Existing Plants – Fleet Assessment

2019 Annual Project Review Meeting for Crosscutting, Rare Earth Elements, Gasification and Transformative Power Generation

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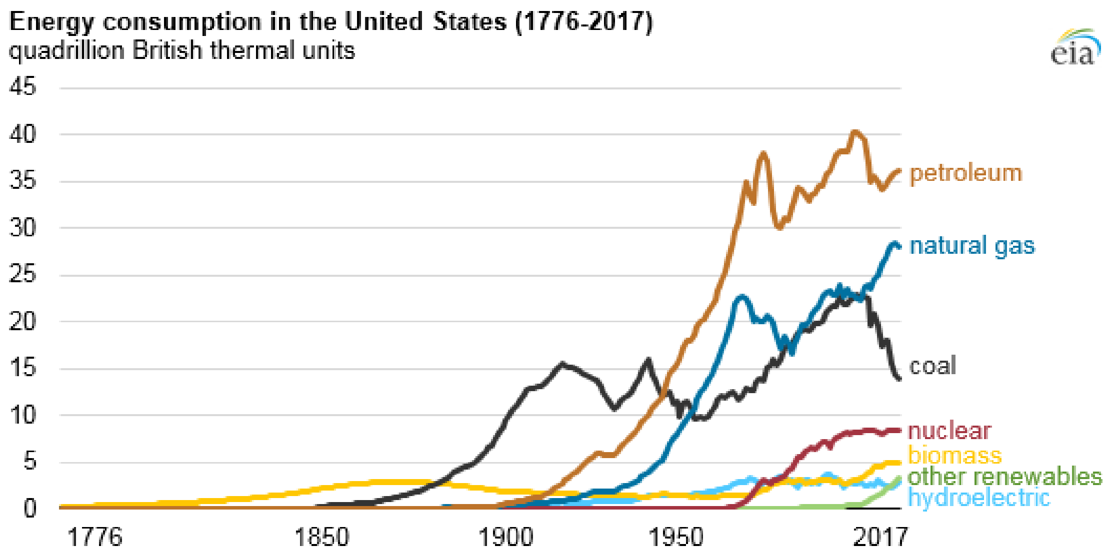
Solutions for Today | Options for Tomorrow

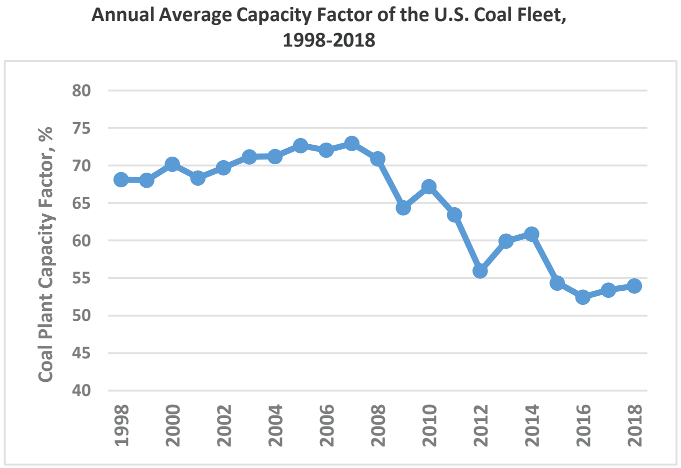
U.S. DEPARTMENT OF ENERGY

Briefing Outline

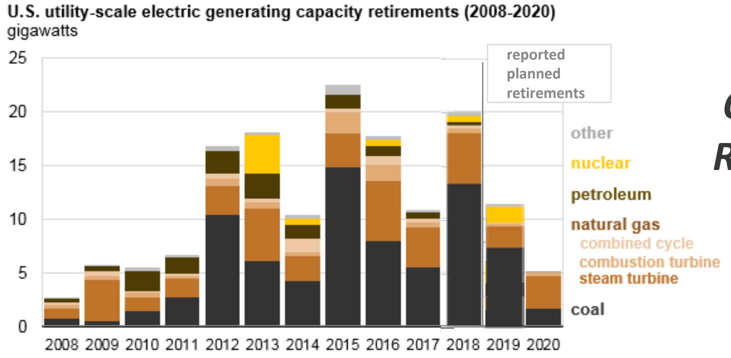
- Coal Fleet Trends
- Diversity in Coal Plant Design and Operation
- Diversity in Electricity Markets
- Coal Plant Retirements
- Closing Thoughts

Recent Trends of the U.S. Coal Fleet





Impact on Coal Fleet



Owners' Response

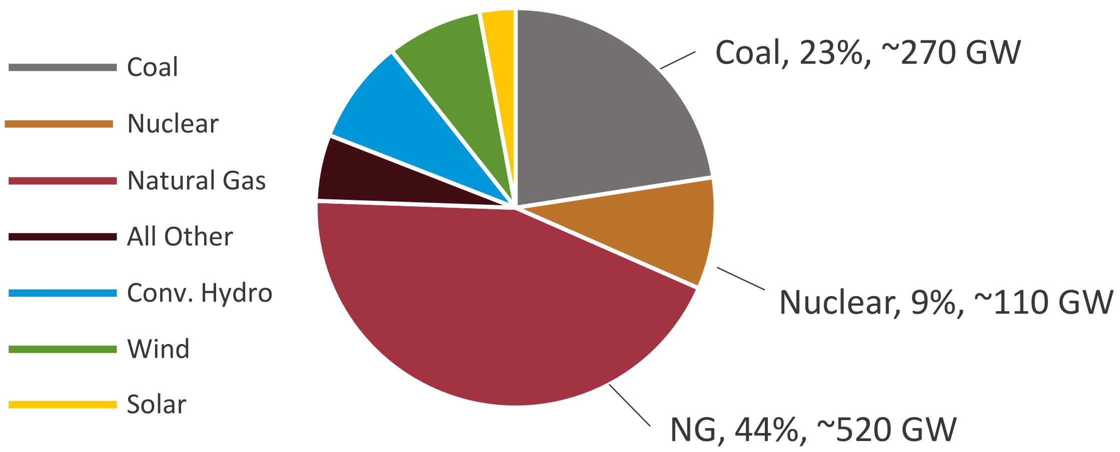
- Decreasing coal-based electricity generation has driven retirement of uneconomic assets

Credits: Left – EIA, *Petroleum, natural gas, and coal still dominate U.S. energy consumption*, https://www.eia.gov/todayinenergy/detail.php?id=36612
Top Right - NETL analysis of EIA data
Bottom Right -EIA, *Almost all power plants that retired in the past decade were powered by fossil fuels*, https://www.eia.gov/todayinenergy/detail.php?id=34452, 2018 and 2019 updated with current EIA Data (Preliminary Monthly Electric Generator Inventory, January 2019)

