Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations 1. Thesis and Dissertation Collection, all items

2019-05

America's Energy Portfolio Current State and Future Trends

Hough, Keith

Monterey California. Naval Postgraduate School

https://hdl.handle.net/10945/63172

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

http://www.nps.edu/library

REPORT DOCUMENTATION PAGE	*Form Approved* **OMB No. 0704-0188**

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
17-05-2019	CAPSTONE PROJECT	

4. TITLE AND SUBTITLE
America's Energy Portfolio

Current State and Future Trends

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Hough, Keith, LT, SC, USN

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Civilian Institutions Office (Code 522)
Naval Postgraduate School
1 University Circle, Herrmann Hall Rm HE046
Monterey, CA 93943-5033

10. SPONSOR/MONITOR'S ACRONYM(S)
NPS CIVINS

11. SPONSORING/MONITORING AGENCY REPORT NUMBER

12. DISTRIBUTION AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

In only a single decade, the use of coal has declined by 40% while natural gas electricity generation has risen by more than 50%. The revolutionary advances in shale recovery of natural gas through hydraulic fracturing has kept supply high and prices low in the face of rapidly increasing demand. Interestingly, this demand for new natural gas power plants is not driven by increased power consumption. This seems to be a rational choice, as natural gas power stations are the subject of new research and have achieved greater efficiencies and lower costs. This cost savings, however, does not justify closing down functioning coal stations and investing huge sums in new construction. Increased regulation costs for coal have been force multipliers for natural gas, increasing costs for keeping coal power online just when gas prices make their alternative more appealing than ever. The conclusion of this report notes that while the rise of natural gas has been enabled by lower fuel prices, it has been caused by government action. How our current energy mix was formed can provide valuable insight into its future and how to prepare. Trends in regulation for the previous decade have been consistent: Less pollutants such as smog are acceptable, and carbon dioxide emissions will be increasingly reduced. This portends even more preference for natural gas in the future.

15. SUBJECT TERMS
Energy, Electricity, Coal, Natural Gas, Government Policy

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPONE NUMBER (*Include area code)***
U	U	U	UU		

THIS PAGE INTENTIONALLY LEFT BLANK

AMERICA’S ENERGY PORTFOLIO

Current State and Future Trends

Keith Hough
C&PE 825 Spring 2019

TABLE OF CONTENTS

Contents

EXECUTIVE SUMMARY

The rapid transformation of the United States from a primarily coal powered country to one powered by natural gas has been remarkable. In only a single decade, the use of coal has declined by 40% while natural gas electricity generation has risen by more than 50%. Understanding what made this change possible, as well as what caused it, is critical to understanding the American energy portfolio: The fundamental makeup of our energy grid which is a cornerstone of our society.

The sudden rise in popularity of natural gas is made possible by large increases in the supply of the fuel. The revolutionary advances in shale recovery of natural gas through hydraulic fracturing has kept prices low in the face of rapidly increasing demand. Interestingly, this demand for new natural gas power plants is not driven by increased power consumption, which has remained very low and stable in the USA.

In fact, the appearance at first blush is the reality: coal plants are being actively taken offline and replaced with natural gas. This is a rational choice, as natural gas power stations are the subject of new research and have achieved greater efficiencies and lower costs. This cost savings, however, does not justify closing down functioning coal stations and investing huge sums in new construction, especially construction that is not satisfying increased demand. For capital intensive projects like power plants, existing capacity provides cheaper power than new construction can provide.

Beyond fuel prices, the only other major factor affecting these kinds of long term economic decisions is the regulatory environment, which has significant influence for electric plant owners and utilities. Increased regulation costs for coal have been force multipliers for natural gas, increasing costs for keeping coal power online just when gas prices make their alternative more appealing than ever. Nationally, regulations have come in the form of new EPA rules on pollution from electricity generation, which also includes carbon emissions. There has been additional legislation at the state level, compounding the disproportionate effect on coal.

The conclusion of this report notes that while the rise of natural gas has been enabled by lower fuel prices, it has been caused by government action. Nations have every right to decide how they provide power for their citizens, but in the absence of a strategic plan individual policies have to be parsed, and a national outcome determined. How our current energy mix was formed can provide valuable insight into its future and how to prepare.

The trends in regulation for the previous decade have been consistent: Less pollutants such as smog are acceptable, and carbon dioxide emissions will be increasingly reduced. This portends even more preference for natural gas in the future. But because natural gas still emits CO2, other alternatives are already taking the notice of legislators, such as nuclear.

INTRODUCTION

The energy infrastructure of the United States is primarily made up of coal, natural gas, and nuclear. The dynamic for the previous decade has been that of a reduction in coal power and increase in energy provided natural gas. This paper will examine the reasons for this dynamic, the direction of current trends and what will drive change in the future for America's energy portfolio.

An important factor in understanding the highly variable nature of our energy supply is the fact that energy demand has not been growing. Energy demand has only grown by an annualized rate of .15% [1] for the last 12 years, so natural gas power plants are not coming online to supplement coal and provide additional, needed energy. Coal plants are being actively shuttered and replaced with natural gas, dropping from 49% to 30% of US power generation in the previous decade (figure 1) [2]. Natural gas power generation has grown from 20% to 33% in the same period.

NATURAL GAS OVERTAKES COAL

What, then is the reason for the growth of natural gas? A large one is its lower price, which is a recent phenomenon and corresponds to its growing share of the US market since 2010. [3] (figure 2) Note that natural gas was also cheaper pre-2000, but power generation from that source was much lower during that period [4] and so is not an accurate representation of natural gas price in the face of high usage. (figure 3)

As natural gas capacity quickly came online in the 2000-2008 period, prices rapidly rose from less than $2.50 per BTU to $7 per BTU, with spikes of over $13. [3] Subsequent advances in hydraulic fracturing technology (fracking) greatly increased the number of economically viable shale deposits. By 2010, the fracking industry had grown by 45% per year for 5 years. [5] The result of the "shale revolution" was, and continues to be, lower and more stable natural gas prices, staying between $2.50 and $4.00 since 2011, only spiking once to $6 in 2014.

