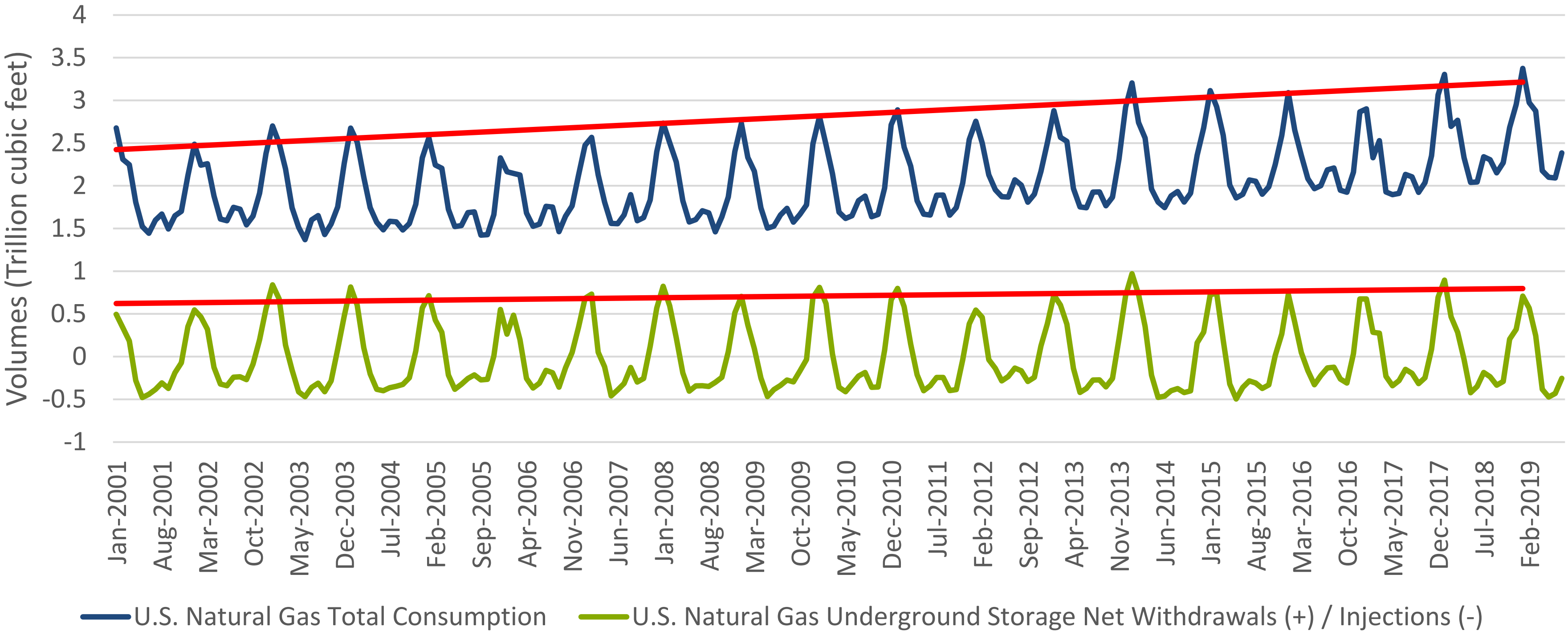
CURRENT GAS PRODUCTION IS PLAYING A GROWING ROLE IN SUPPLYING PEAK GAS DEMAND



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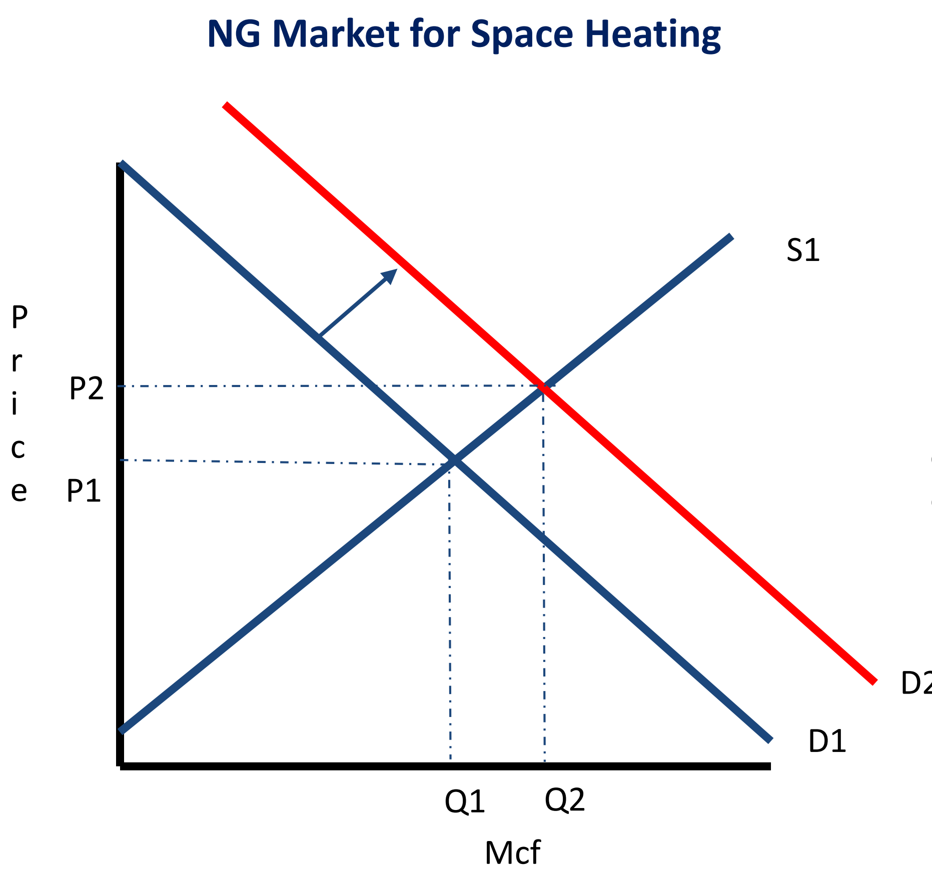
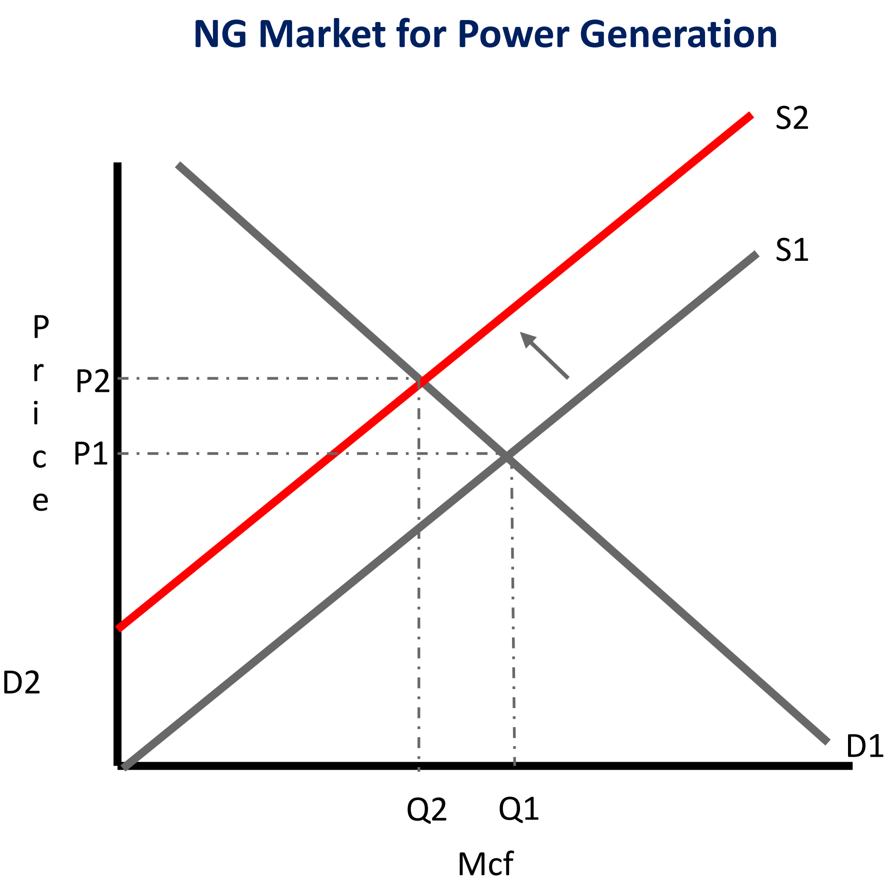
EFFECT OF A DRAMATIC INCREASE IN HEATING DEGREE DAYS ON NG MARKETS