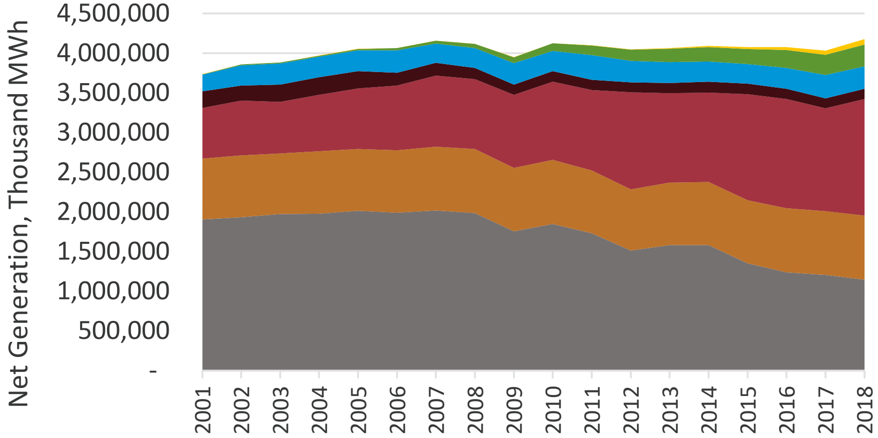
Changing Generation Mix

2018 Installed Electricity Generating Capacity

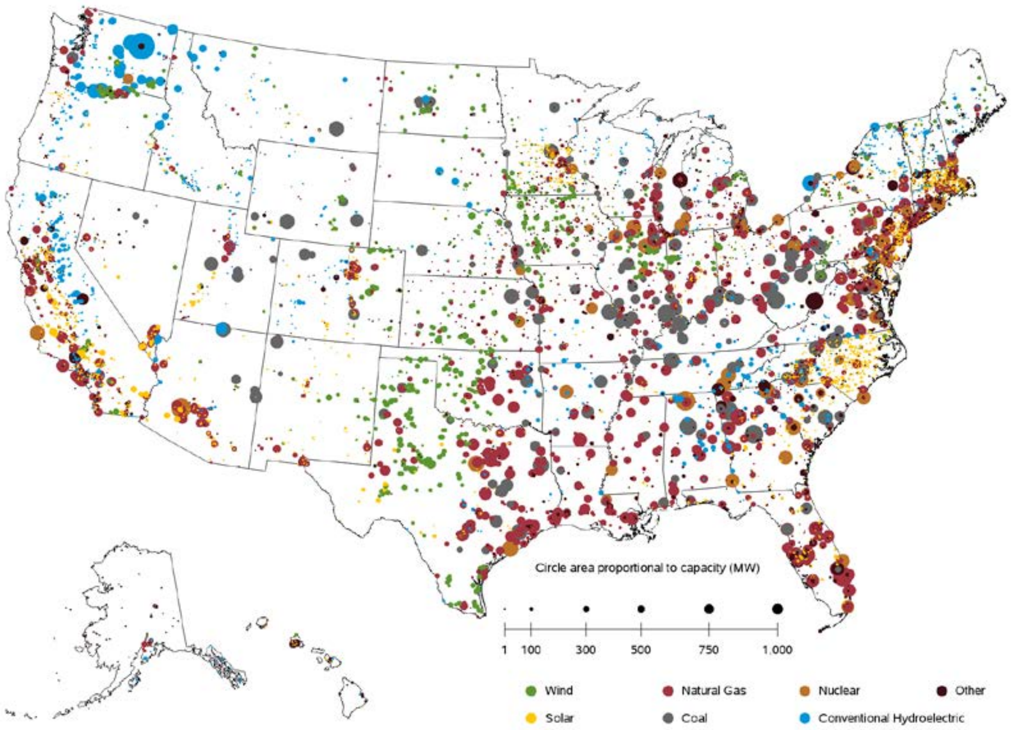
% Share of ~1,200 GW



2018 Annual U.S. Electricity Generation

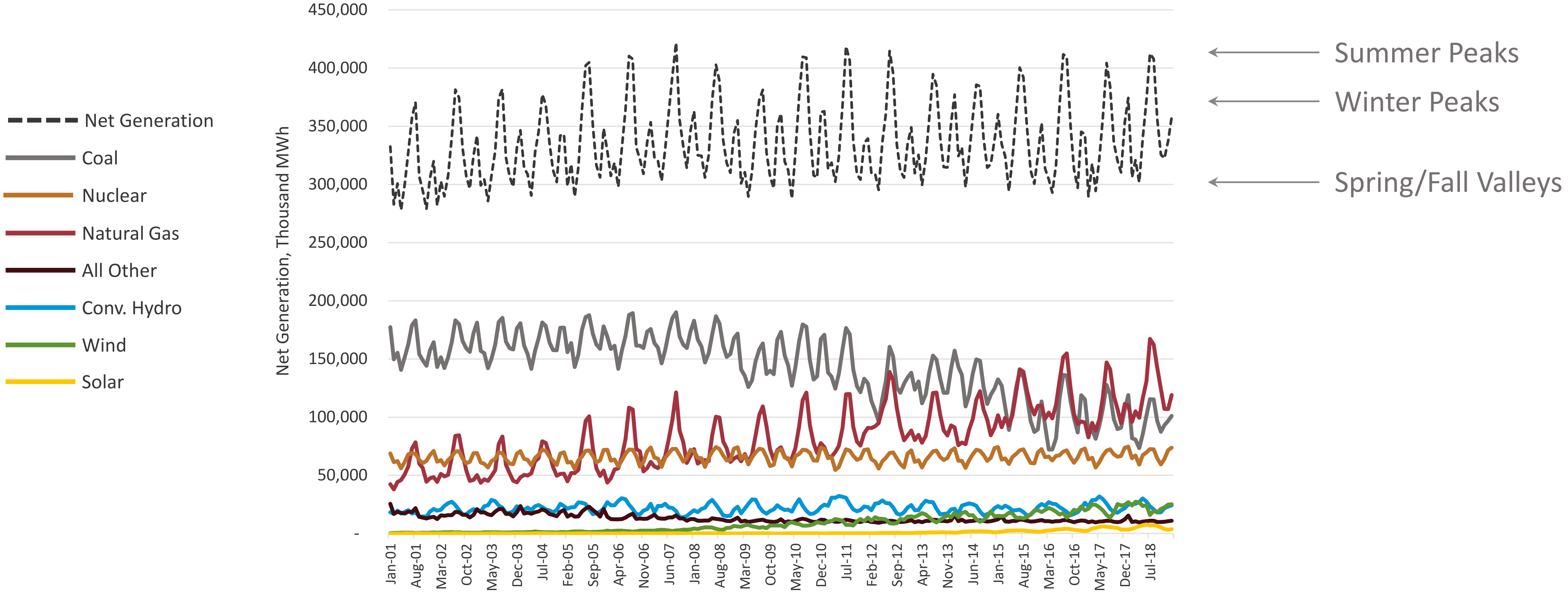


Operable Utility-Scale Generating Units (as of January 2019)



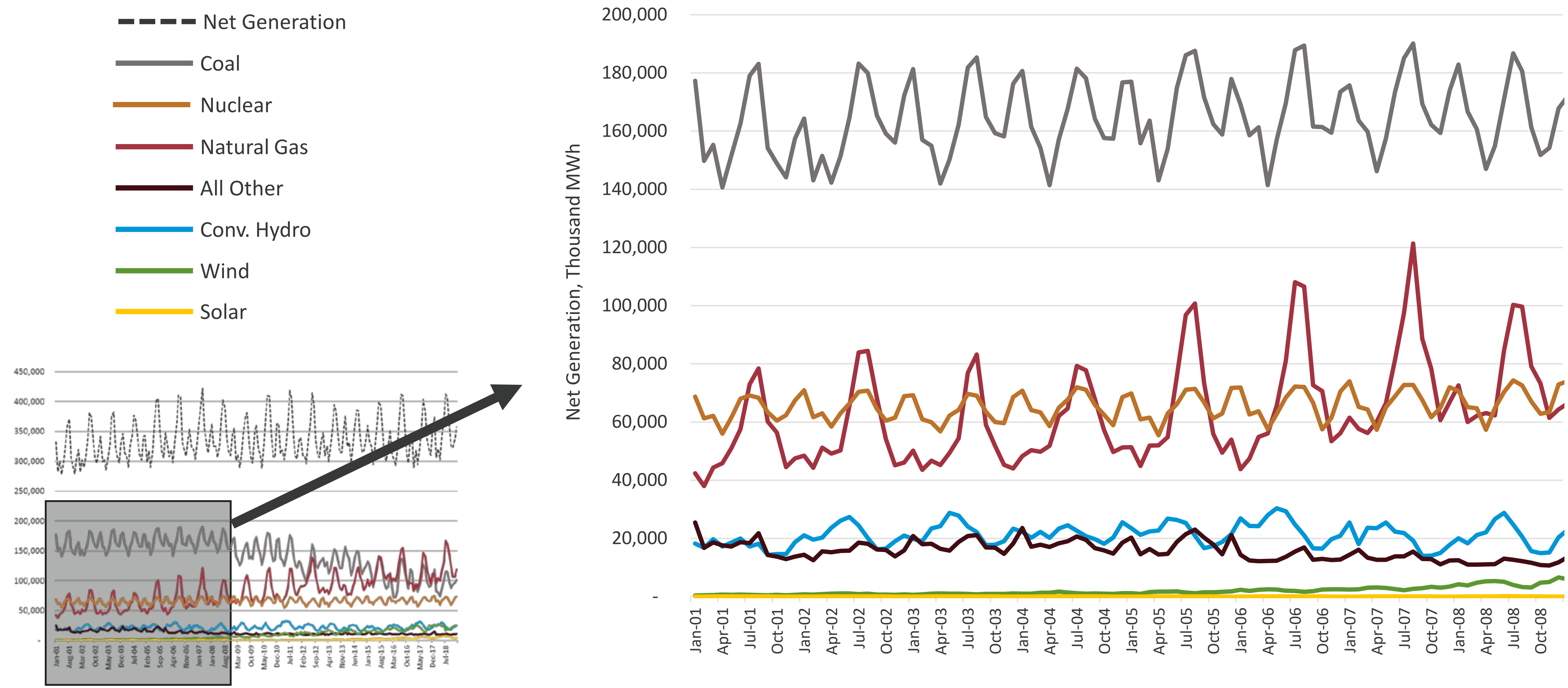
Credits: Top Left – Adapted from OE Energy Market Snapshot, National – Data through October 2018, FERC Office of Enforcement, November 2018
Bottom Left – NETL analysis of monthly data as provided in EIA's Electricity Data Browser
Right -EIA, https://www.eia.gov/electricity/data/eia860M/ (Release Date March 26, 20`9)

Monthly Data Provide Greater Insight



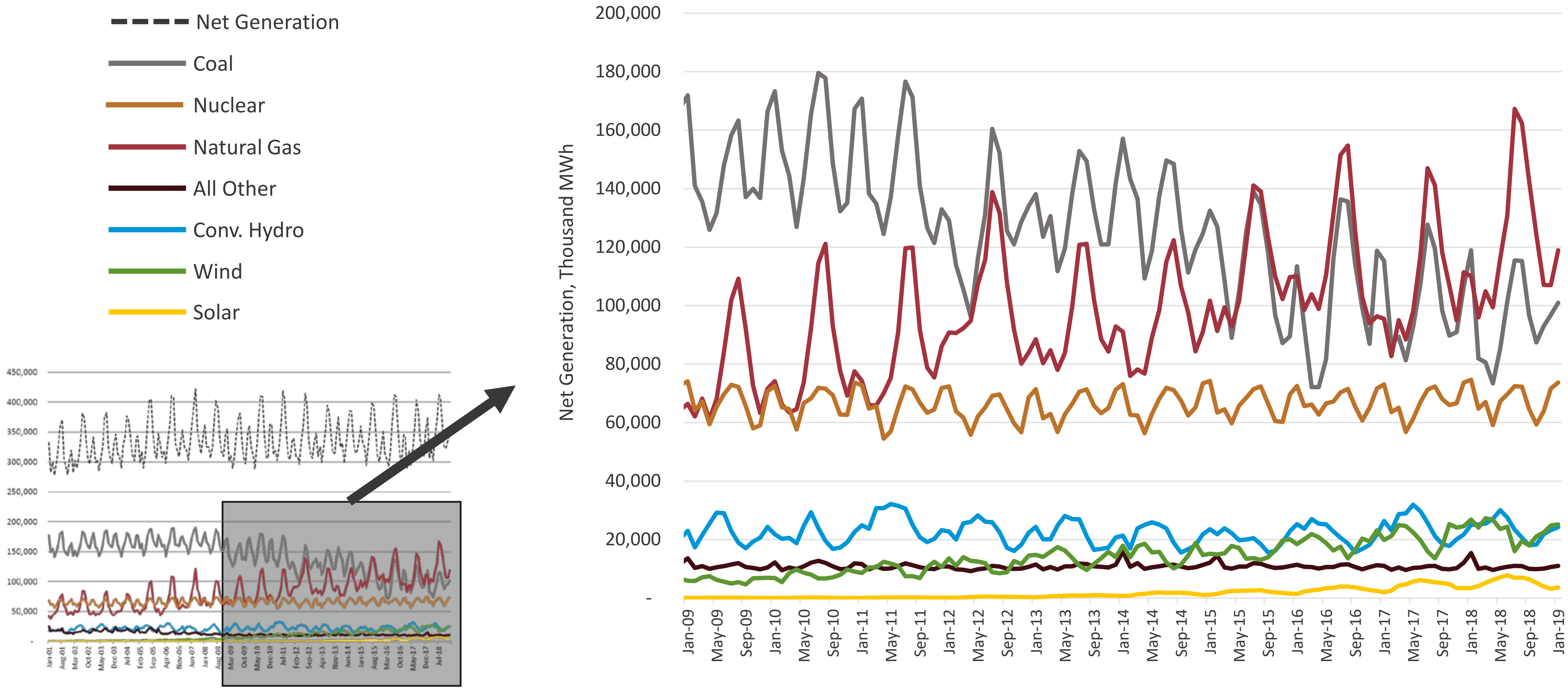
Source: NETL analysis of monthly data as provided in EIA's Electricity Data Browser