Natural gas power generation also enjoyed advances in efficiency and cost, speeding its adoption and enabling quick scaling of its use. [6] Beyond lower fuel prices making natural gas capacity more attractive for producers, the plants also have lower operating costs than coal. [7] (figure 4)

Combined cycle plants have excellent base load capacities and account for over half of total US natural gas capacity [4]. These kinds of plants also have the lowest Levelized Cost of Electricity (LCOE) of scalable, dispatchable power generation [8] (figure 5). The LCEO takes into account construction costs, fuel costs, costs of repaying debt for the initial capital requirement as well as a variety of other factors in order to accurately estimate the cost of electricity over the lengthy lifespan of a power plant. The lower LCOE offered by gas power means power plant operators are incentivized to construct new natural gas plants when making long term decisions.

But extending the life of an existing resource, even a coal plant, is nearly always less expensive than shutting the it down and building a new plant. This is true even if the new plant has lower cost, because much of the capital is allocated immediately for construction, and money spent today is more valuable than money spent years from now on fuel and maintenance. [9] (figure 6) Lower fuel prices cannot fully account for the early retirement of paid for coal plants.

REGULATORY ENVIRONMENT

Power generation is a highly regulated industry, which often runs as a state authorized monopoly. In order to completely understand why our energy structure looks the way it does we need to understand the regulations that govern its operation and major management decisions, such as when to close a plant, or when to build a new plant versus extending the life of an existing one.

Since plant operators and states are failing to extend the life of coal plants, it stands to reason that new regulations play a significant role in determining power plant decisions and thus the energy makeup of the United States. This is an intended effect; the government needs to manage pollution and ensure citizen safety and access to affordable power. These regulations must be studied in order to understand our current power resources and project their capabilities and limitations into the future.

NATIONWIDE REGULATIONS

The Environmental Protection Agency (EPA) sets national standards for power plants under the Clean Air Act. While the law itself doesn't change much, the EPA can set new standards (via rules) as an executive agency. An example is the Toxics Rule, which further limits mercury, Nitrogen Oxide and Sulfur Dioxide emissions, which will reduce smog. [10] States implement these rules, and must meet the EPA's standards. But they can also impose stricter standards if desired. The EPA estimates that the Toxics rule alone will reduce the country's coal power capacity from 309 to 299 GW, while not negatively affecting any other power source.

Additionally, the EPA has begun to regulate Carbon Dioxide (CO_2) in addition to traditional pollutants. The Clean Power Plan, an EPA rule proposed in 2014, has had a large effect on new plant construction decisions, especially coal. This rule strictly limits the carbon emissions from power plants, and as a result requires coal plants to use carbon capture and sequestration (CCS) technology. [8] This technology has not been proven commercially viable, as there are only two large scale CCS coal plants in the world [11] and it is not clear the technology will be economically efficient in all locations that power plants are needed. The EPA estimates the LCOE of mandated CCS coal plants to be above that of nuclear and more than double that of natural gas. [8] (figure 7)

Even though the Clean Power Plan has not yet been implemented, [12] due to a Supreme Court injunction [13] and the Trump Administrations plan to repeal the rule, [14] the regulatory uncertainty is affecting energy infrastructure decisions nonetheless. While various carbon emission rules are litigated, there remains elevated risk in coal, as it produces nearly double the amount of carbon than natural gas. [15] (figure 8)

An important aspect of new regulations that has tremendous influence on power plant construction are the EPA's use of grandfathering and "New Source Review." New EPA regulations do not affect existing plants, they are grandfathered in under the regulations they were built under. However, major modifications are required to undergo New Source Review and must meet additional standards that are not grandfathered in. [16] Such major modifications include life extension maintenance to keep existing plants running longer, further tipping the scales for decision making in the direction of building a new plant rather than continuing to use older ones.

Because the EPA is an executive agency, the President has a great deal of control over its regulatory proposals which directly affect power plants. When then candidate Obama was campaigning in 2008, he discussed his carbon cap and trade plan and said "If somebody wants to build a coal-fired power plant, they can. It's just that it will bankrupt them." [17] Whether such a plan could have been directly implemented with a congressional law is beyond the scope of this paper. But the connection between a government head promising such a thing and actual results very closely replicating that promise (coal plant construction quickly fell to zero during President Obama's first term) warrants attention. [18] (figure 9)

A few examples have been summarized of how policy implementation today has impacted plant construction decisions with 30 to 50-year timescales, even if that policy started out as an aspirational campaign discussion. One can reasonably estimate similar impacts from the states, for which the governor and legislature have similar power in their realm compared to the EPA and the president. The exact mechanisms upon which the policy relies on to effect power plants are varied and complex, but a glance at state leadership, and the legislation they prioritize is sufficient to determine the causes of change in their energy portfolio as well as to estimate future trends.

STATE REGULATIONS

States carry out EPA mandates, but they are able to determine their own stricter standards as well. California passed a carbon emissions control bill in 2006 aimed at lowering use of high carbon power sources, [19] and today the current governor is committed to continuing down that path and aiming at 100% renewable generation by 2045. [20] The results speak for themselves with coal providing 46,235 GWH in 2006, down to only 12,075 in 2017, with virtually none being produced in state. [21] Bucking the national trend, natural gas use has also dropped from 122,000 GWH to 98,000 GWH. The results for consumers have been increased electricity prices which continue to be 50% higher than the national average. [22] Natural gas provides the state with needed base load capacity with a marked increase in renewables filling the gap left by coal and to a lesser extent natural gas declines.

Michigan, by contrast, has been following the national trend. New coal construction has been halted by the operator due to new pollution regulations and lack of new energy demand. Natural gas plants were not affected. [23] New York has been following in California's footsteps, with higher than average electricity prices [24] and leadership commitments to eliminate coal and increase the use of renewable power. [25] There, too, natural gas remains a staple, continuing to provide over half their grid capacity. [26] Even in coal dependent states like Kentucky and West Virginia, the use of coal has decreased while natural gas power generation has increased. [27]

WHAT THE STATES TELL US ABOUT THE FUTURE OF US NATIONAL ENERGY STRATEGY

These state level decisions are very similar across the country [28] (figure 10): Coal generation capacity is being decreased everywhere, natural gas use is rising. States that make a concerted effort to increase their own standards beyond national requirements provide a useful microcosm to examine what may happen if such efforts are duplicated at the federal level.