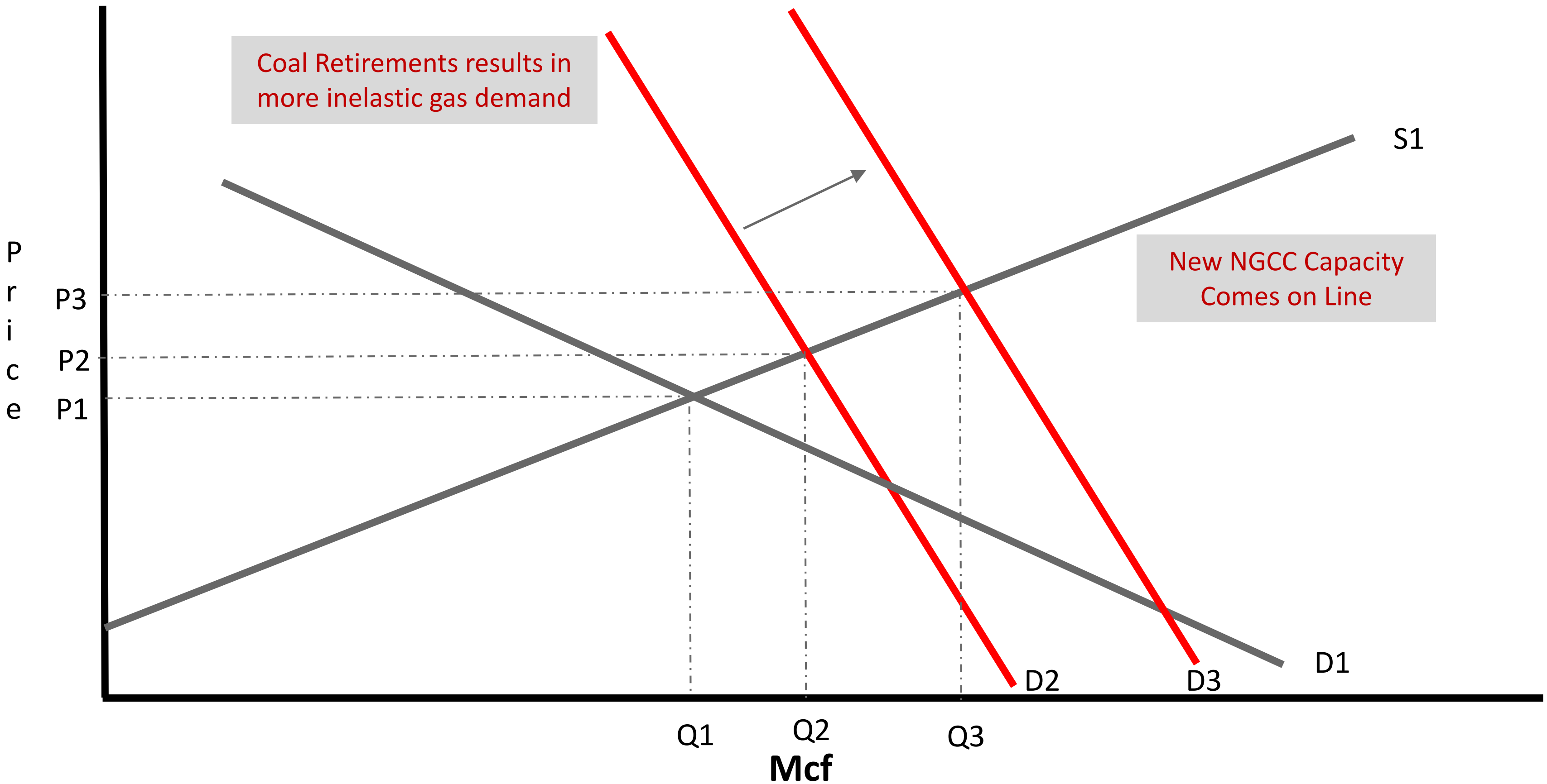


More HDDs shifts NG outward, raising price and consumption



Draw from space heating removes available supply for power generation, reducing consumption