Coal Relatively Stable Through 2008



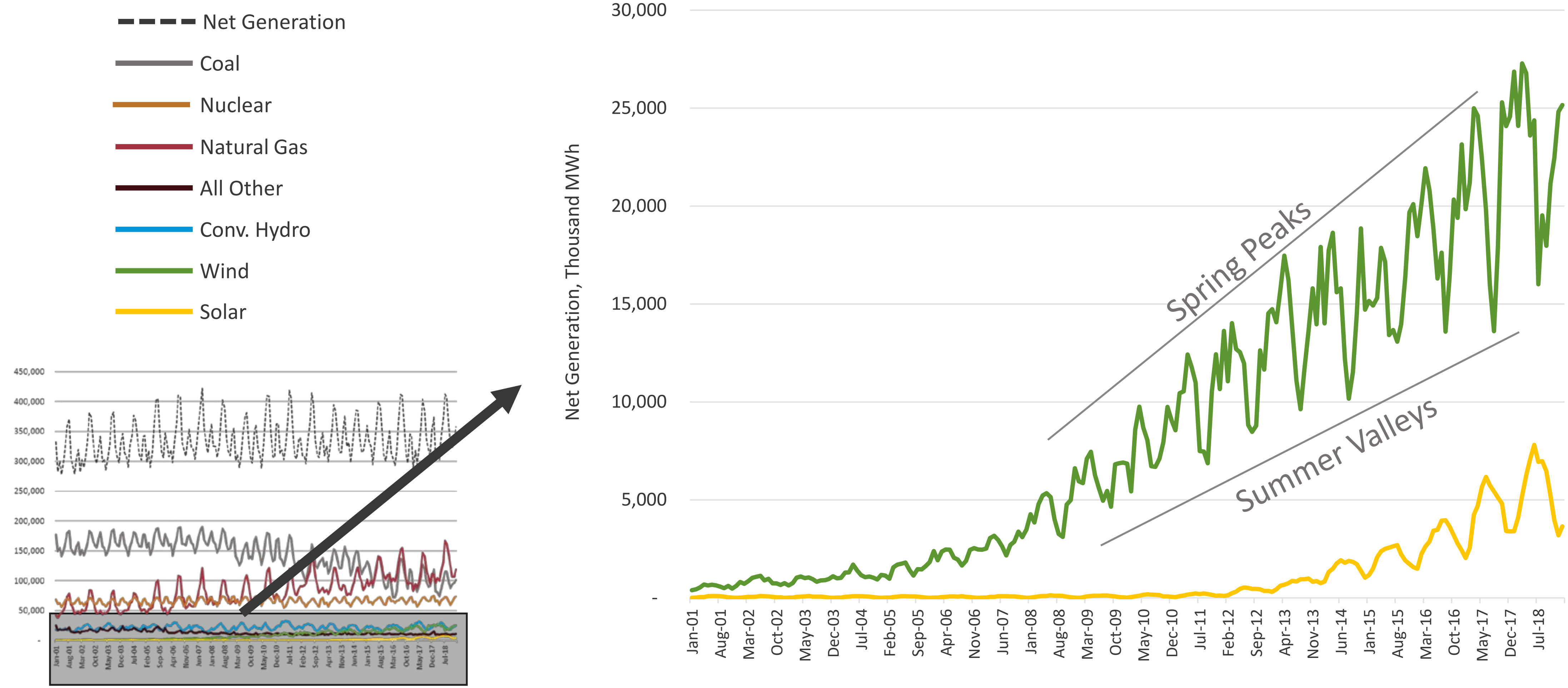
Source: NETL analysis of monthly data as provided in EIA's Electricity Data Browser

Coal Decline Starts 2009 and Continues



Source: NETL analysis of monthly data as provided in EIA's Electricity Data Browser

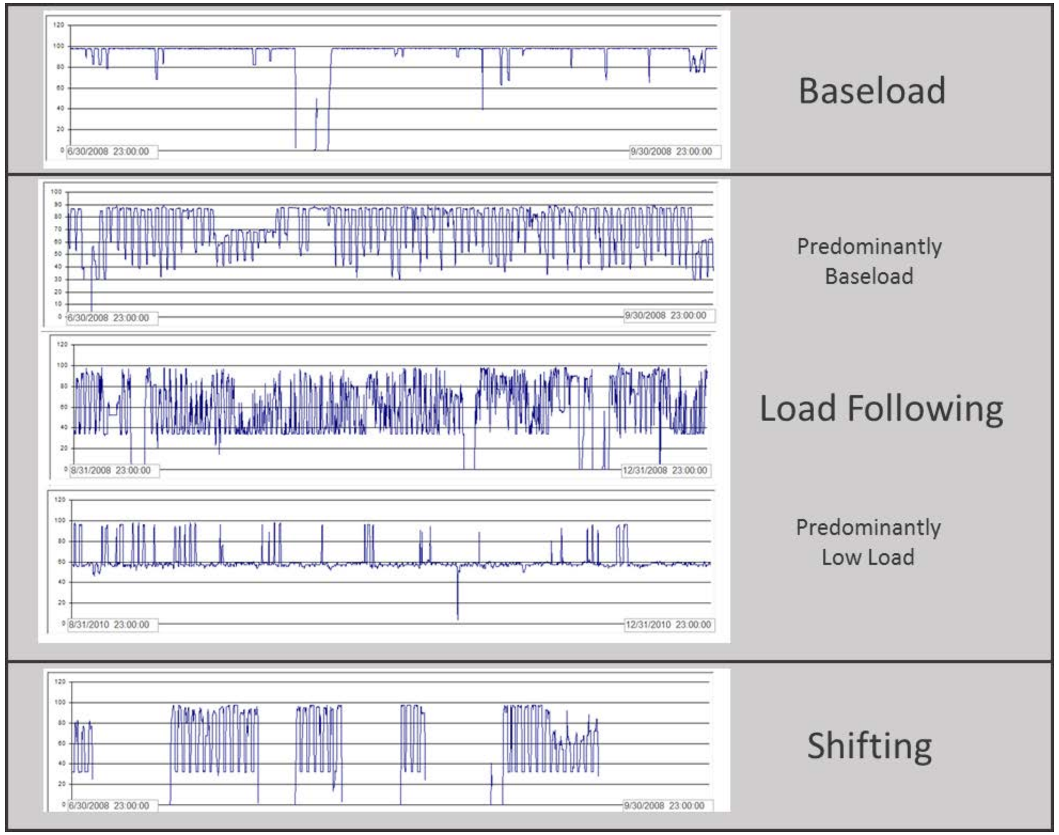
Renewable Variability is Interesting



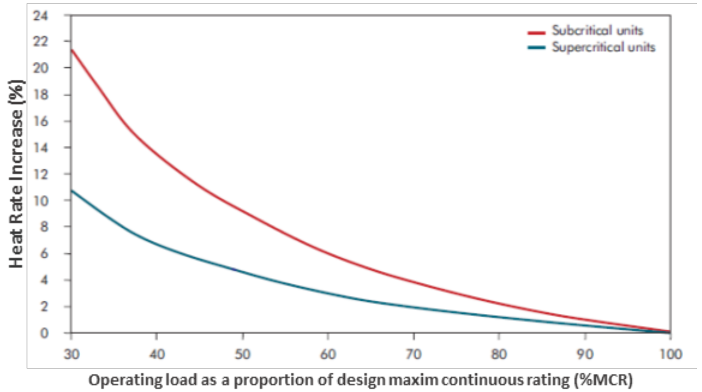
Source: NETL analysis of monthly data as provided in EIA’s Electricity Data Browser

Utilization Trends of the Existing Fleet

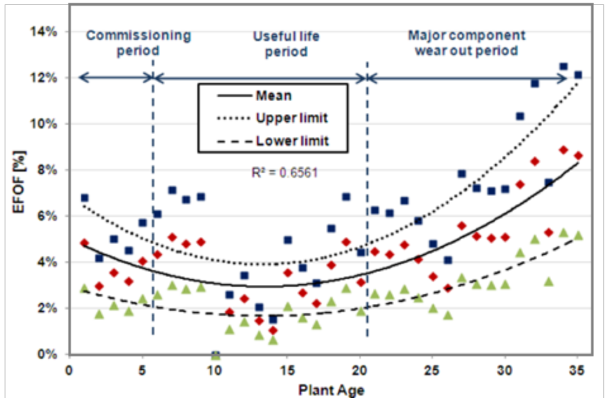
Power Plant Operating Profiles



Impact of unit operating load on heat rate



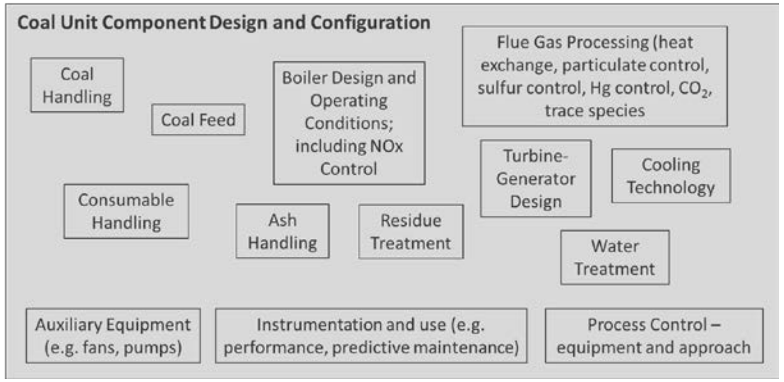
Average EFOF vs. Age for coal-power plants designed for baseload operating in a cycling regime