The Clean Power Plan (CPP) aims to lower US greenhouse gas emissions by 30% by 2030. [29] We know from states attempting the same thing that these reductions will primarily come from eliminating coal power. The risk of higher power prices from forced use of renewables and lengthy legal battles, barriers which are easier to overcome at the state level, stand to dramatically slow any nation-wide action. Since it is 5 years since the Clean Power Plan was announced and it is still in legal limbo, predicting future environmental overhauls that will see actual implementation appears impossible. But we can measure the market perception of where regulations where go in the future.

The trend is mandates for less pollution and less CO2. The EPA's 2011 Toxins rule went into effect relatively easily, so national standards promoting cleaner burning fuels can be expected. Carbon standards are a tougher sell nationally, but the risk of stricter standards taking hold in the future is still there with changing administrations and unpredictable court rulings. States are more likely to directly implement carbon reduction legislation, which tend to include electricity imports, so they will affect neighboring states regardless of their own local policies. Renewable power sources come with major downsides such as lack of base load capability and a tendency to raise electricity prices when deployed in large quantities as seen in Germany and California. [30] Barring a force majeure, natural gas is the only way to satisfy current requirements and potential future regulations. Even states dedicated to eliminating CO2 emissions like California have a hard time getting rid of natural gas in significant amounts.

With fifty independent states, a cohesive, nationwide energy plan is unlikely to materialize. But that has not stopped the country from moving as if it did have a plan, taking advantage of the cost and environmental advantages of natural gas.

RISKS OF POTENTIAL NATURAL GAS DOMINANCE

Natural gas has already taken over coals place as the number one energy provider for the United States. By the time existing coal plants are slated to be shut down, natural gas could take over its 30% of US market share. But what if some of the enablers of this rapid transition evaporate in the next few decades?

Natural gas prices have fallen dramatically since America's "energy renaissance", but they remain highly unstable. They routinely spike 30% or more in winter months, whereas coal has remained between $2 and $2.50 per BTU with no seasonality. (figure 11) Natural gas prices are predicted to be relatively stable in the medium term by McKinsey and Company, with production and delivery infrastructure keeping pace with global demand growth. [31] The Energy Information Administration has a long-term outlook that agrees with this assessment, but notes that prices will heavily depend on advances in fracking technology as cheaper shale resources are used up and more expensive shale must be utilized. [32] (figure 12)

New environmental regulations could also come into play, although major fracking opposition has yet to materialize. [33] Several states have banned fracking, although these states (Vermont, Maryland New York) do not have significant shale reserves. [34] The potential dangers of this gas recovery method are well known and scientifically documented, from causing small earthquakes [35] to contaminating drinking water. [36] New developments in fracking research could result in more uncovered risks and potential harm being quantified, which could lead to stricter regulations even if not outright bans. Any restrictions to fracking capacity would quickly result in higher costs for producers and thus higher prices for consumers.

As natural gas becomes more and more common for power generation, the consequences side of price risk becomes more severe. Although not likely, baring a large change from the status quo, the United States still needs to be prepared for price shocks. The amount of resources required to address this risk will rise along with the percentage of our power generation that comes from natural gas.

CONCLUSION

The use of natural gas power generation will continue to rise, driven primarily by public policies which disproportionally affect coal, and enabled by historically high natural gas supply. Nuclear power is a potential trend breaker as it can directly replace natural gas plants with base load capabilities, and new bipartisan legislation being introduced to modernize and expand our nuclear fleet. [37] Nuclear power development also has the support of noted environmental groups [38], and this widespread support warrants attention as policies supporting nuclear move ahead.

With natural gas and coal prices projected to remain stable, environmental regulations are also a primary consideration to gauge future energy trends. The resolution of how exactly the EPA will choose to regulate carbon is of utmost importance: once the rule is final and it passes muster in the courts, there is very little chance of change without major political will. The details will affect estimates for how energy in the US will be generated, but some kind of regulation in this vein will occur and all states and plant operators will have to take that into account for future planning.