POWER GENERATION MARKET: DEMAND FOR NG 2019



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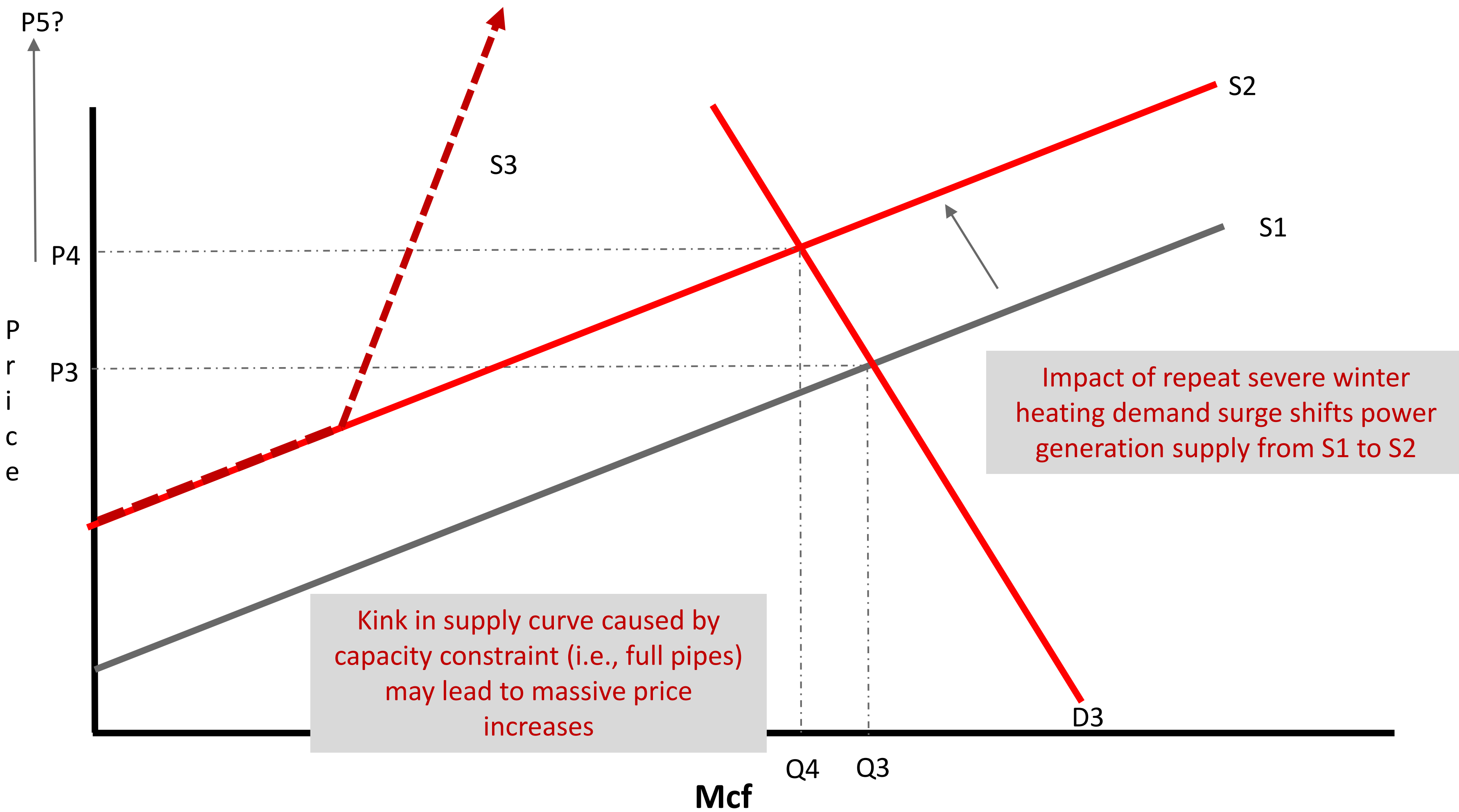
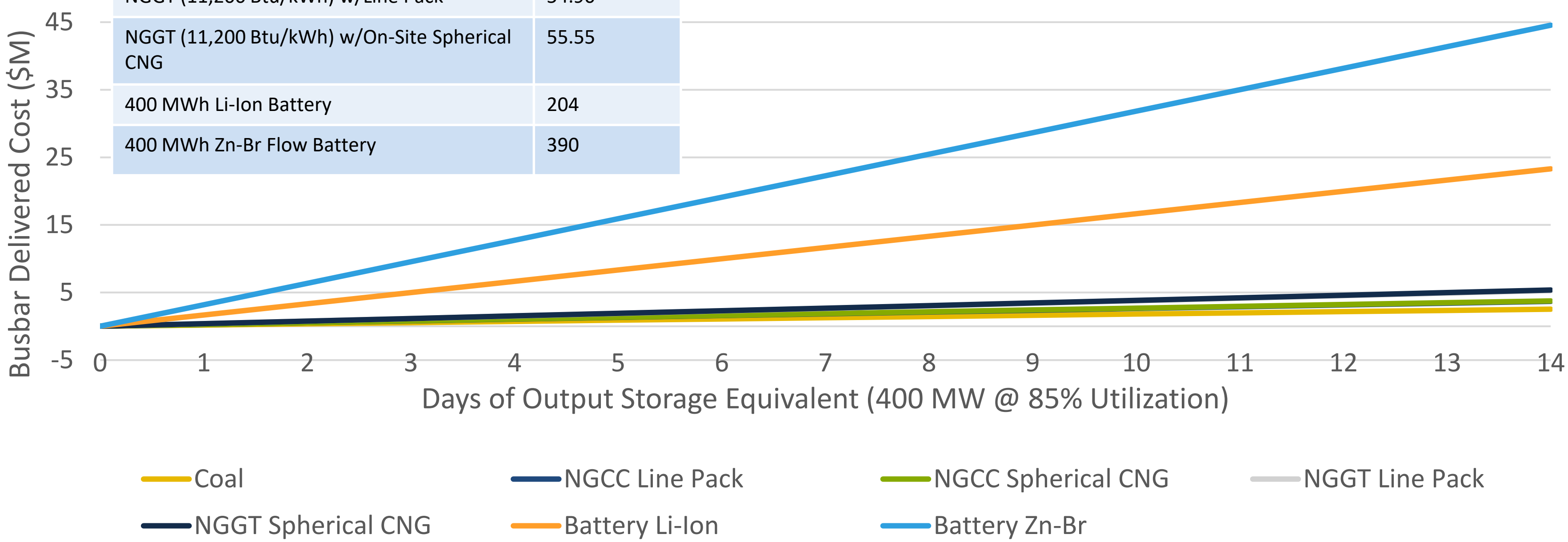
EXTREME WINTER EVENT