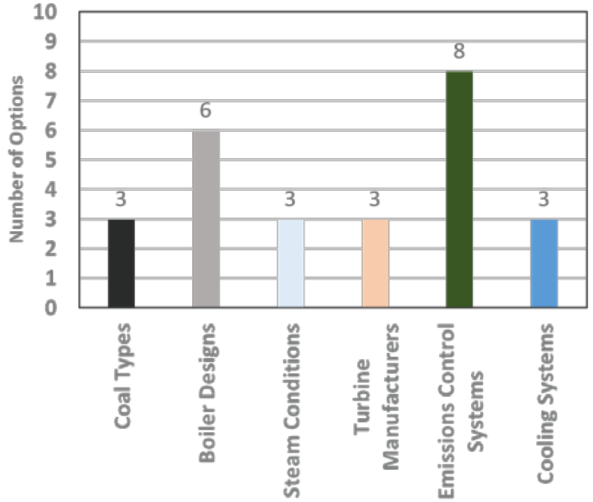


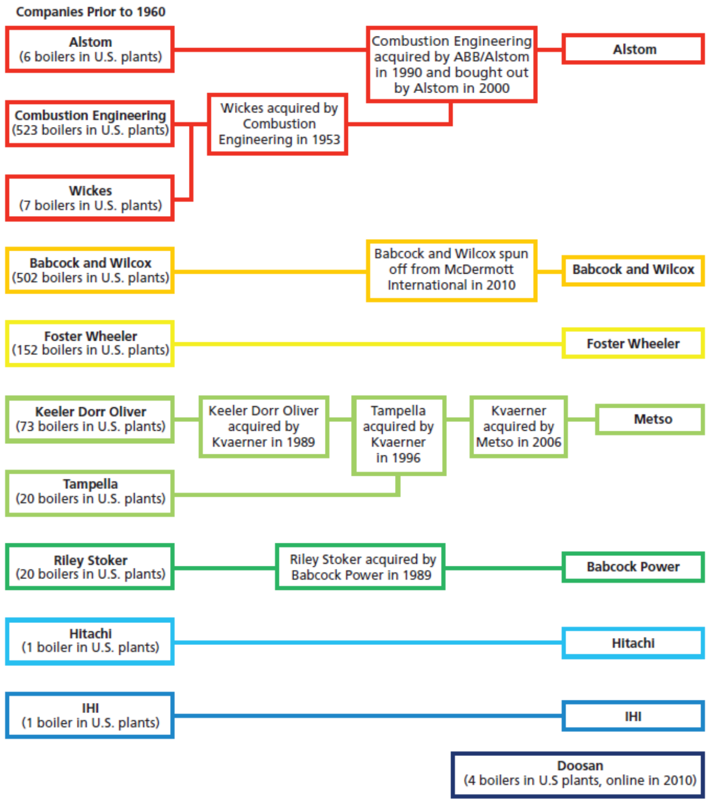
Credits: Left – Analysis of unit-level hourly output
Top Right – Adapted from IEA Coal Industry Advisory Board, *Power Generation from Coal*, 2010
Bottom Right – Adapted from European Technology Development Ltd, *Impacts of Cyclic Operation on Maintenance Programs*

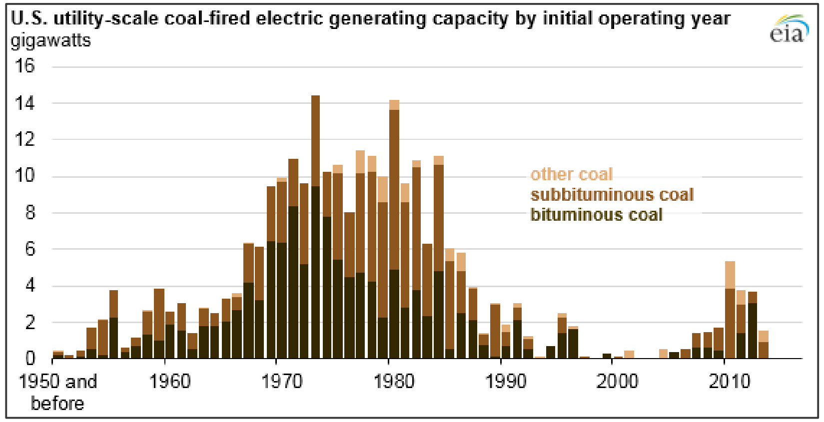
Observations on Coal Plant Performance and Design

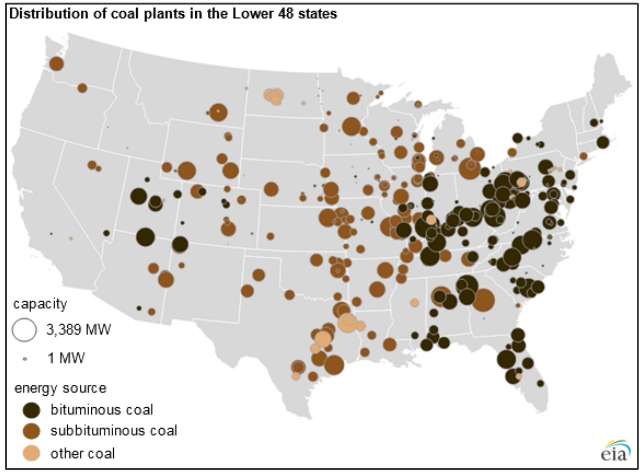
Diversity Across the U.S. Coal Fleet











Credits: Bottom Left, NETL analysis of Ventyx Energy Velocity Suite Database information
Center: Samaras, C., et.al., Characterizing the U.S. Industrial Base for Coal-Powered Electricity, RAND Corporation, 2011
Right Top and Bottom, DOE EIA

2016 Fleet Performance Characteristics

Segment Criteria			Sub-population Characteristics					Efficiency	
Unit Type	Coal Type	Size (MW)	Capacity (GW)	# Units	Generation (BkWh)	Average Age	Std. Dev Age	Average	90th Percentile
Low Pressure Subcritical (1,600 psig and less)	Bit	0-200	1.9	41	2.9	41	13	27.7%	32.0%
	Sub		3.4	55	10.4	49	14	27.4%	31.0%
	Other		0.64	11	0.97	40	17	25.0%	27.6%
High Pressure Subcritical (1,800-2,600 psig)	Bit	0-199	8.2	49	23.0	56	8	30.7%	33.5%
		200-499	30.4	93	108.0	42	13	31.6%	34.7%
		500+	29.8	48	127.6	37	7	33.0%	35.2%
	Sub	0-199	4.4	29	13.0	54	8	30.3%	32.1%
		200-499	27.3	83	113.9	43	13	31.5%	34.0%
		500+	66.6	100	309.8	36	7	32.0%	34.6%
	Other	All	8.86	18	52.70	31	12	31.6%	34.6%
Supercritical (Over 3334 psig)	Bit	All	62.1	78	285.8	41	11	34.7%	37.3%
	Sub		17.2	23	74.1	35	16	34.5%	36.9%
	Other		7.88	11	41.49	34	14	31.5%	32.9%
Fleet		NA	**269**	**639**	**1164**	**42**	**13**	**31.4%**	**35.2%**

Sources: NETL analysis of Ventyx Energy Velocity Suite Database, Platts 2016 UDI Database

Technologies to Improve Performance

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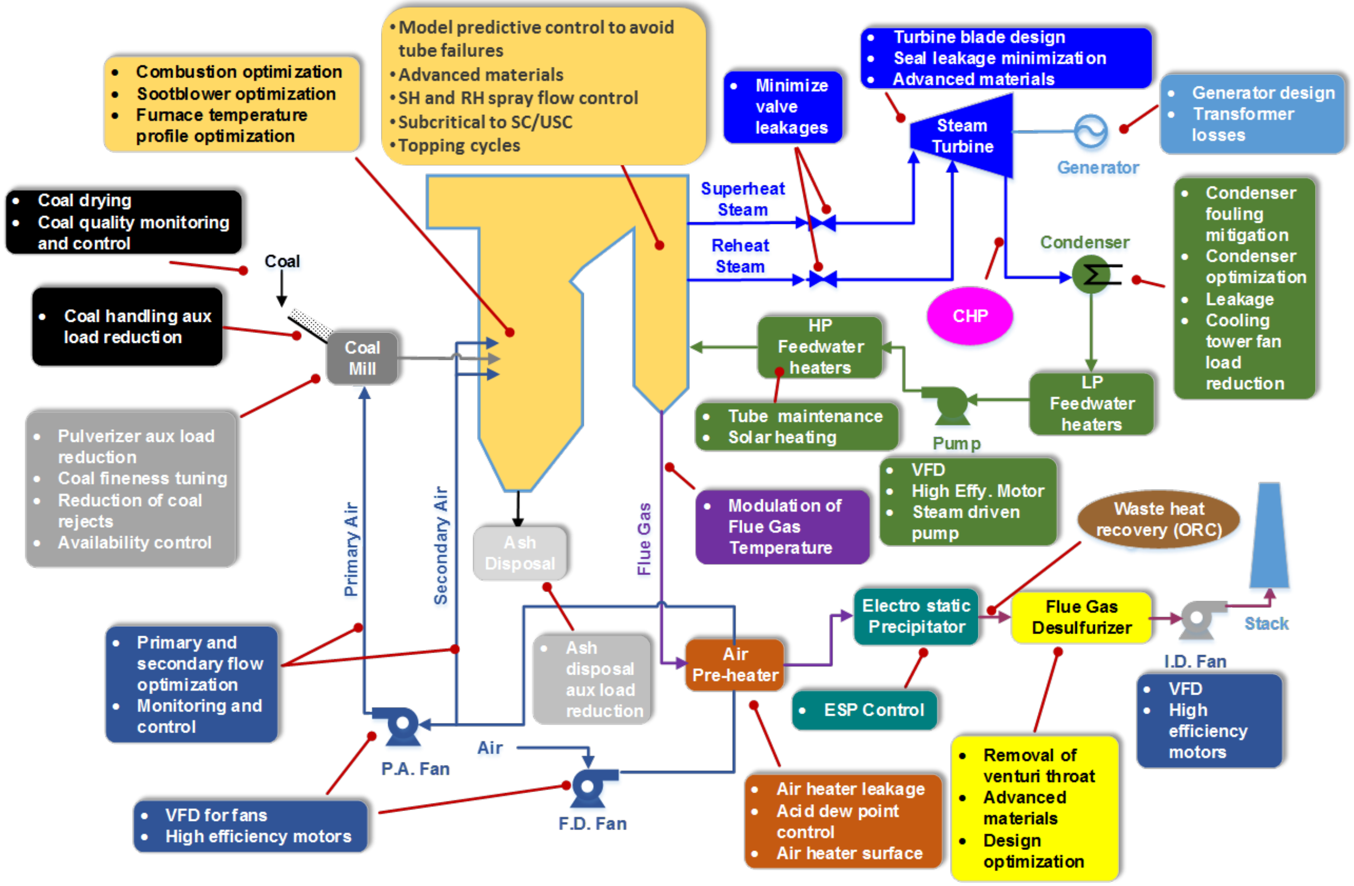
- Many plant areas have room for improvement
- Solutions are commercially offered
- Key factors limiting implementation:
  - High cost
  - Inadequate performance improvement



Sample List of Improvement Opportunities

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Upgrade Options	
Boiler Island	Redesign/replace economizer
	Boiler tube coatings
	Fuel delivery upgrades
	Sootblower upgrades
	Air heater upgrades/lower outlet temp.
	Condenser upgrades
	Ash handling upgrades
Turbine Island	Upgrade (e.g., blades, seals, materials, coatings)
	Boiler feed pump upgrades
	Generator upgrades
Flue Gas System	Fan and pump upgrades
	Emissions control modifications

Upgrade Options	
Water Treatment	Cooling tower upgrades
	FGD waste water treatment
Instrumentation & Control	Digital controls
	Neural network
Coal Choices	Pre-beneficiation
	Reduce moisture
	Reduce ash
	Change fuel
CHP Opportunities	Waste heat utilization
	Sell low-pressure steam
	Incorporate thermal energy storage

- For any given unit, only a subset will be technically feasible, of which only a few may be economically feasible
- The implication is that there is no practical one-size-fits-all solution