FIGURES

Figure 1

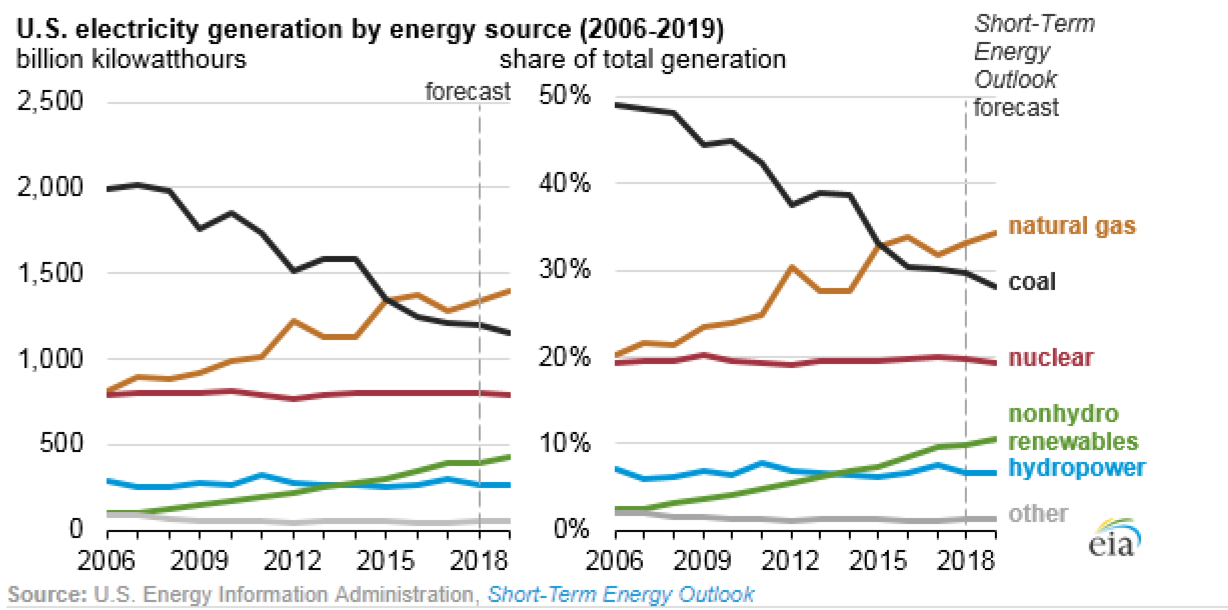


Figure 2

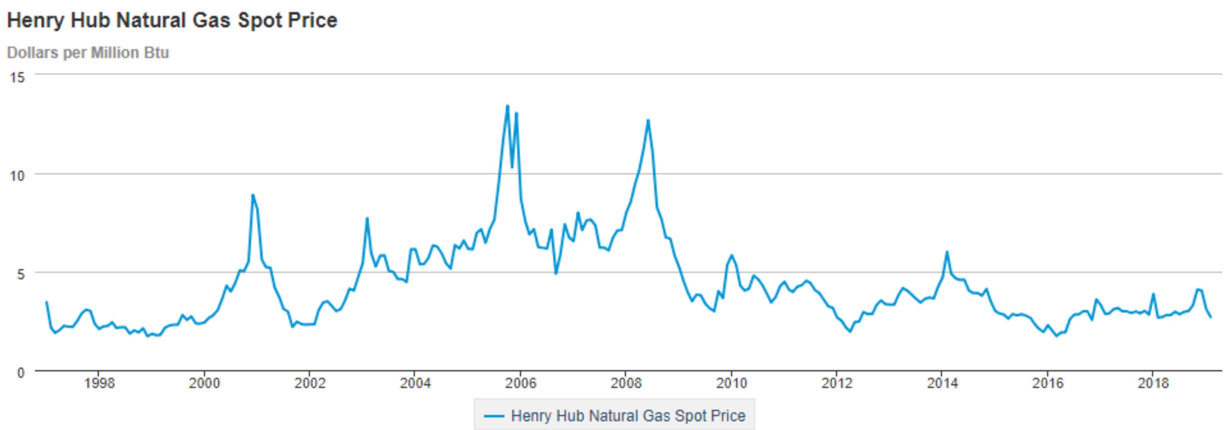


Figure 3

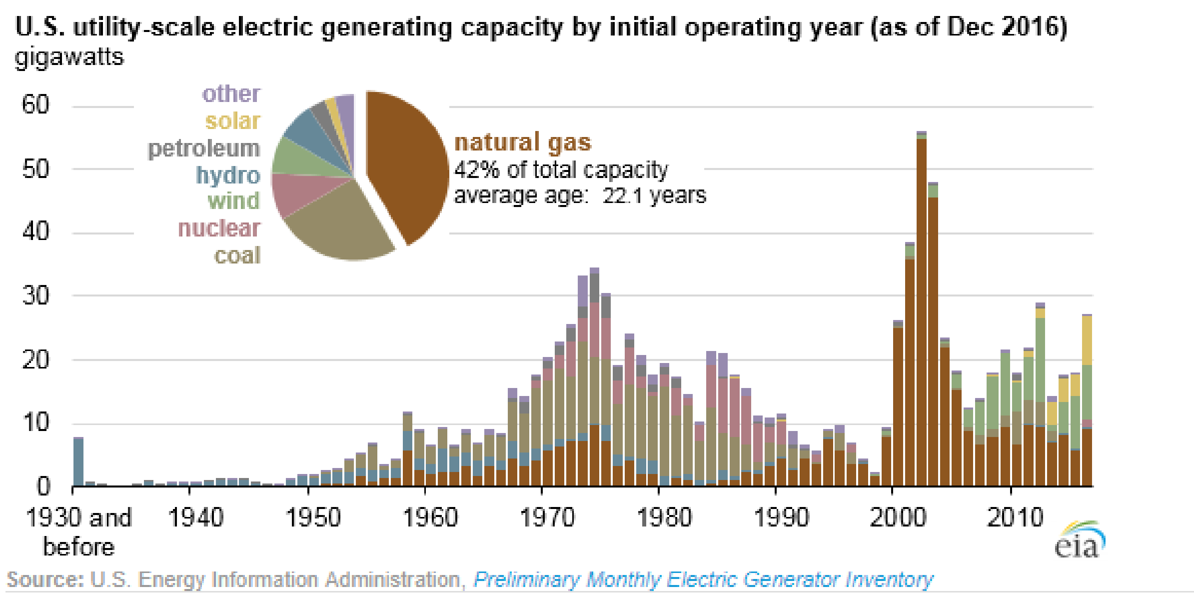


Figure 4

Technology	Plant Characteristics		Plant Costs (2016$)			
	Nominal Capacity (MW)	Heat Rate (Btu/kWh)	Overnight Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Variable O&M ($/MWh)	NEMS Input
Coal						
Ultra Supercritical Coal (USC)[10]	650	8,800	3,636	42.1	4.6	N
Ultra Supercritical Coal with CCS (USC/CCS)[11]	650	9,750	5,084	70	7.1	Y
Pulverized Coal Conversion to Natural Gas (CTNG)	300	10,300	226	22	1.3	N
Pulverized Coal Greenfield with 10-15 percent	300	8,960	4,620	50.9	5	N
Pulverized Coal Conversion to 10 percent biomass –	300	10,360	537	50.9	5	Y
Natural Gas						
Natural Gas Combined Cycle (NGCC)	702	6,600	978	11	3.5	Y
Advanced Natural Gas Combined Cycle (ANGCC)[13]	429	6,300	1,104	10	2	Y
Combustion Turbine (CT)	100	10,000	1,101	17.5	3.5	Y
Advanced Combustion Turbine (ACT)	237	9,800	678	6.8	10.7	Y
Reciprocating Internal Combustion Engine (RICE)	85	8,500	1,342	6.9	5.85	N
Uranium						
Advanced Nuclear (AN)	2,234	N/A	5,945	100.28	2.3	Y
Biomass						
Biomass (BBFB)	50	13,500	4,985	110	4.2	N
Wind						
Onshore Wind (WN)	100	N/A	1,877	39.7	0	Y
Solar						
Photovoltaic – Fixed	20	N/A	2,671	23.4	0	N
Photovoltaic – Tracking	20		2,644	23.9	0	N
Photovoltaic – Tracking	150	N/A	2,534	21.8	0	Y
Storage						
Battery Storage (BES)	4	N/A	2,813	40	8	N