A COAL PILE IS THE CHEAPEST FORM OF ENERGY STORAGE DELIVERED TO THE BUSBAR

Technology	Cost ($/MWh)
Coal (10,000 Btu/kWh)	31.15
NGCC (7,700 Btu/kWh) w/Line Pack	35.91
NGCC (7,700 Btu/kWh) w/On-Site Spherical CNG	36.56
NGGT (11,200 Btu/kWh) w/Line Pack	54.90
NGGT (11,200 Btu/kWh) w/On-Site Spherical CNG	55.55
400 MWh Li-Ion Battery	204
400 MWh Zn-Br Flow Battery	390

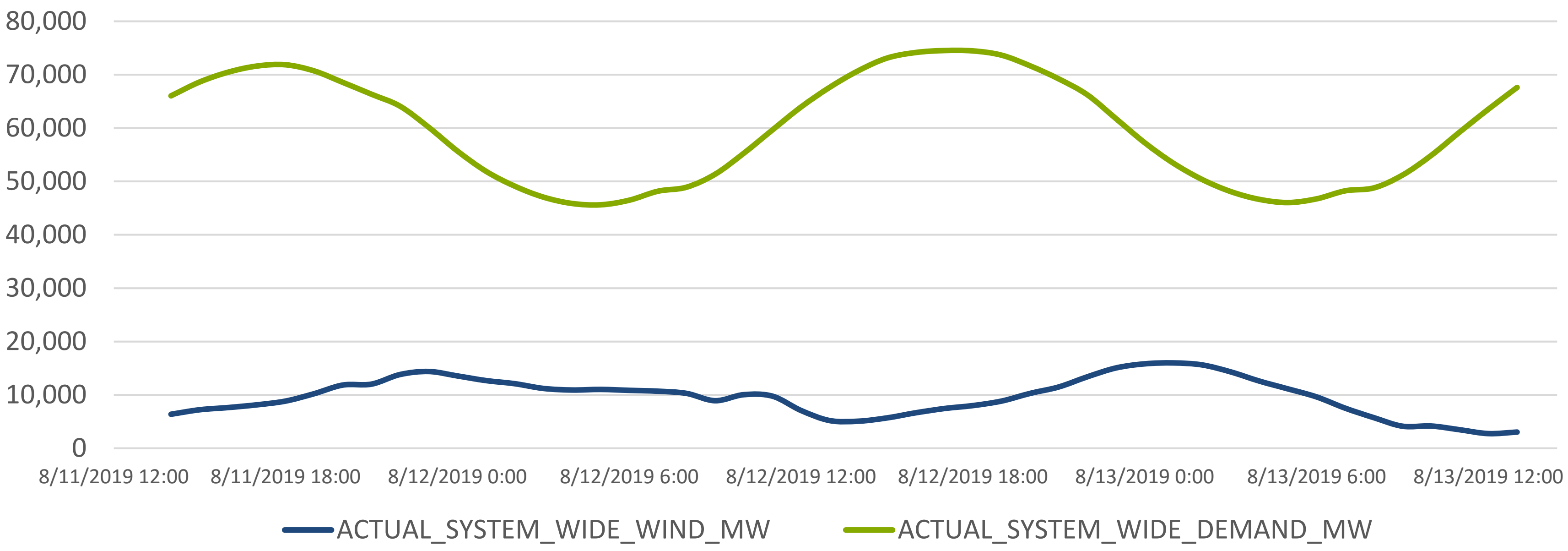


Storage technology options represent the lowest and highest cost options for gas and battery to show the potential range

Heat rates and fuel costs from EIA Electric Power Annual
NGCC/NGGT/Coal O&M costs from Lazard Levelized Cost of Energy Analysis 12.0
Gas infrastructure costs from DOE/NETL-2017/1816
Coal infrastructure costs from Doyle Trading Consultants
Battery costs from Lazard Levelized Cost of Storage 4.0