Performance Improvement Opportunity

- **Navajo Generating Station**
  - 3 x ~800 MWe (Nameplate)
  - 1970's vintage bituminous-fired supercritical units
  - Env. Control - Hot-side ESP (PM), Wet FGD (SO_2) and ACI (Hg)
  - Supplies the WECC Desert Southwest market
  - Online years – 1974-1976, scheduled retirement in 2019
- **Primary drivers for retirement**
  - Changing economic circumstances (low NG prices, low demand)
  - Required future retrofit of SCR on Units 2 &3 to comply with Regional Haze regulations
  - Other site-specific drivers (site lease, closure requirements)

Credits: Top: Salt River Project
Bottom, NETL modification of Google Earth imagery

Case Study – Navajo Generating Station

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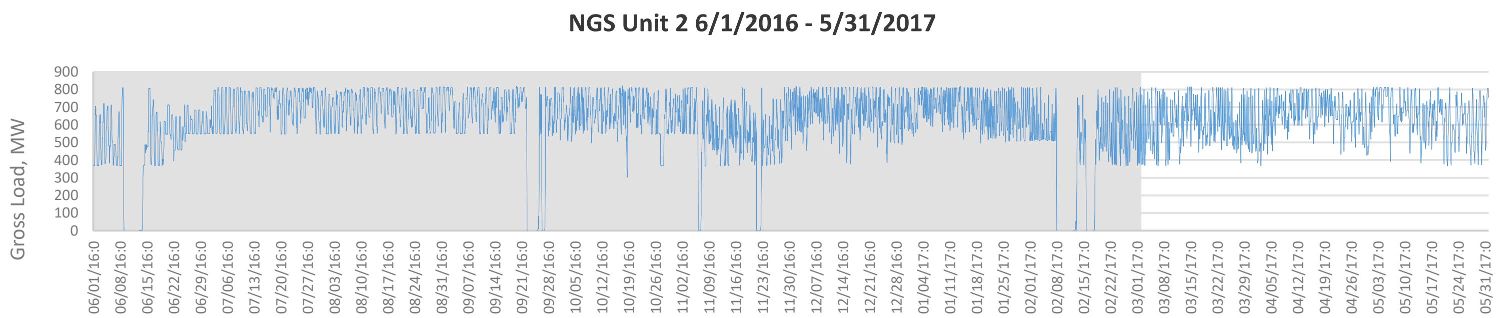
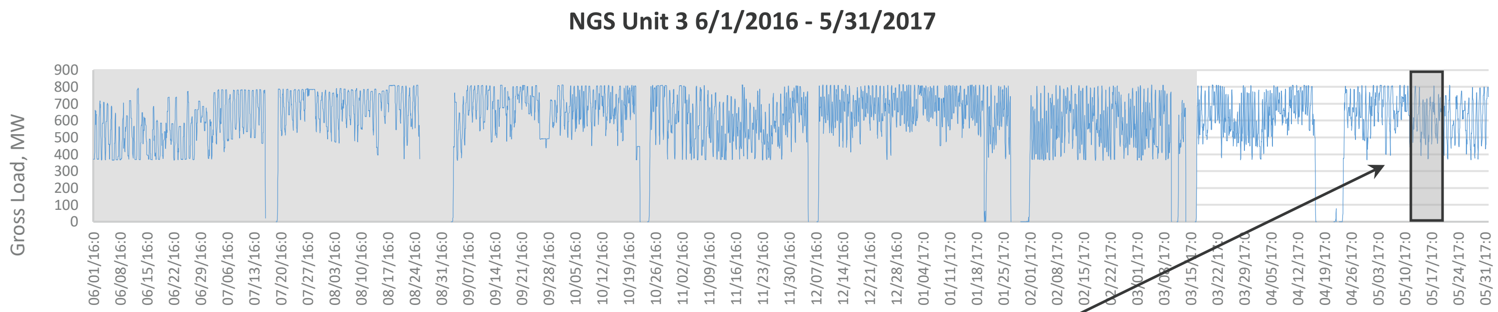
Annual Operational Statistics 2011-2018

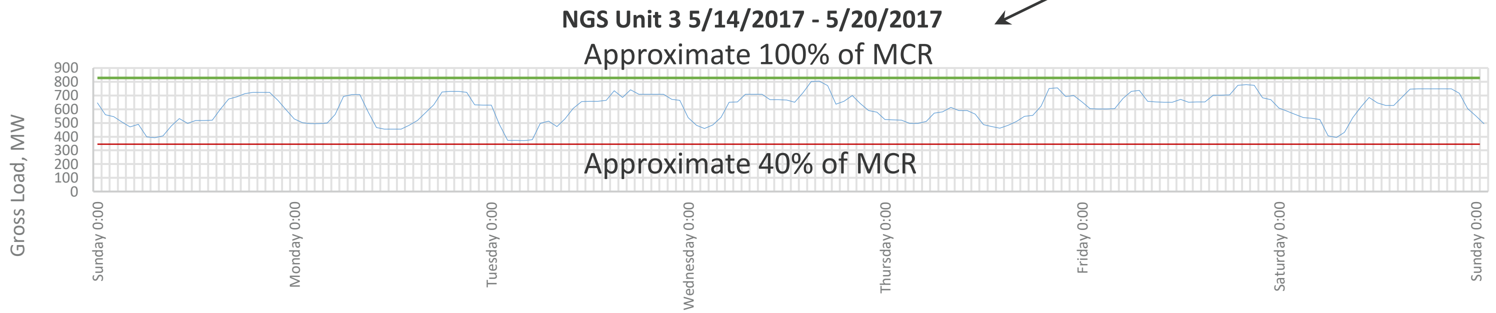
	Plant Level (all Net)			Unit Level CF, %		
	Output, MWh	HR, BTU/kWh	CF, %	U1	U2	U3
2011	16,951,775	10,060	80.2	***69.0***	84.4	***87.4***
2012	15,888,068	10,042	75.3	75.2	***75.7***	***74.8***
2013	17,131,763	10,135	81.2	***82.8***	***75.0***	85.3
2014	17,297,076	10,263	***82.0***	***79.5***	***85.7***	80.6
2015	13,572,760	10,392	64.3	***71.6***	65.6	***55.6***
2016	12,058,583	10,417	***57.1***	***59.3***	***54.6***	57.4
2017	13,781,218	10,349	65.3	***61.2***	***68.3***	66.3
2018	13,017,437	10,545	61.7	***61.0***	61.9	***62.0***

Source – EIA Form 923





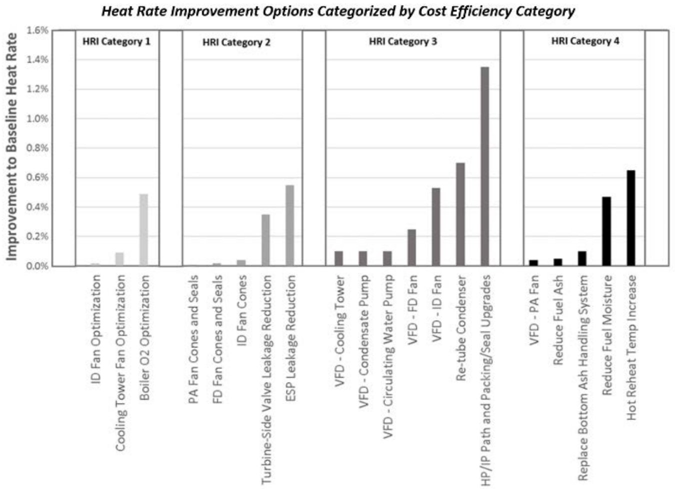
- **Already showing negative effects**
  - Decreasing EAF
  - Increasing EFOR

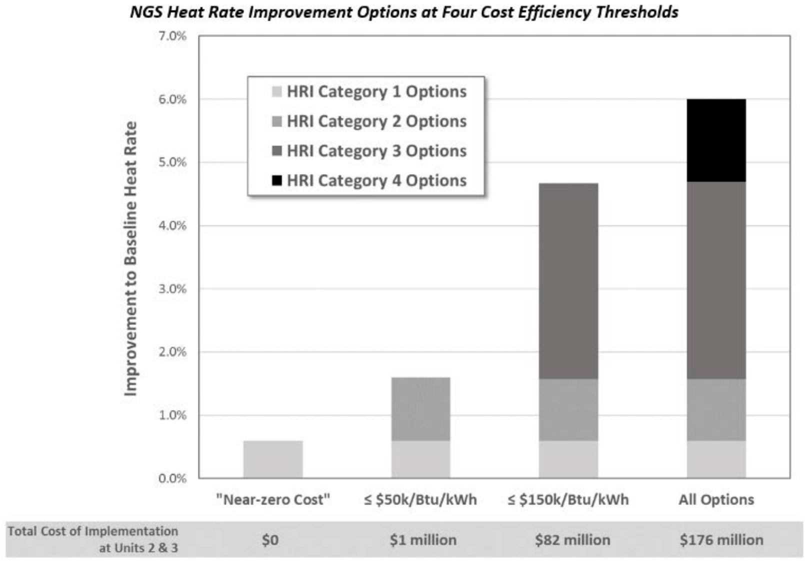


Hourly load data source - https://ampd.epa.gov/ampd/

Case Study – Navajo Generating Station

- **Study Objective**
  - Identify and evaluate potentially feasible heat rate improvement (HRI) opportunities
  - Consider only commercially-available, state-of-the-art technologies
  - Focus on technical assessment including magnitude of potential HRI and order of magnitude implementation costs
- **Study Findings**
  - Twenty three individual HRI opportunities identified and evaluated
    - Individual improvements ranging from very small to ~1.4%
    - Individual implementation costs from negligible to ~$18M/unit (~$24/kW)
    - Individual cost efficiencies ranging from "free" to >$150k per Btu/kWh improvement to unit heat rate
  - Maximum "feasible" HRI ~4.7% at cumulative implementation cost ~$40M/unit (~$55/kW)
- **NGS Operator (Salt River Project) Perspective**
  - Has "considered many of the options" identified by Black & Veatch
  - Acted on or dismissed options based on "operating and economic factors"





Credits: NETL, *Plant Efficiency Evaluation at Navajo Generating Station*, DOE/NETL-2018/1891, January 2018