Figure 5

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmission cost	Total system LCOE	Levelized tax credit[2]	Total LCOE including tax credit
Dispatchable technologies								
Coal with 30% CCS[3]	NB	NB	NB	NB	NB	NB	NB	NB
Coal with 90% CCS[3]	NB	NB	NB	NB	NB	NB	NB	NB
Conventional CC	87	8.1	1.5	32.3	0.9	42.8	NA	42.8
Advanced CC	87	7.1	1.4	30.7	1.0	40.2	NA	40.2
Advanced CC with CCS	NB	NB	NB	NB	NB	NB	NB	NB
Conventional CT	NB	NB	NB	NB	NB	NB	NB	NB
Advanced CT	30	17.2	2.7	54.6	3.0	77.5	NA	77.5
Advanced nuclear	NB	NB	NB	NB	NB	NB	NB	NB
Geothermal	90	24.6	13.3	0.0	1.4	39.4	-2.5	36.9
Biomass	83	37.3	15.7	37.5	1.5	92.1	NA	92.1
Non-dispatchable technologies								
Wind, onshore	44	27.8	12.6	0.0	2.4	42.8	-6.1	36.6
Wind, offshore	45	95.5	20.4	0.0	2.1	117.9	-11.5	106.5
Solar PV[4]	29	37.1	8.8	0.0	2.9	48.8	-11.1	37.6
Solar thermal	NB	NB	NB	NB	NB	NB	NB	NB
Hydroelectric[5]	75	29.9	6.2	1.4	1.6	39.1	NA	39.1

Figure 6

GENERATOR TYPE	LCOE of Existing Generation (at actual 2015 Capacity Factors and Fuel Costs)	LCOE of New Generation (at actual 2015 Capacity Factors and Fuel Costs)
DISPATCHABLE FULL-TIME-CAPABLE RESOURCES		
Conventional Coal	39.9	N/A[4]
Conventional Combined Cycle Gas (CC gas)[1]	34.4	55.3
Nuclear	29.1	90.1
Hydro	35.4	122.2
DISPATCHABLE PEAKING RESOURCES		
Conventional Combustion Turbine Gas (CT gas)	88.2	263.0
INTERMITTENT RESOURCES - AS USED IN PRACTICE	N/A[3]	
Wind including cost imposed on CC gas	N/A[3]	107.4 +other costs[5]
PV Solar including cost imposed on CC and CT gas[2]		140.3 +other costs[5]

Figure 7

Table 1b. Estimated levelized cost of electricity (unweighted average) for new generation resources entering service in 2023 (2018 $/MWh)

Plant type	Capacity factor (%)	Levelized capital cost	Levelized fixed O&M	Levelized variable O&M	Levelized transmis-sion cost	Total system LCOE	Levelized tax credit[1]	Total LCOE including tax credit
Dispatchable technologies								
Coal with 30% CCS[2]	85	61.3	9.7	32.2	1.1	104.3	NA	104.3
Coal with 90% CCS[2]	85	50.2	11.2	36.0	1.1	98.6	NA	98.6
Conventional CC	87	9.3	1.5	34.4	1.1	46.3	NA	46.3
Advanced CC	87	7.3	1.4	31.5	1.1	41.2	NA	41.2
Advanced CC with CCS	87	19.4	4.5	42.5	1.1	67.5	NA	67.5
Conventional CT	30	28.7	6.9	50.5	3.2	89.3	NA	89.3
Advanced CT	30	17.6	2.7	54.2	3.2	77.7	NA	77.7
Advanced nuclear	90	53.8	13.1	9.5	1.0	77.5	NA	77.5
Geothermal	90	26.7	12.9	0.0	1.4	41.0	-2.7	38.3
Biomass	83	36.3	15.7	39.0	1.2	92.2	NA	92.2
Non-dispatchable technologies								
Wind, onshore	41	39.8	13.7	0.0	2.5	55.9	-6.1	49.8
Wind, offshore	45	107.7	20.3	0.0	2.3	130.4	-12.9	117.5
Solar PV[3]	29	47.8	8.9	0.0	3.4	60.0	-14.3	45.7
Solar thermal	25	119.6	33.3	0.0	4.2	157.1	-35.9	121.2
Hydroelectric[4]	75	29.9	6.2	1.4	1.6	39.1	NA	39.1

Figure 8

Pounds of CO_2 emitted per million British thermal units (Btu) of energy for various fuels:

Coal (anthracite)	228.6
Coal (bituminous)	205.7
Coal (lignite)	215.4
Coal (subbituminous)	214.3
Diesel fuel and heating oil	161.3
Gasoline (without ethanol)	157.2
Propane	139.0
Natural gas	117.0