ERCOT SYSTEM DEMAND VS WIND OUTPUT

8/11/2019 1400 CDT to 8/13/2019 1300 CDT



Hour Ending
http://ercot.com/gridinfo/generation

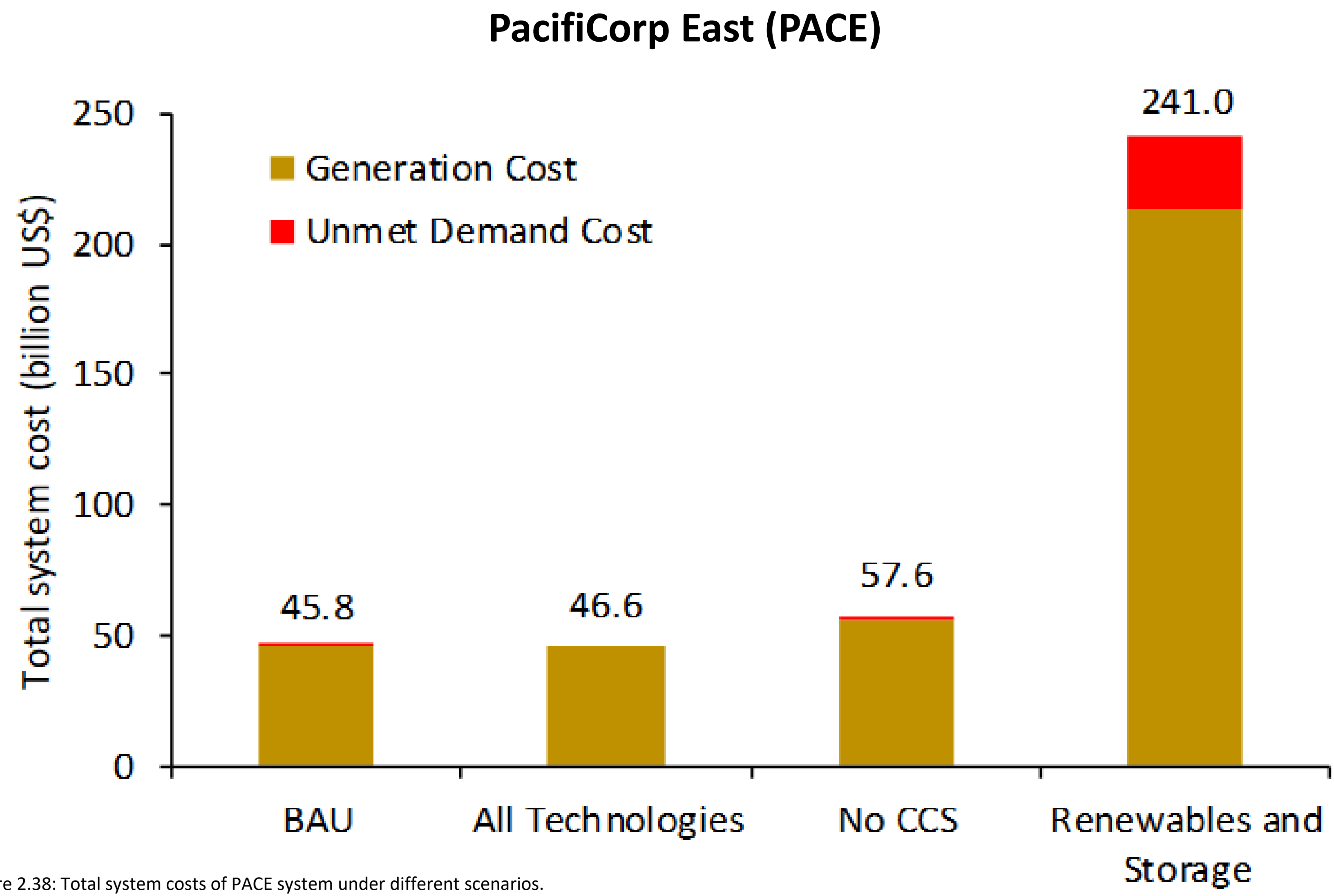
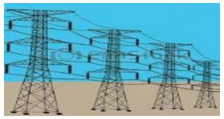
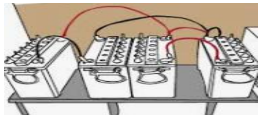


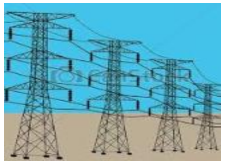
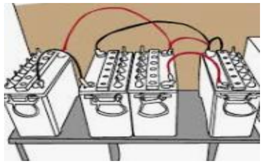
Figure 2.38: Total system costs of PACE system under different scenarios.

Source: Imperial College London, “The role and value of CCS in different national contexts” report for the CIAB

THE CHALLENGE FOR RENEWABLE ENERGY....RELIABILITY AND COST


Solar
+

In remote areas
+

4 Hour backup
+

Long term
Back-up + CCS
Grid ancillary services
=
0% GHG


Wind
+

In remote areas
+

4 Hour backup
+

Long term
Back-up + CCS
Grid ancillary services
=
0% GHG



Coal First
+
Unlikely, generally located near urban areas and existing lines
+
On-site secure fuel
+
NO Need
=
0% GHG

Coal First Less Expensive Option

Coal FIRST: THE FUTURE OF POWER GENERATION

(Flexible, Innovative, Resilient, Small, Transformative)

Secure, Stable, Reliable Power
Near-Zero Emissions

Flexible **coal plant operations to meet the needs of the grid**

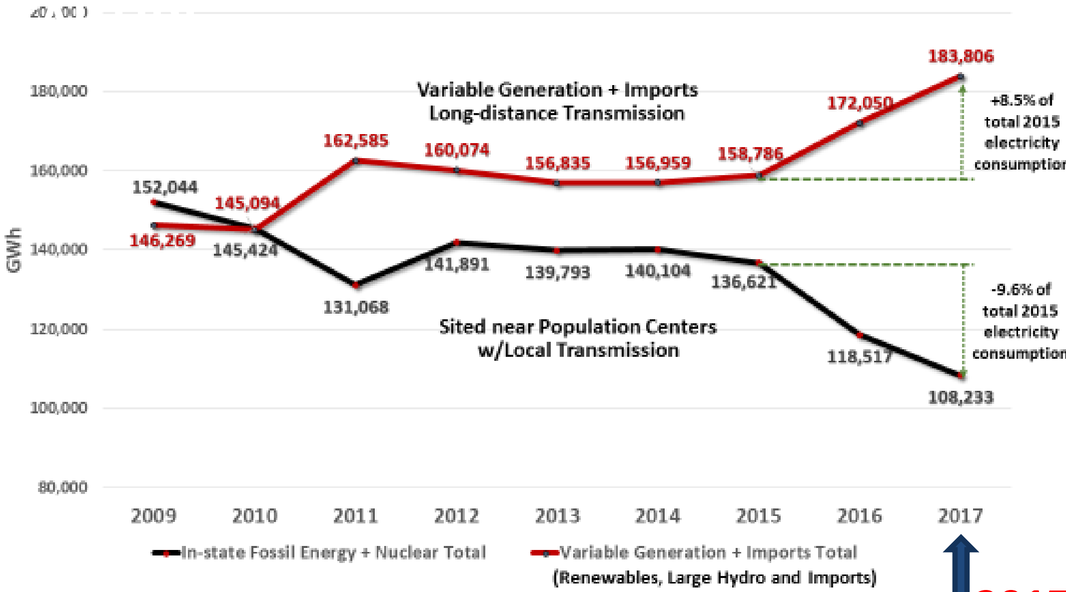
Transforms **how coal technologies are designed and manufactured**