Observations on U.S. Electricity Markets

Diversity Across U.S. Electricity Markets

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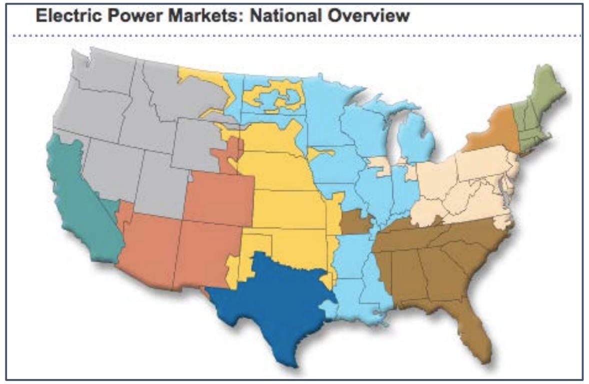
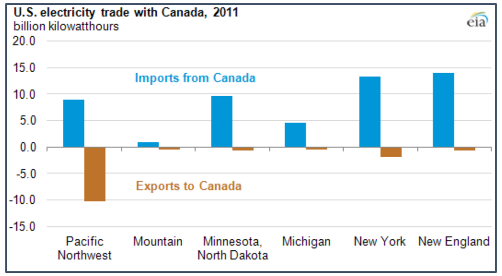
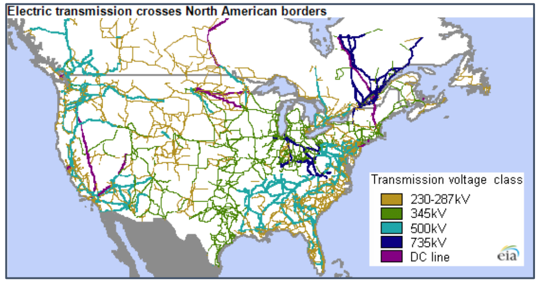




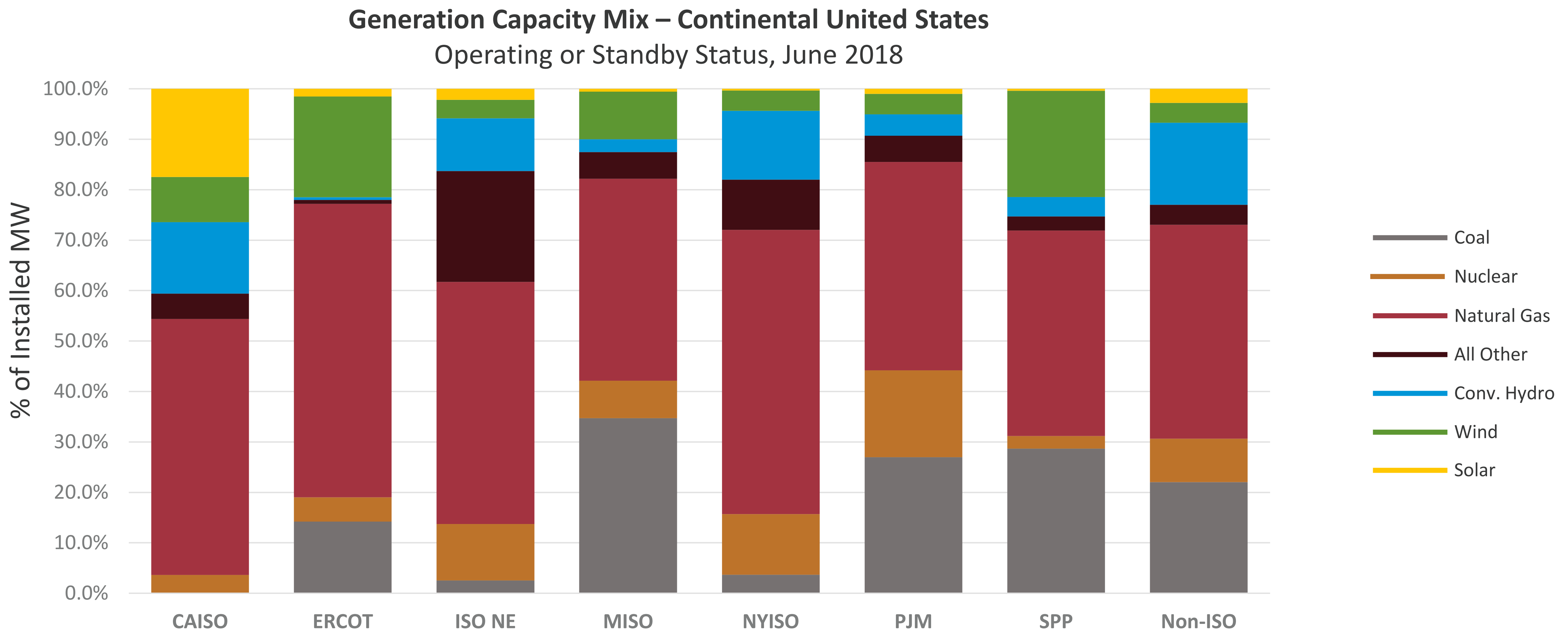


	2016 Nameplate Capacity, MW	Capacity Composition			Market Characteristics
		Coal	Gas	Int[1]	
CAISO	82,379	0%	53%	23%	Access to electricity markets across eight western states; CO_2 constraints
MISO	184,427	38%	43%	11%	Access to shale gas and wind; a number of state utilities continue to be vertically integrated monopolies; seasonal (i.e., winter) challenges for flexibility and reliability, capacity market and ancillary service opportunities; power import/export with Canada
ISO-NE	31,798	3%	52%	8%	Increasing NG capacity; NG infrastructure challenge; power import/export with Canada
NYISO	41,646	3%	53%	5%	Declining electricity demand and aging infrastructure; increasing NG and wind with coal & oil declining; hydro & nuclear (mostly) constant; changing demand profile due to efforts focused on energy efficiency and other behind-the-meter opportunities; power import/export with Canada
Northwest	81,494	15%	25%	16%	Heavy reliance on hydro; legacy state-regulated, vertically integrated, monopoly markets; significant Federal presence (Bonneville Power); power import/export with Canada
PJM	200,440	32%	38%	6%	Declining electricity demand and aging infrastructure; changing demand profile due to efforts focused on energy efficiency; large legacy generation disproportionate in some states; capacity market and ancillary service opportunity
Southeast	232,614	28%	49%	3%	Legacy state-regulated, vertically integrated, monopoly markets
Southwest	59,070	29%	47%	17%	Legacy state-regulated, vertically integrated, monopoly markets
SPP	87,255	30%	39%	12%	Increasing NG capacity, wind generation, ancillary service opportunity
ERCOT	107,569	17%	59%	22%	Excess capacity, increasing wind growth
Total	**1,108,691**	**25%**	**45%**	**12%**	

1. % Intermittent includes wind and solar; does not include geothermal, landfill gas, MSW, black liquor, biomass or hydro

Credits: Ventyx Energy Velocity Suite Database (data); EIA, FERC (graphics)

Market Variability – Capacity Mix



Credits: Adapted from OE Energy Market Snapshot, National – Data through October 2018, FERC Office of Enforcement, November 2018
Wind & Solar split based on FERC-cited data source (EIA Form 860M, June 2016)

Market Variability – Priced Components

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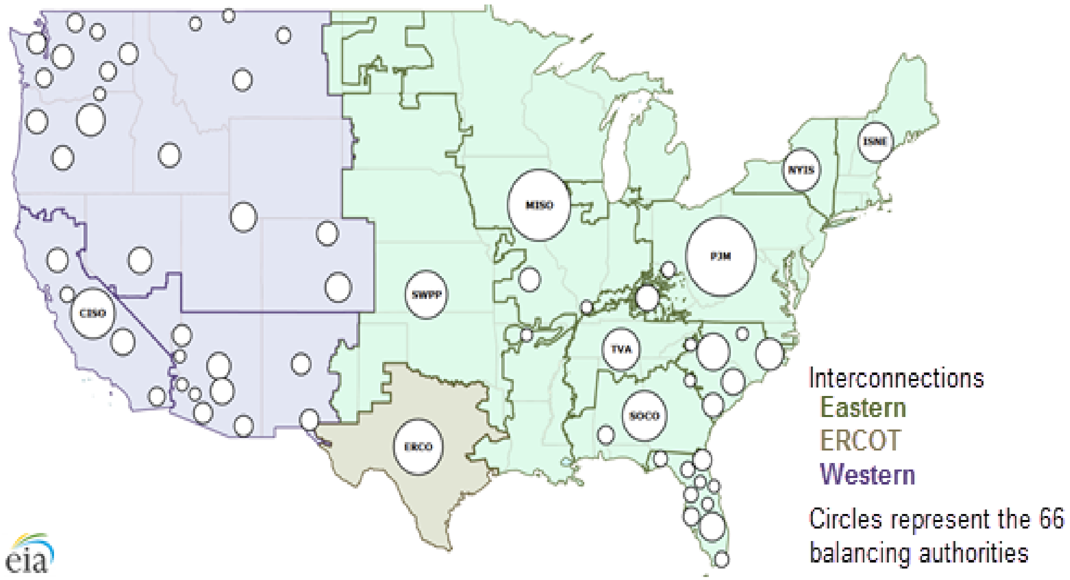
Bulk Power Grid of the Continental United States



Comparison of Market Components Across Competitive Electricity Markets (as of 2015-2016)

	ISO-NE	NYISO	PJM	MISO	SPP	ERCOT	CAISO
Energy	DA/RT	DA/RT	DA/RT	DA/RT	DA/RT	DA/RT	DA/RT
Ancillary Services							
Regulation	RT	DA/RT	RT	DA/RT	DA/RT	DA	DA/RT
Reserves[1]	FP/RT	DA/RT	DA/RT	DA/RT	DA/RT	RT	DA/RT
Voltage Support	Yes[2]	Yes[2]	Yes[2]	Yes[2]	Yes[2]	Yes[2]	Yes[2]
Black Start	Yes[2]	Yes[2]	Yes[2]	Yes[2]	No	Yes[2]	Yes[2]
Transmission	FTR	TCC	FTR	FTR	TCR	CRR	CRR
Capacity	Yes	Yes	Yes	Yes	No	No	Yes

Notes:

1. Reserves include one or more of the following services: Spinning, Non-Spinning, 30-minute, Supplemental
2. Voltage support and black start ancillary services are compensated through cost-based mechanisms and are not a "competed" component of the market structure.