Figure 9

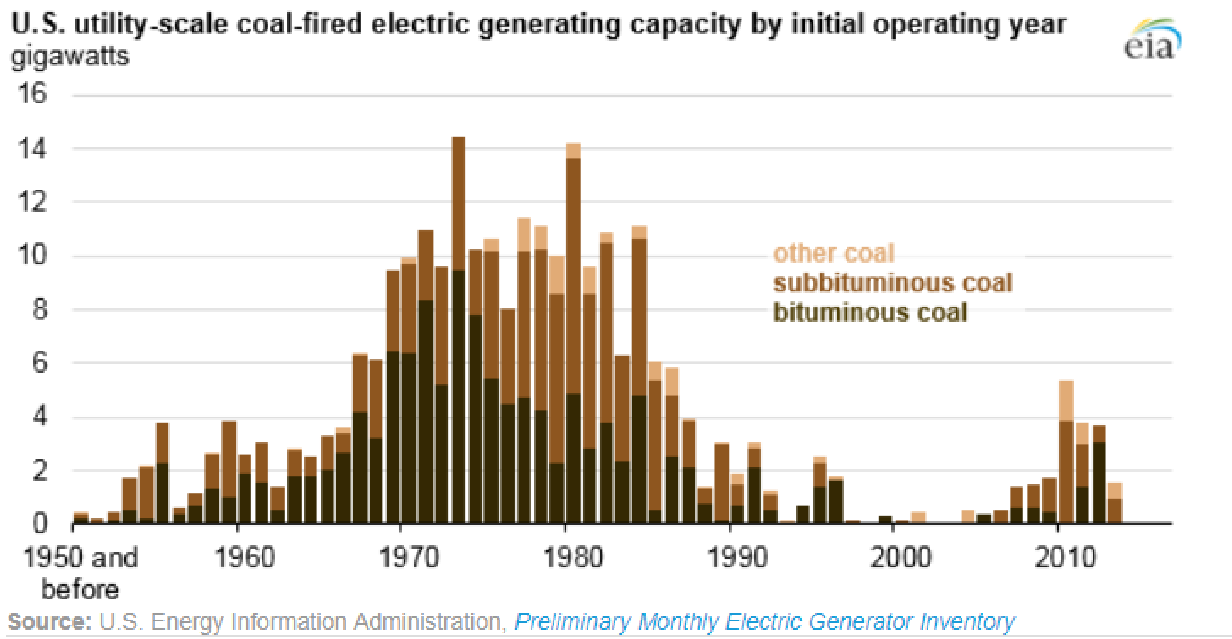
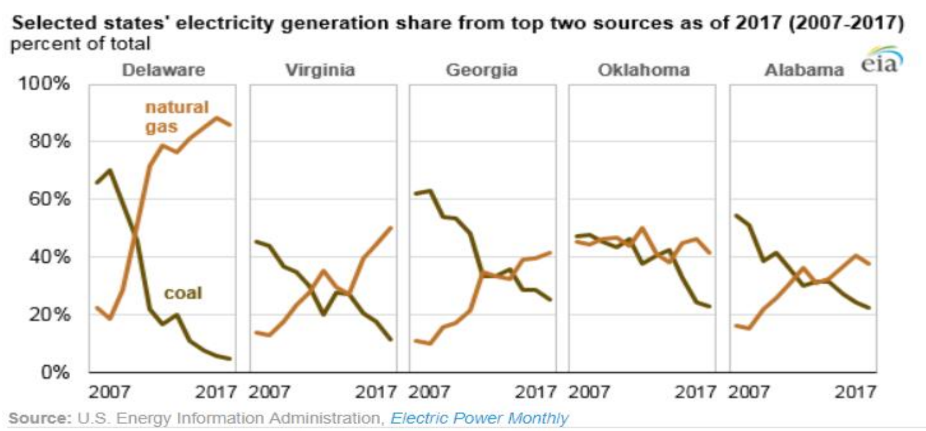


Figure 10



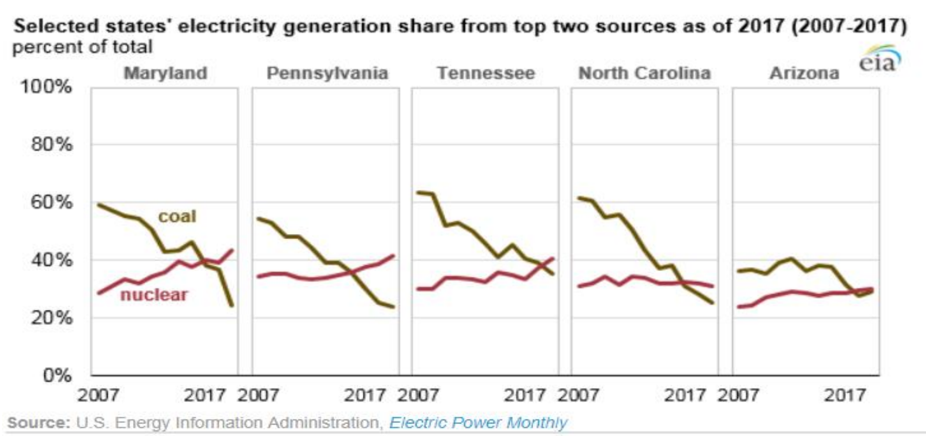
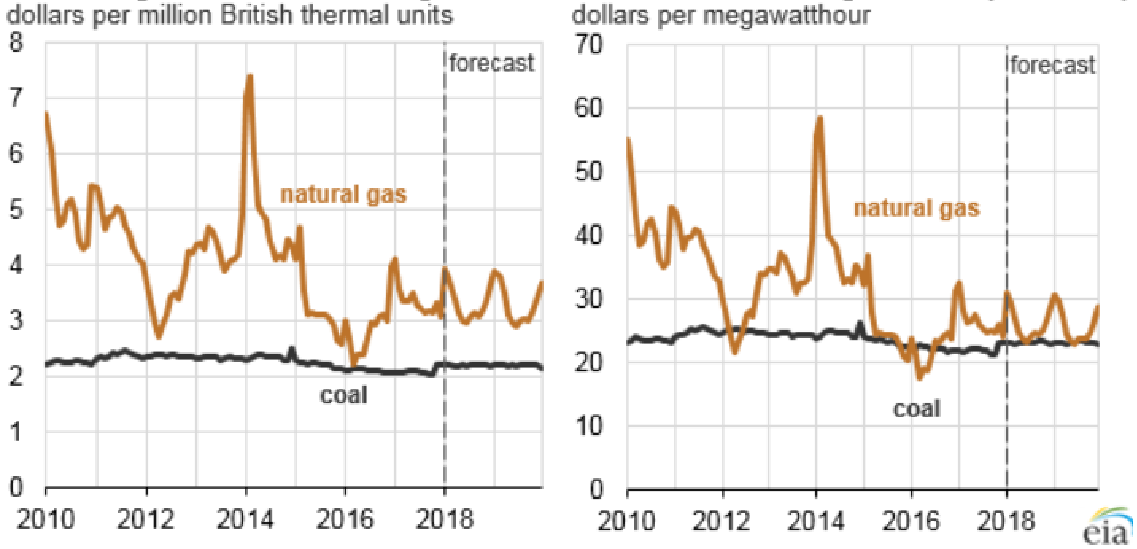


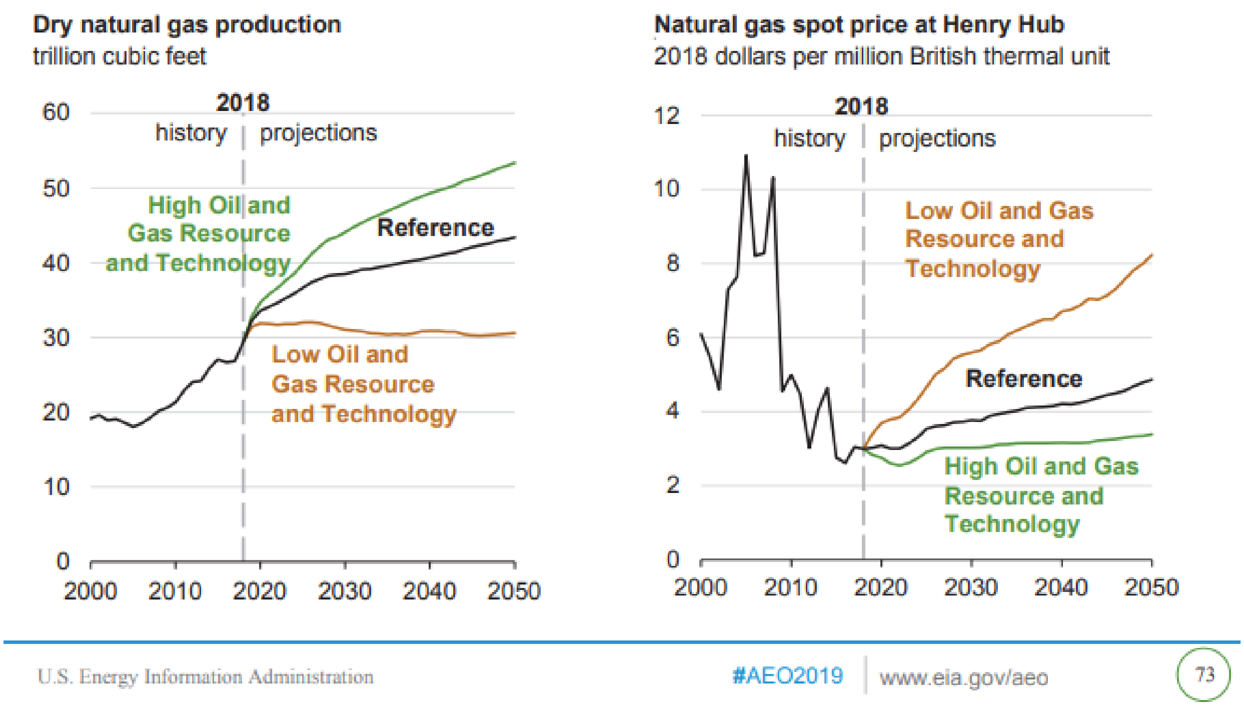
Figure 11

U.S. average **fuel cost** of natural gas and coal delivered to electric generators (2010-2019)



Source: U.S. Energy Information Administration, *Short-Term Energy Outlook*
Note: Costs in dollars per megawatthour are calculated using average coal and natural gas heat rates as reported in *Electric Power Annual* Table 8.1.

Figure 12



REFERENCES

Cover Sheet Image: Jamasmie, Cecilia. “First Time Ever: Gas Overtakes Coal in US Power Mix.” MINING.com, 13 July 2015, www.mining.com/first-time-ever-gas-overtakes-coal-in-us-power-mix/.

1. US Energy Information Administration. March 2019. “Electricity Net Generation: Total (All Sectors)” Retrieved from: https://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf

2. “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” EIA Forecasts Natural Gas to Remain Primary Energy Source for Electricity Generation - Today in Energy - U.S. Energy Information Administration (EIA), 22 Jan. 2018, www.eia.gov/todayinenergy/detail.php?id=34612.

3. *Henry Hub Natural Gas Spot Price*, US Energy Information Administration, 3 Apr. 2019, www.eia.gov/dnav/ng/hist/rngwhhdm.htm.

4. “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” Natural Gas Generators Make up the Largest Share of Overall U.S. Generation Capacity - Today in Energy - U.S. Energy Information Administration (EIA), US Energy Information Administration, 18 Dec. 2017, www.eia.gov/todayinenergy/detail.php?id=34172.

5. “Shale of the Century.” The Economist, The Economist Newspaper, 2 June 2012, www.economist.com/business/2012/06/02/shale-of-the-century.

6. “Trail-Blazing Power Plant Technology.” Www.siemens.com, Siemens, 19 May 2011, www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2011/fossil_power_generation/efp201105064.htm.

7. United States Energy Information Administration (2016). Capital Cost Estimates for Utility Scale Electricity Generating Plants. Retrieved from: https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capcost_assumption.pdf

8. United States Energy Information Administration (2019). Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2019. Retrieved from: https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

9. Stacy, T. Taylor, G. Institute for Energy Research (2016). Levelized Cost of Electricity from Existing Generation Resources. Retrieved from: http://instituteforenergyresearch.org/wp-content/uploads/2016/07/IER_LCOE_2016-2.pdf

10. United States Environmental Protection Agency (2011). Regulatory Impact Analysis of the Proposed Toxics Rule. Pg. 1-2, 18-20 Retrieved from: https://www3.epa.gov/ttn/atw/utility/ria_toxics_rule.pdf

11. Folger, P. Congressional Research Service (2018). Carbon Capture and Sequestration (CCS) in the United States. Pg 2. Retrieved from: https://fas.org/sgp/crs/misc/R44902.pdf

12. Muehlberger, Chris. Lecture, University of Kansas, Overland Park, 26 Mar 2019

13. Liptak, Adam, and Coral Davenport. "Supreme Court Deals Blow to Obama's Efforts to Regulate Coal Emissions." The New York Times, The New York Times, 9 Feb. 2016, www.nytimes.com/2016/02/10/us/politics/supreme-court-blocks-obama-epa-coal-emissions-regulations.html?smid=pl-share.