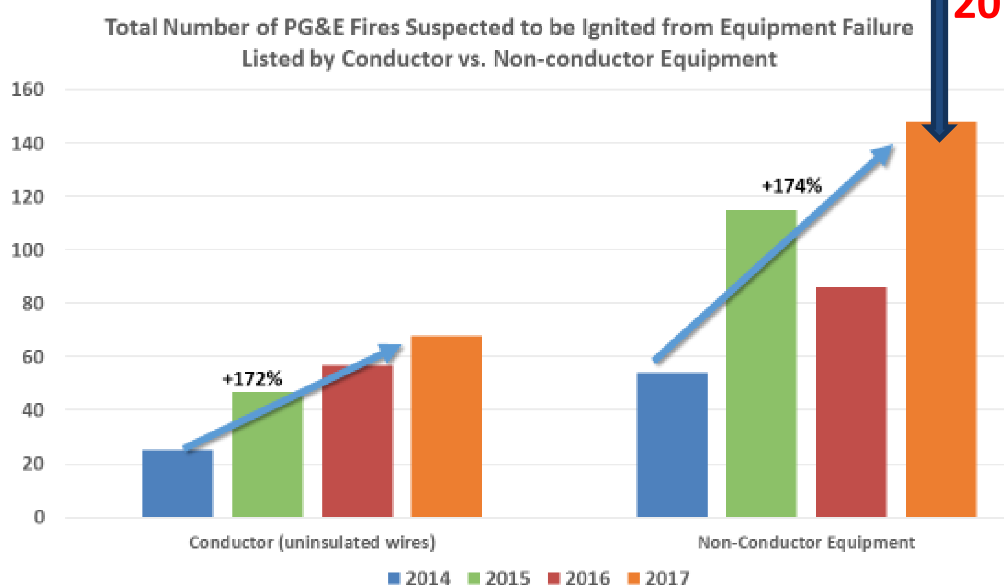
Innovative **and cutting-edge components; improved efficiency and near-zero emissions**

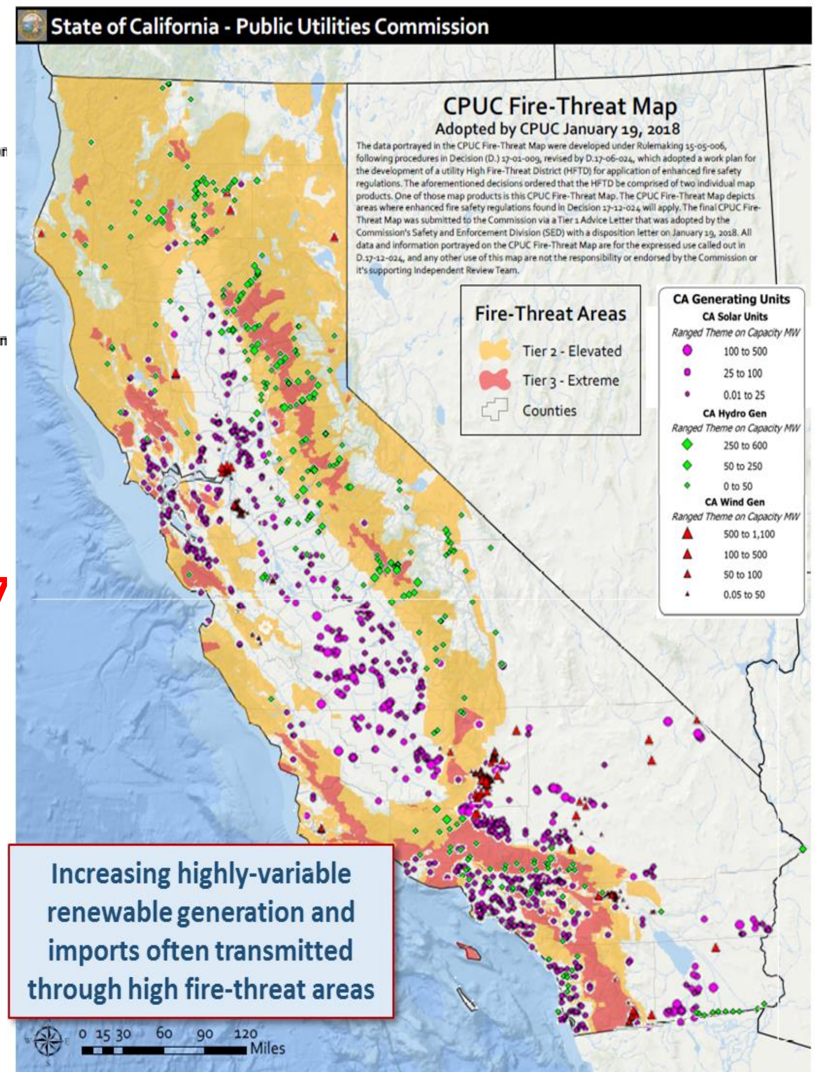
Smaller **than conventional utility-scale coal plants**