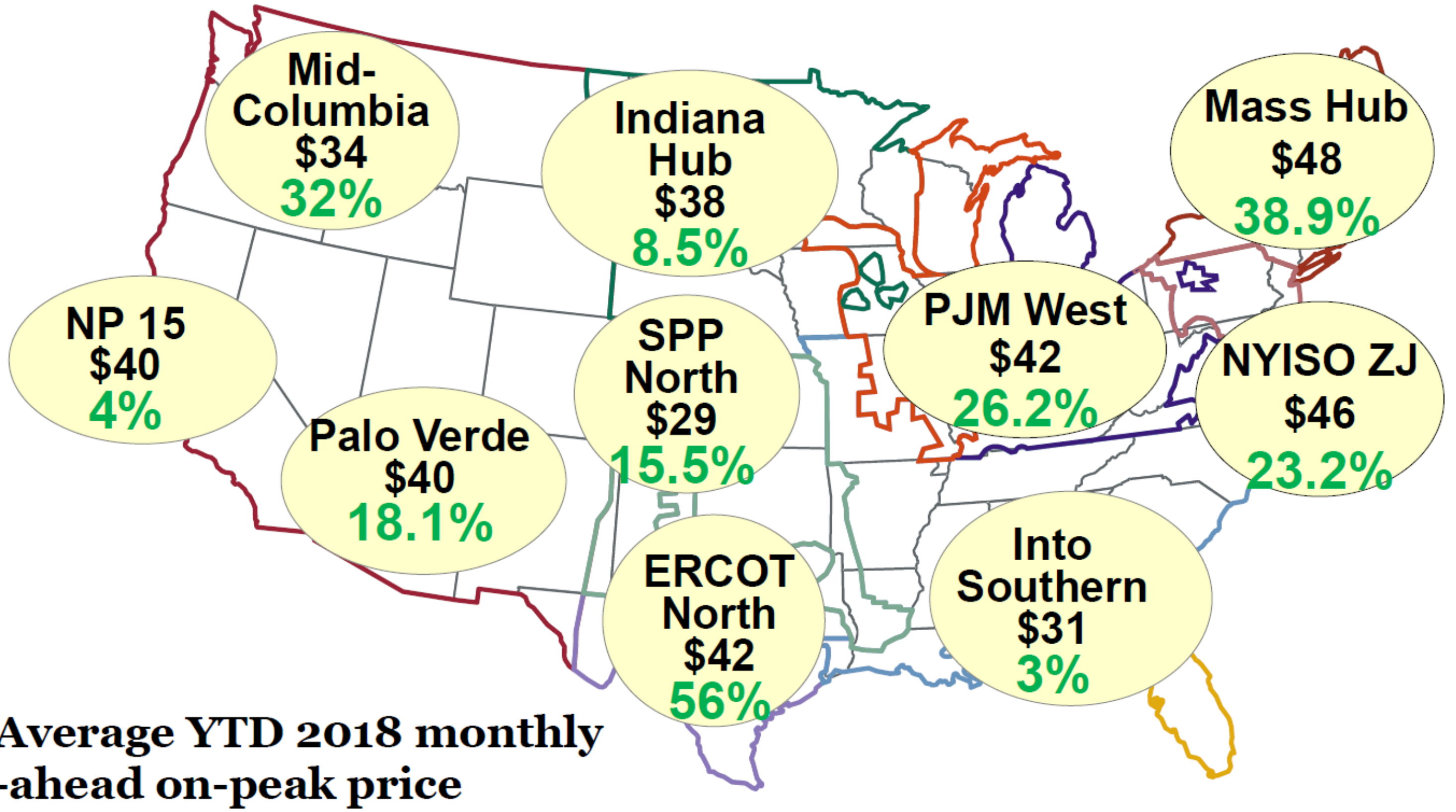
Table Abbreviations:

DA – Day Ahead
RT – Real Time
FP – Forward Planning (pre-DA)
FTR – Financial Transmission Rights
TCC – Transmission Congestion Contracts
TCR – Transmission Congestion Rights
CRR – Congestion Revenue Rights

Credits: Left – EIA, U.S. electric system is made up of interconnections and balancing authorities, July 2016, Online at: https://www.eia.gov/todayinenergy/detail.php?id=27152#
Right – Adapted from Wholesale Electricity Market Design Initiatives in the United States: Survey and Research Needs. EPRI, Palo Alto, CA:2016, 3002009273

Market Variability – Power Pricing

2018 Spot Power Prices ($/MWh)

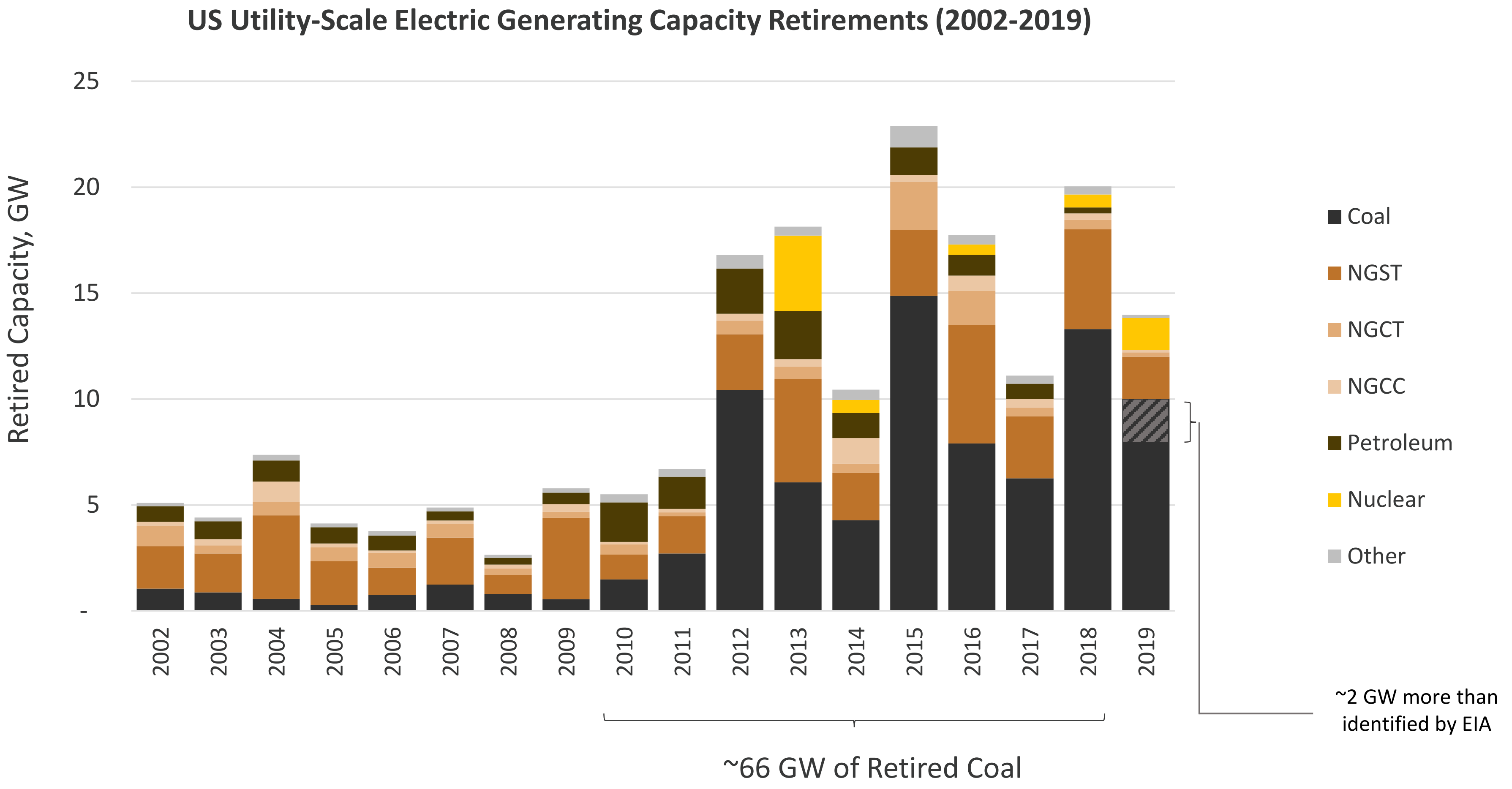


$ = Average YTD 2018 monthly day-ahead on-peak price
% = Percent increase from 2017 YTD
Source: RTO/ISO data and SNL Day-ahead Prices

Credit: OE Energy Market Snapshot, National – Data through October 2018, FERC Office of Enforcement, November 2018

Observations on Coal Plant Retirements

A Significant Decade for Coal Retirements

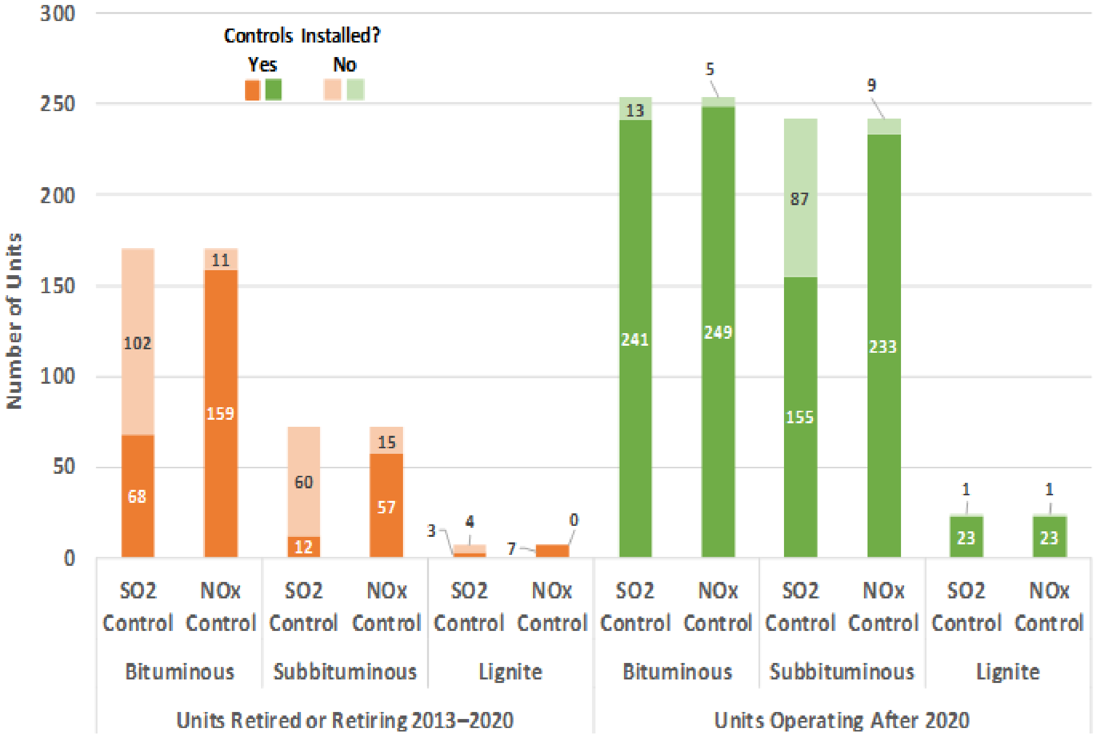


Source – NETL analysis of EIA data, augmented with information from ABB Energy Velocity Database