14. "Complying with President Trump's Executive Order on Energy Independence." EPA, Environmental Protection Agency, 18 June 2018, www.epa.gov/energy-independence.

15. "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." How Much Carbon Dioxide Is Produced When Different Fuels Are Burned? - FAQ - U.S. Energy Information Administration (EIA), 8 June 2018, www.eia.gov/tools/faqs/faq.php?id=73&t=11.

16. Hankins, Meredith. "The Clean Power Plan Replacement Comes With a Major Change to NSR (Part 1)." Insight & Analysis: Environmental Law and Policy, Legal Planet, 21 Aug. 2018, legal-planet.org/2018/08/21/the-clean-power-plan-replacement-comes-with-a-major-change-to-nsr-part-1/.

17. Martinson, Erica. "Uttered in 2008, Still Haunting Obama." POLITICO, 6 Apr. 2012, www.politico.com/story/2012/04/uttered-in-2008-still-haunting-obama-in-2012-074892.

18. Jell, Scott. "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." Most Coal Plants in the United States Were Built before 1990 - Today in Energy - U.S. Energy Information Administration (EIA), US Energy Information Administration, 17 Apr. 2017, www.eia.gov/todayinenergy/detail.php?id=30812.

19. California Energy Commission (2018).California's Declining Reliance on Coal. Pg. 1 Retrieved from: https://www.energy.ca.gov/renewables/tracking_progress/documents/declining_reliance_coal.pdf

20. Newsom, Gavin. A Sustainable World Can Start in California. Medium, 5 Dec. 2017, medium.com/@GavinNewsom/a-sustainable-world-can-start-in-california-df8c0d1332d4.

21. California Energy Commission. Total System Electric Generation. California Energy Commission, 21 June 2018, www.energy.ca.gov/almanac/electricity_data/total_system_power.html.

22. "U.S. Energy Information Administration - EIA - Independent Statistics and Analysis." California - Rankings - U.S. Energy Information Administration (EIA), Dec. 2018, www.eia.gov/state/rankings/?sid=CA#series/31.

23. Sweet, C. "Michigan Utility To Scrap 'Clean-Coal' Plant, Shut Older Coal Units." The Wall Street Journal, 2 Dec. 2011, archived.

https://web.archive.org/web/20131022055334/http:/online.wsj.com/article/BT-CO-20111202-713204.html

24. Average Energy Prices, New York-Newark-Jersey City – February 2019 : New York–New Jersey Information Office. U.S. Bureau of Labor Statistics, 13 Mar. 2019, www.bls.gov/regions/new-york-new-jersey/news-release/averageenergyprices_newyorkarea.htm.

25. “Governor Cuomo Announces Proposed Regulations to Make New York Power Plants Coal-Free by 2020.” Governor Andrew M. Cuomo, Press Office for Governor Cuomo, 22 May 2018, www.governor.ny.gov/news/governor-cuomo-announces-proposed-regulations-make-new-york-power-plants-coal-free-2020.

26. “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” New York - State Energy Profile Analysis - U.S. Energy Information Administration (EIA), US Energy Information Administration, 16 Aug. 2018, www.eia.gov/state/analysis.php?sid=NY.

27. Popovich, Nadja. “How Does Your State Make Electricity?” The New York Times, The New York Times, 24 Dec. 2018, www.nytimes.com/interactive/2018/12/24/climate/how-electricity-generation-changed-in-your-state.html.

28. Comstock, Owen. “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” Coal Is the Most-Used Electricity Generation Source in 18 States; Natural Gas in 16 - Today in Energy - U.S. Energy Information Administration (EIA), US Energy Information Administration, 10 Sept. 2018, www.eia.gov/todayinenergy/detail.php?id=37034.

29. “FACT SHEET: Clean Power Plan Benefits.” EPA, Environmental Protection Agency, 9 May 2017, archive.epa.gov/epa/cleanpowerplan/fact-sheet-clean-power-plan-benefits.html.

30. Bohringer, C et al. “Economic Impacts of Renewable Energy Promotion in Germany.” The Energy Journal, Vol 38 S11. 2017. pg 1. Retrieved from: http://theargeo.org/August/files/Economic%20Impacts%20of%20Renewable%20Energy%20Promotion%20in%20Germany.pdf

31. Global Gas & LNG Outlook to 2035. McKinsey & Company, 2019, www.mckinsey.com/solutions/energy-insights/global-gas-lng-outlook-to-2035.

32. US Energy Information Administration. January 2019. “Annual Energy Outlook 2019” pg 74 Retrieved from: https://www.eia.gov/totalenergy/data/monthly/pdf/sec7_5.pdf

33. Soraghan, Mike. CAMPAIGN 2018: Fracking Falls from Dems' Sights as They Eye Majority. E&E News, 2 Nov. 2018, www.eenews.net/stories/1060104977.

34. “U.S. Energy Information Administration - EIA - Independent Statistics and Analysis.” State Energy Profile Analysis, 16 Aug. 2018, www.eia.gov/state/analysis.php?sid=NY.

35. Oklahoma Now Has More Earthquakes on a Regular Basis than California. Are They Due to Fracking? United States Geological Survey, www.usgs.gov/faqs/oklahoma-now-has-more-earthquakes-a-regular-basis-california-are-they-due-fracking?qt-news_science_products=0#qt-news_science_products.

36. Hill, E., Ma, L. "Shale Gas Development and Drinking Water Quality"
American Economic Review, Vol 107(5) 522-525. 2017. pg 1. Retrieved from:
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5804812/

37. "S.3422 - 115th Congress (2017-2018): Nuclear Energy Leadership Act." Congress.gov, 29 Nov. 2018, www.congress.gov/bill/115th-congress/senate-bill/3422.

38. The Nuclear Power Dilemma (2018). Union of Concerned Scientists, 2018, www.ucsusa.org/nuclear-power/cost-nuclear-power/retirements.