Resilient **power generation**

LOCATION OF GENERATING SOURCES, GWH OF VARIABLE AND LONG-DISTANCE TRANSMISSION AND EQUIPMENT





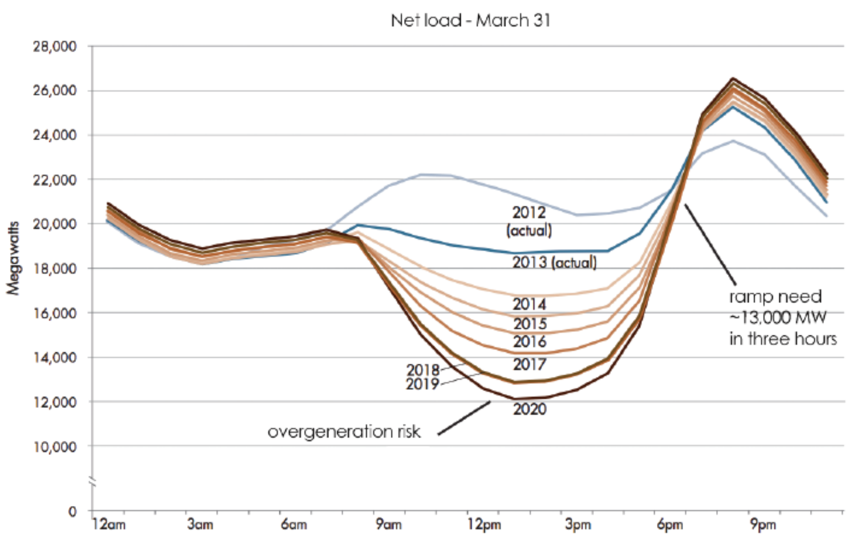


Increasing highly-variable renewable generation and imports often transmitted through high fire-threat areas

"DUCK CURVE" TIME OF DAY, EXCESSIVE OVER-HEATING

Figure 3.9 California ISO Projected Electricity Supply

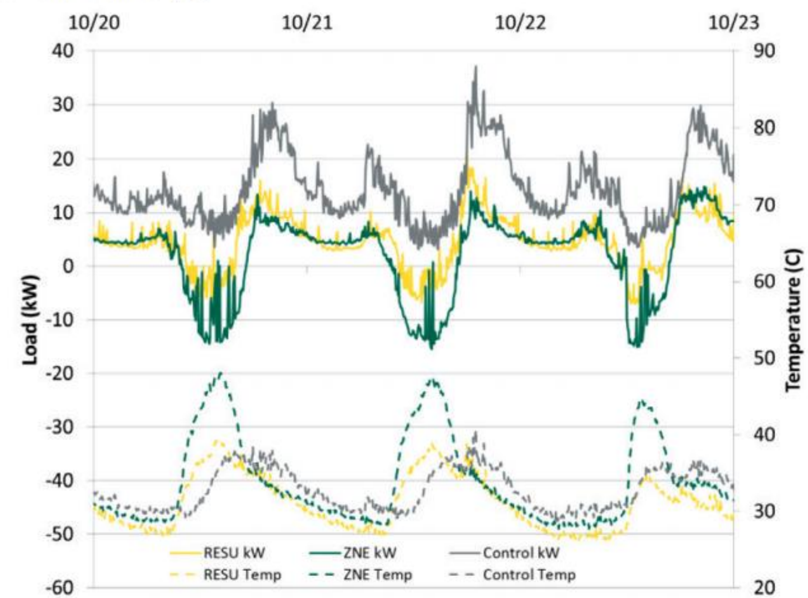
Credit: California Independent System Operator Corporation



In projected scenarios, variable renewable generation is plentiful midday, but decreases just as energy demand spikes in the early evening—requiring increased system flexibility to meet challenges with steep ramps and over-generation risks. Note the offset of the vertical scale.

Figure 3.F.2 Excessive Transformer Heating

Credit: Southern California Edison Company



"Distributed energy resources also introduce new challenges, with reversed power flows, increased harmonics, and potentially larger fault currents on distribution systems. For example, reverse power flow can result in excessive heating of distribution transformers"

DOE Quadrennial Technology Review 2015

GRID RELIABILITY & SECURITY:

WHOLESALE POWER MARKET RECOGNIZES THERE'S A PROBLEM

"the possibility that power plants won't have or be able to get the fuel they need to run, particularly in winter—is the ***foremost challenge to a reliable power grid in New England***."

ISO New England

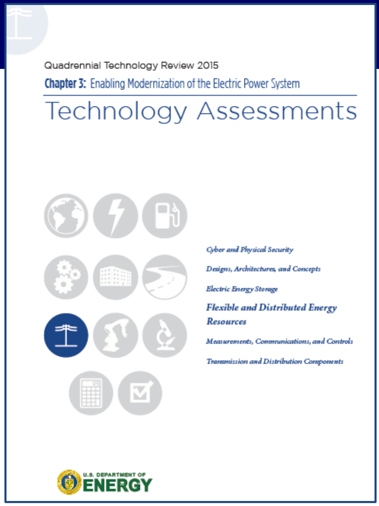
Fuel Security

Analyzing Fuel Supply Resilience in the PJM Region

"While there is **NO** imminent threat, **Fuel Security is an important component of ensuring reliability** – especially if multiple risks come to fruition. The findings underscore the importance of PJM exploring proactive measures to value fuel security attributes, and PJM believes this is best done through competitive wholesale markets"

CASIO- Summer 2018- The continuing decline in gas generation as gas units retire is beginning to challenge the system supply's ability to meet the net peak demand after sunset