Attributes of Retired and Operating Units

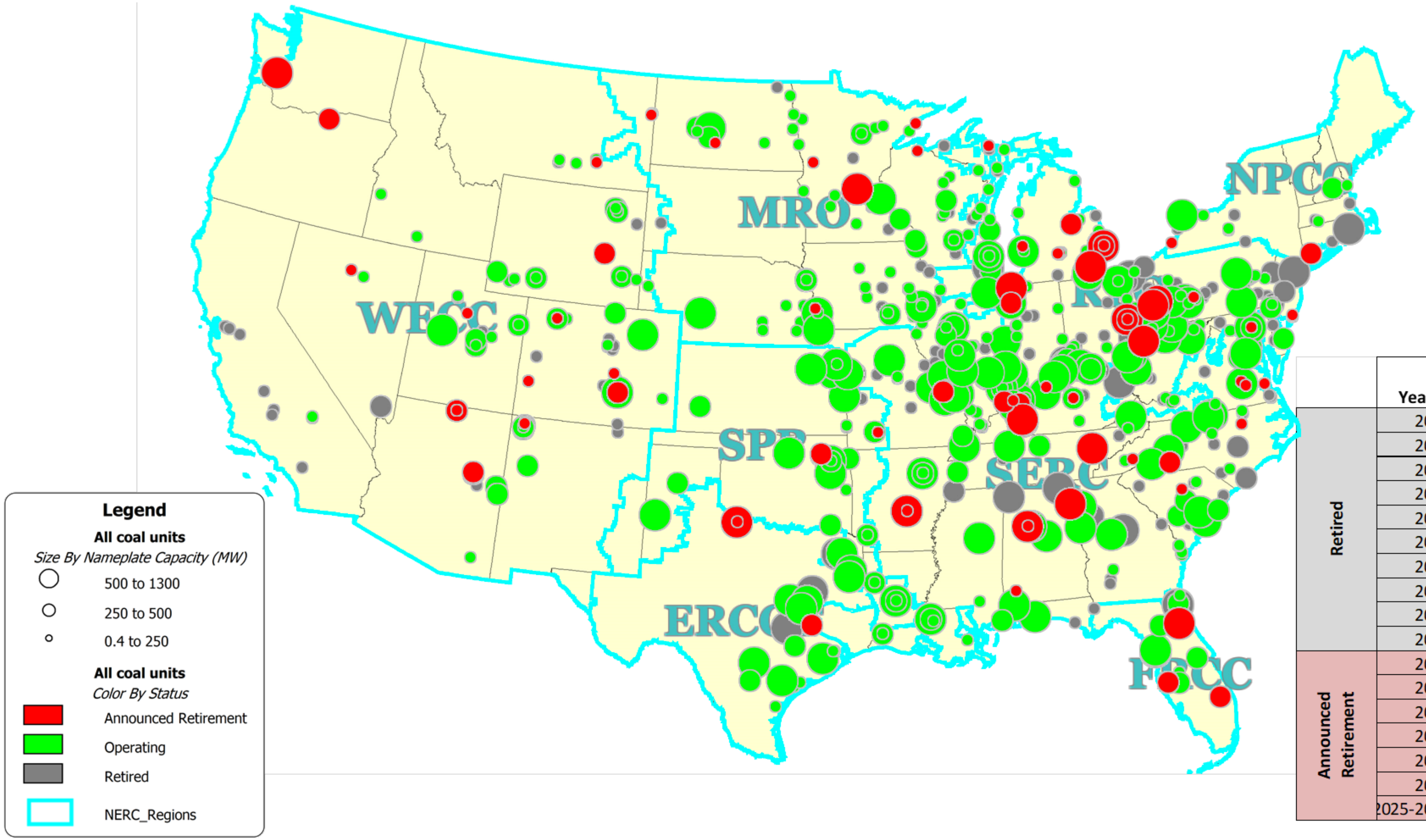
Coal Retirements According to Heat Rate and Environmental Controls

Coal Plant Status - Environmental Controls and Fuel Type



Credits: Left – Charles River Associates, The growing risks of regulated coal ownership, *CRA Insights: Energy*, April 2016
Right - – NETL analyses of EIA unit-level data

U.S. Coal Fleet Through 2030



	Year	Nameplate capacity (MW)	Total
Retired	2010	2,086	76,632
	2011	3,265	
	2012	9,811	
	2013	6,384	
	2014	5,349	
	2015	16,002	
	2016	9,250	
	2017	8,529	
	2018	13,723	
	2019	2,232	
Announced Retirement	2019	7,785	38,875
	2020	6,053	
	2021	2,571	
	2022	9,387	
	2023	4,270	
	2024	1,295	
	2025-2030	7,515	

Source: NETL analysis

Why do coal plants retire?

- **Revenue insufficient to cover cost of ownership**
  - "Routine" increased costs associated with aging and normal use of plant equipment
  - "Non-routine" increased costs due to accelerated wear from non-baseload operations
  - Decreased capacity utilization
- **Factors that influence decision**
  - Competition with lower-cost alternatives (e.g., natural gas, renewables)
  - Changing market conditions, largely unfavorable to coal (e.g., decreasing demand, market incentives for renewables, inadequate or non-existent compensation mechanisms)
  - Increasing corporate/investor focus on "clean" energy options
  - Public policies (e.g., renewable portfolio standards, state and federal regulations)
  - Societal concerns (e.g., "customer choice" for renewables, active opposition resulting in protracted permitting efforts, uncertainty in future public policy)

Retirement Example (Retired in 2018)

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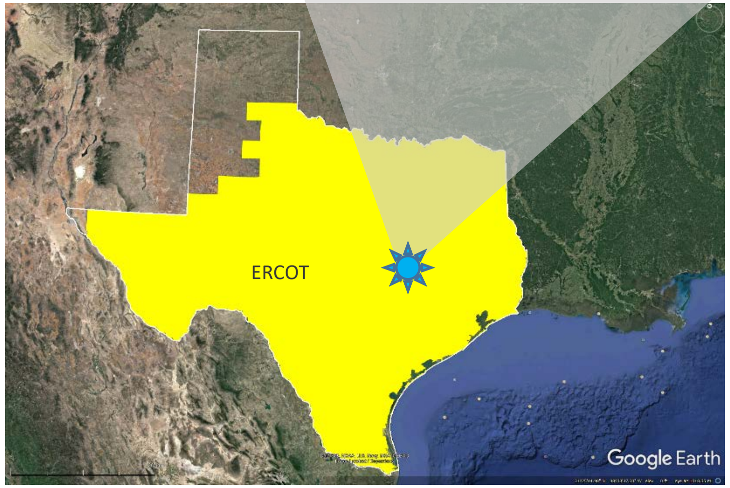
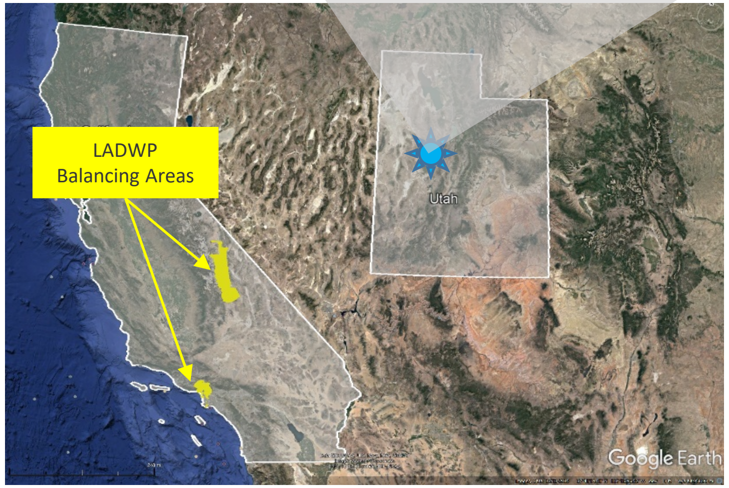
- **Sandow Power Plant**
  - Unit 5 – 692 MWe Lignite-fired fluidized bed combustor
  - Full-load efficiency – 35%
  - Full suite of environmental controls
  - Supplied the competitive wholesale ERCOT market
  - Online year – 2010, retired in 2018
- **Primary drivers for retirement**
  - Low wholesale power prices due to oversupply of generation, largely due to:
    - Recent and continued addition of wind and solar generation
    - Sustained low natural gas prices



Credits: Top: Luminant, https://www.luminant.com/wp-content/uploads/2017/07/sandow-300px.jpg
Bottom, NETL modification of Google Earth imagery

Retirement Example (Planned for 2025)

- **Intermountain Generating Station**
  - Units 1 & 2 – 1,775 MWe Bituminous-fired pulverized coal
  - Full-load efficiency – 35.2% (Unit 1), 35.9% (Unit 2)
  - Full suite of environmental controls
  - Supplied multiple customers in Utah and California
  - Online year – 1986 (Unit 1), 1987 (Unit 2), both scheduled for retirement in 2025
- **Primary drivers for retirement**
  - LADWP (plant operator and purchaser of 48.6% of generation) will not renew power purchase agreement, in part due to CA limitations on CO_2 emissions
  - New NGCC planned for site of existing coal units



Credits: Top: Power Engineering, https://www.power-eng.com/articles/2017/05/utah-s-largest-coal-plant-to-close-convert-by-2025.html
Bottom, NETL modification of Google Earth imagery

Closing Thoughts

Time is of the Essence

- **Solutions relevant to the existing fleet are needed in the near-term**
- **Must bring meaningful improvements to targeted attribute (e.g., efficiency, flexibility, reliability)**
- **Must be low cost, rapid return on investment**
- **Must be low risk in all aspects**
  - Performance – must function as intended
  - Reliability – must not negatively impact the existing plant
  - Cost – must have high cost certainty, minimal "collateral costs" (i.e., costly investments in other parts of the plant for system integration, life extension, etc.)
  - Integration – must be easily "absorbed" by existing plant infrastructure (including workforce)
  - Execution – predictable implementation, acceptable impact to short- and long-term operations

Opportunities for Targeted R&D

R&D Focus	Benefit to Owner/Operator	Benefit to System and Society
Improved Efficiency	• Increased capacity utilization via higher unit dispatch • lower cost of generation	• Lower electricity cost to the consumer • Decrease in environmental emissions from coal-fired electricity production
Increased Flexibility	• Greater agility to respond to rapid changes in electricity supply and demand	• Improved system capability to handle increased penetration of VERs • Lower system cost due to decreased need for replacement generation capacity
Enhanced Reliability	• Decreased maintenance costs • Fewer and shorter unplanned outages	• Improved energy security supported through higher system reliability • Lower cost to consumer through decreased need to source higher cost replacement power when unplanned outages occur

Thank You

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