CALIFORNIA REGULATORS KNEW THE IMPLICATIONS TO THEIR GRID IN 2015



Quadrennial Technology Review 2015

Transmission and Distribution Components

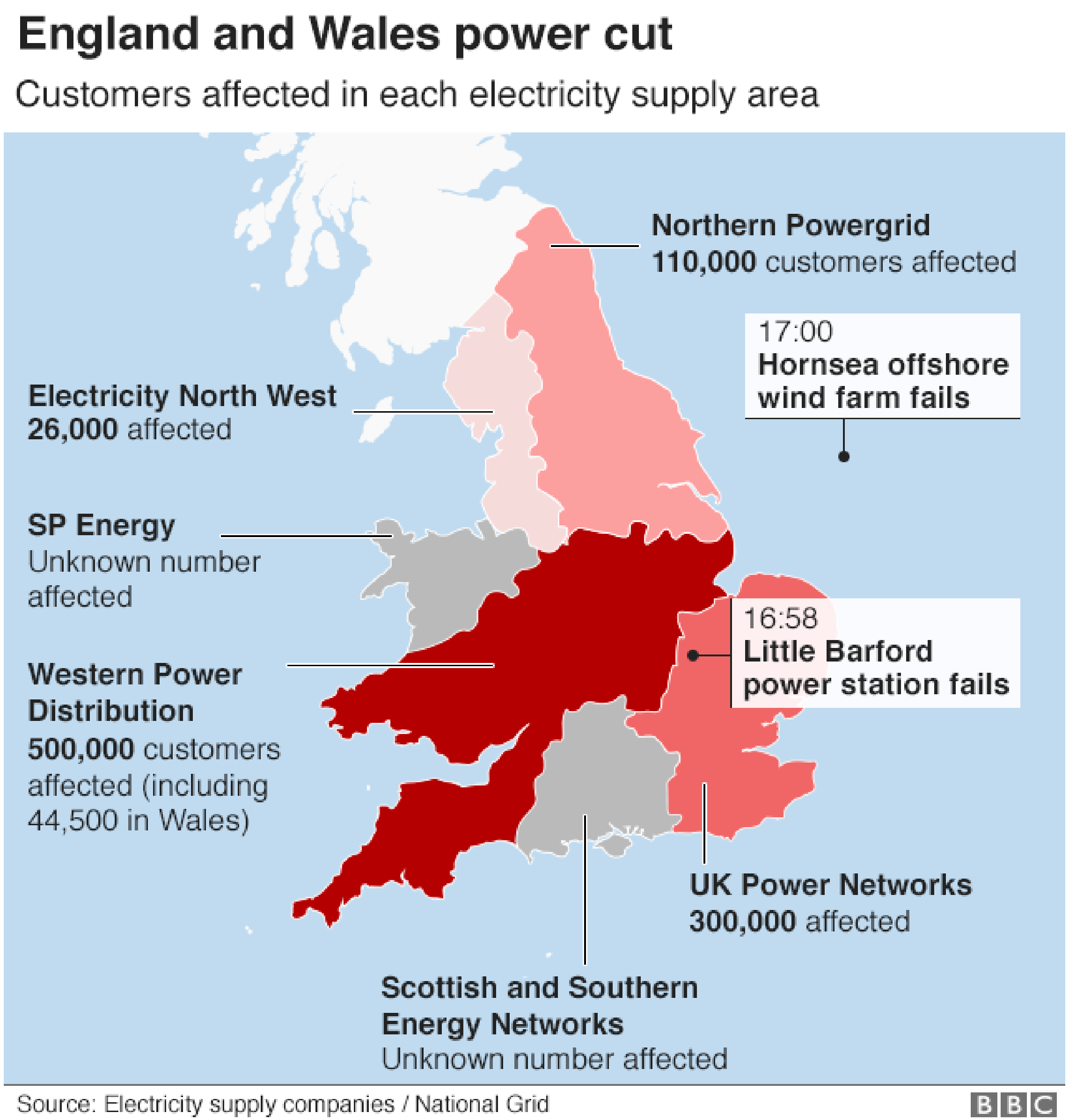
Chapter 3: Technology Assessments

"The age of these components degrades their ability to withstand physical stresses and can result in higher failure rates. Failure of key grid components can lead to widespread outages and long recovery times."

"The more dynamic operating environment associated with increased penetration of variable renewable resources and distributed energy resources (DERs) present a unique challenge for current grid components"

"Understanding and mitigating the impact of these issues on grid components, old and new, are essential to ensure the future grid can continue to deliver electricity in a safe, stable, and reliable manner."

BLACKOUT: UNITED KINGDOM



August 9, 2019

- **Two hour long blackout**
- **800k plus consumers affected**
- **Gas-fired power station at Little Barford, Bedfordshire failed**
- **Two minutes later, Hornsea offshore wind farm disconnected from the grid**
- **Prompted automatic safety systems to shut off power to some places**

OFFICE OF CLEAN COAL AND CARBON MANAGEMENT

Mission:

Discover and develop advanced coal technologies that ensure America's access to resilient, affordable, reliable, and near-zero emitting coal energy resources.

R&D Priorities:

1. Advancing small-scale modular coal plants of the future, which are highly efficient and flexible, with near-zero emissions
2. Improving the performance, reliability, and efficiency of the existing coal-fired fleet
3. Reducing the cost of carbon capture
4. Creating new market opportunities for coal

HOLISTIC APPROACH TO ENERGY GENERATION FROM FOSSIL FUELS

COAL R&D OVERVIEW

Advanced Energy Systems

Efficiency improvements for new and existing units

- Advanced energy materials
- Advanced gasification
- Solid oxide fuel cells
- Advanced coal processing
- Advanced turbines
- Advanced combustion
- Sensors and controls

Crosscutting Research

Crosscutting technology development program

- Power generation efficiency
- Supercritical transformational electric power
- Critical minerals
- Coal utilization science
- Transformational coal pilots
- University research
- SBIR/STTR*
- Technology Commercialization Fund (TCF)*

CO_2 Capture and Utilization

Reducing the cost of CO_2 capture for new and existing units

- Post-combustion capture
- Pre-combustion capture
- New pathways to utilize captured CO_2

CO_2 Storage

Safely and permanently storing CO_2

- Safe use and permanent storage of CO_2 from power generation and industry
- Minimizing subsurface risks (coordinated with other subsurface offices, e.g., Office of Oil and Natural Gas)
- CO_2 infrastructure analysis

Note: Programmatic not necessarily budgetary groupings

**SBIR/STTR and TCF are managed under the Crosscutting Program but funded by all R&D programs*

FOSSIL ENERGY IS CRITICAL IN ALL SECTORS

CCUS IS A PLATFORM TECHNOLOGY FOR MANY INDUSTRIAL SECTORS

EIA, *Annual Energy Outlook 2019*, Reference Case, *https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf*