Forecasting Coal Unit Competitiveness

Coal Retirement Assessment Using Synapse's Coal Asset Valuation Tool (CAVT)

2015 Update

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EXECUTIVE SUMMARY

As new, more stringent federal environmental regulations come into effect, the fleet of United States coal-fired power plants is becoming increasingly expensive in comparison to the alternative of electricity market purchases. Numerous industry groups, environmental advocates, and government agencies have published estimates of the U.S. coal capacity at risk of retirement as coal-fired generation becomes less economic. However, many of these estimates have been conservative in that they have excluded the costs of installing and operating some of the controls expected to be required for compliance with environmental regulations. In addition, many have inappropriately assumed a long-term carbon-emission price of zero.

This study explores a more comprehensive set of assumptions using the latest version of Synapse's Coal Asset Valuation Tool (CAVT). CAVT v.5.0 is a spreadsheet-based database and model that forecasts the costs for individual coal units to comply with environmental regulations, and compares these forecasts to electricity market prices. It includes cost estimates for all expected environmental retrofits along with forecasted carbon prices.

Based on CAVT analysis, Synapse's mid-case projection indicates that 77 percent of current U.S. coal capacity is uneconomic, or "at risk," compared to the all-in costs of building and operating new natural gas combined-cycle units, and 94 percent is uneconomic compared to the wholesale electricity market purchases from existing natural gas combined-cycle units (see Table ES1). These findings indicate that it would be cheaper to retire rather than to continue operating 242 to 296 gigawatts (GW) of coal, out of a total of 314 GW operating in the U.S. in 2013. If all coal units that are projected to be uneconomic were to retire, the U.S would save an estimated $262 billion in present value savings between 2015 and 2044 by purchasing all-in market energy instead of installing and operating environmental controls on uneconomic coal plants.

Table ES1. Coal units, coal capacity, and coal generation uneconomic compared to market replacements under a mid-case environmental retrofit scenario

	Uneconomic Coal Compared to All-in Market Price Replacement		Uneconomic Coal Compared to Energy-only Market Price Replacement	
Number of Units	771	87%	852	96%
Capacity (GW)	242	77%	296	94%
Generation (TWh)	1,096	74%	1,371	92%

Note that market conditions are likely to change as coal plants retire—for example, natural gas prices may rise or coal prices may drop—shifting these cost comparisons. Synapse's analysis focuses on each plant's individual economics, and not on the broader macroeconomic ramifications of retiring most of the country's coal capacity en masse.

1. INTRODUCTION

As of spring 2015, retirements have been announced for 48 of the 314 gigawatts (GW) of coal capacity in the United States. But that's just the beginning. In strictly economic terms, many more coal units are no longer worth running; it would be cheaper to retire these units and purchase power from the market than to invest in retrofits to comply with new, more stringent environmental regulations.[1]

Synapse uses its Coal Asset Valuation Tool (CAVT) to analyze which U.S. coal plants are projected to be no longer cost effective in the future.[2] CAVT is a spreadsheet-based database and model that aggregates publicly available data (such as capacity, generated power, and heat rate) on non-cogenerating coal units and combines this with publicly available cost methodologies to calculate the cost of complying with environmental regulations. The calculated future cost of each coal unit—that is, the discounted present value of costs from 2015 to 2044—is compared to the estimated future cost of wholesale electricity market purchases to determine future economic viability on a unit-by-unit basis. All costs in this report are net present value accrued from 2015 through 2044, based on a 4.71 percent real discount rate, in 2012 dollars.

This report is an update to the October 2013 Synapse report "Forecasting Coal Unit Competitiveness,"[3] and uses the latest available version of CAVT, version 5.0. Version 5.0 uses power plant capacity, generation, and control data as recent as 2014, includes carbon dioxide (CO_2) prices from the latest 2015 Synapse forecast, and provides the latest versions of likely expected environmental retrofit scenarios, as well as several bug fixes. It also includes new modules for calculating the cost of dry flue gas desulfurization (FGD) and SNCR systems, and updates control cost information for the following compliance technologies: Wet FGD for sulfur emissions, selective catalytic reduction (SCR) for nitrogen

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[1] This report focuses on coal units' economic viability with respect to the cost of purchasing power from natural gas combined cycle units. Similar analyses could be performed comparing coal units' economic viability against the cost of purchasing electricity from wind or other types of resources.

[2] Many other studies have analyzed the amount of coal capacity that is likely to become uneconomic in the future. Examples include: Charles River Associates (2010) *A Reliability Assessment of EPA's Proposed Transport Rule and Forthcoming Utility MACT*. Retrieved from http://crai.com/uploadedFiles/Publications/CRA-Reliability-Assessment-of-EPA%27s-Proposed-Transport-Rule.pdf; North American Electric Reliability Corporation (2010) *2010 Special Reliability Scenario Assessment: Resource Adequacy Impacts of Potential U.S. Environmental Regulations*. Retrieved from http://www.nerc.com/files/EPA_Scenario_Final_v2.pdf; Credit Suisse (2010) *Growth from Subtraction*. Retrieved from http://op.bna.com/env.nsf/id/jstn-8actja/$File/suisse.pdf; Bipartisan Policy Center (2011) *Environmental Regulation and Electric System Reliability*. Retrieved from http://bipartisanpolicy.org/sites/default/files/BPC%20Electric%20System%20Reliability.pdf; Edison Electric Institute (2011) *Potential Impacts of Environmental Regulation on the U.S. Generation Fleet*. Retrieved from http://www.pacificorp.com/content/dam/pacificorp/doc/Energy_Sources/Integrated_Resource_Plan/2011IRP/EEIModelingReportFinal-28January2011.pdf; Brattle Group (2012) *Potential Coal Plant Retirements: 2012 Update*. Retrieved from http://www.brattle.com/_documents/UploadLibrary/Upload1082.pdf; Union of Concerned Scientists (2012) *Ripe for Retirement: The Case for Closing America's Costliest Coal Plants*. Retrieved from http://www.ucsusa.org/assets/documents/clean_energy/Ripe-for-Retirement-Full-Report.pdf; U.S. Energy Information Administration (2013) *Annual Energy Outlook 2013*. Retrieved from http://www.eia.gov/forecasts/aeo/pdf/0383%282013%29.pdf.

[3] Available at http://www.synapse-energy.com/sites/default/files/SynapseReport.2013-10.EF_.CAVT-Report.13-020A.pdf.

oxides, baghouse technology for dust containment, and activated carbon injection (ACI) systems for mercury removal. Other additions include a revised "dashboard" page, facilitating easier construction of new environmental retrofit scenarios; a new "snapshot" page, illustrating the total up-front capital costs of environmental upgrades along with the average operating and maintenance costs in dollars per megawatt hour (MWh); and a new "citations" page which provides a single repository for all the sources of calculations used throughout CAVT. Readers interested in performing their own analysis of uneconomic coal using different assumptions may download CAVT from www.synapse-energy.com/cavt and substitute their own assumptions.

This study uses CAVT to assess U.S. coal units' economics compared to the "all-in" market price of energy (based on the cost of constructing and operating a new natural gas combined-cycle plant) and the "energy only" market price (based on the cost of operating an existing natural gas combined-cycle plant).

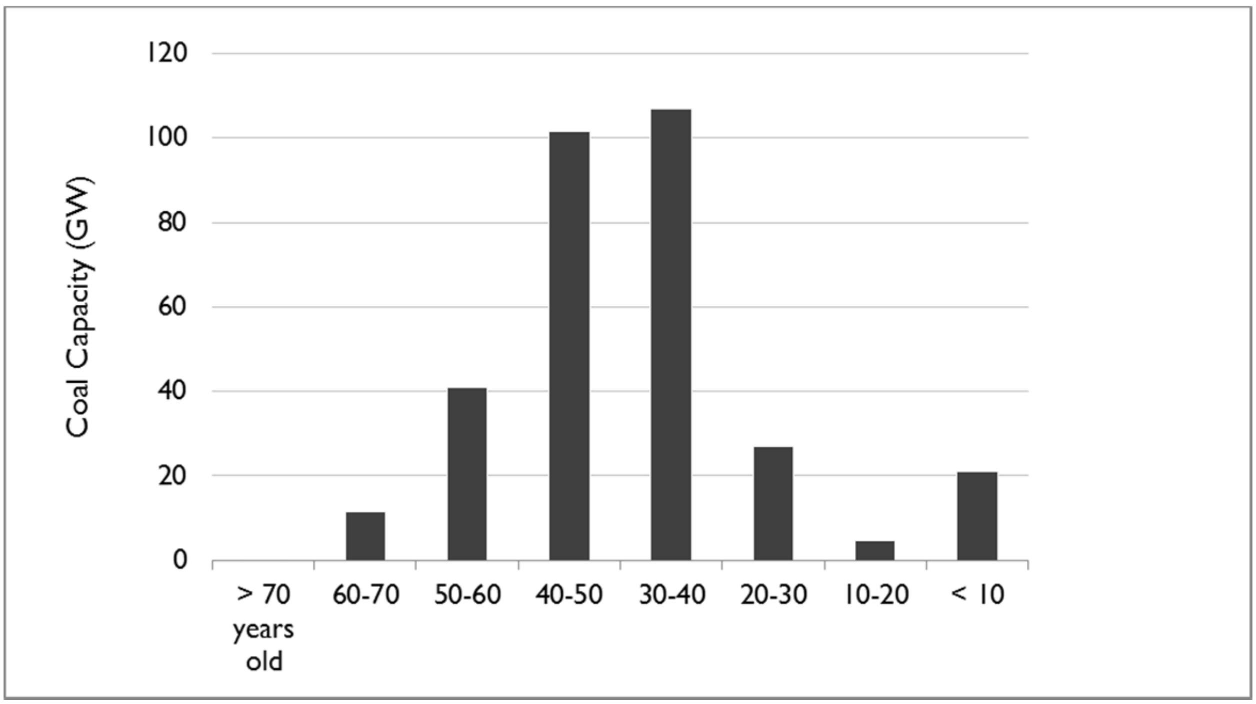
Section 3 of this report evaluates U.S. coal units' economics compared to "typical" national market prices for electricity, and investigates the effects of using differing assumptions for gas prices and the stringency of environmental regulations. Section 4 discusses recent real-world applications of CAVT. Appendix A describes the methodology used by CAVT in its calculations, and identifies the underlying data and assumptions used in this report regarding coal unit characteristics, electricity market prices, and environmental control requirements.

2. ASSESSING THE U.S. COAL FLEET

From the 680 MW Avon Lake 9 unit in Ohio to the 12 MW Silver Lake 2 unit in Minnesota, coal units all over the country are announcing their retirement. Fifteen percent of U.S. coal capacity—238 coal units with a combined capacity of 48 GW—is currently slated to retire. Sixty percent of these units will retire by 2015; and 77 percent will retire by 2016. Averaging 200 MW, these units are smaller than the U.S. mean coal unit, which is 355 MW. Half of the retiring units are in the East North Central region (WI, MI, IL, IN, OH) or the South Atlantic region (FL, GA, SC, NC, VA, WV, MD, DC, DE).

Much of the existing coal fleet is also nearing the end of its originally-intended lifespan. Figure 1 displays a histogram of the U.S. coal fleet's capacity, broken out by age group. Two-thirds of existing capacity (208 GW) was built between 30 and 50 years ago. Approximately half of nationwide coal capacity is more than 40 years old. Much of this older coal capacity is uncontrolled, inefficient, and uneconomic—or has a high likelihood of becoming uneconomic in the near future.

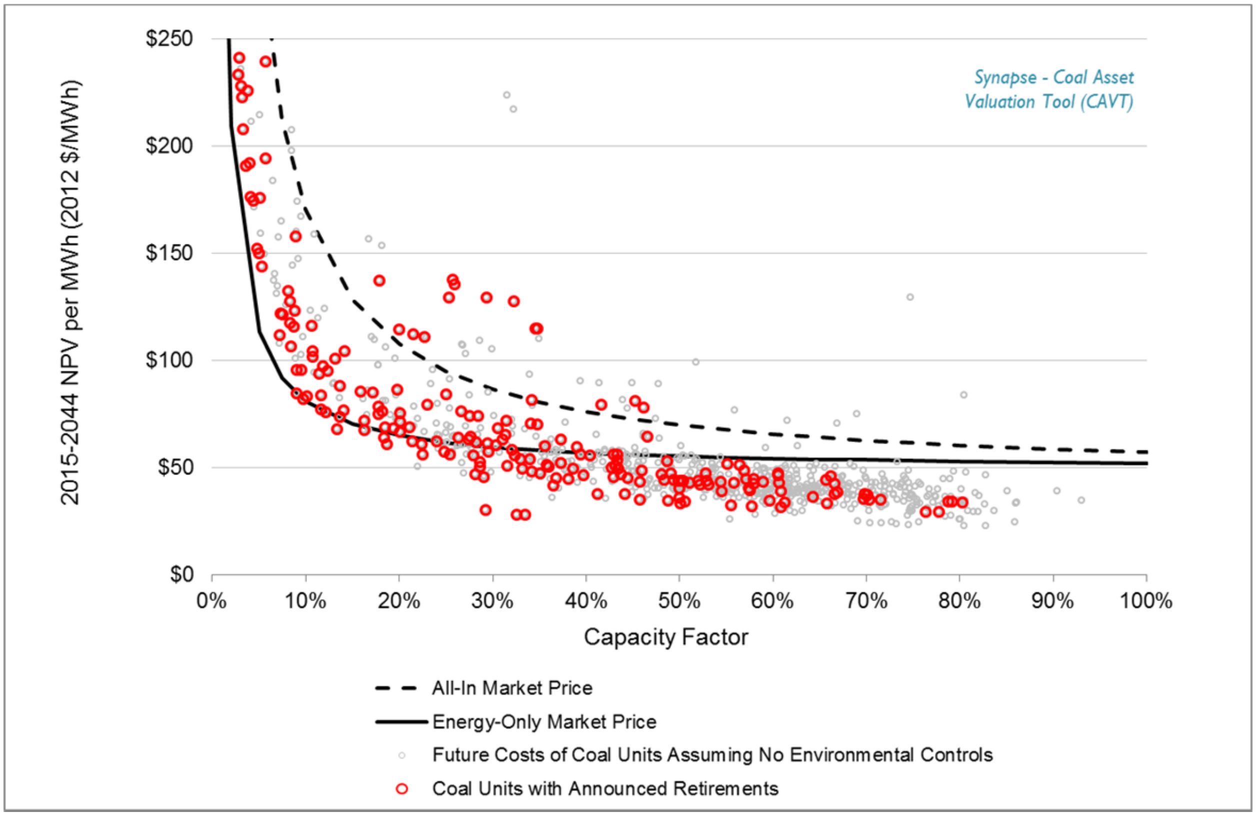
Figure 1. Age of coal capacity in the United States



2.1. Coal unit competitiveness with and without new retrofit costs

Based on CAVT estimates, Figure 2 illustrates how U.S. coal units compare economically to market electricity purchases, assuming no additional environmental retrofits beyond those that had already been installed in 2014. Each unit's current operating costs[4] (in 2012 dollars per MWh) are plotted against that same unit's current annual capacity factor (shown as grey circles).[5] Markers for the coal units that have announced their retirements are circled in red.

Figure 2. Projected net present value of coal units assuming no new environmental retrofits compared to typical national market electricity prices , 2015-2044



Also shown in Figure 2 are two curves approximating the wholesale market price of electricity under the same scenario, which includes no additional environmental controls or carbon price. The lower, solid line depicts an energy-only market price based on the operating costs of an existing natural gas combined-cycle plant. The higher, dashed line depicts an "all-in" market price based on the cost of constructing and operating a new natural gas combined-cycle plant. In this figure, market prices include the assumption of a natural gas price that closely follows the U.S. Energy Information Administration's

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4 Operating costs include unit-specific fixed and variable operating and maintenance costs, coal fuel costs, and for units that currently have environmental controls, fixed and variable operating and maintenance costs associated with those controls. Current costs for generating units include neither the capital nor the operating costs of required environmental costs that have not yet been installed and only include the carbon costs associated with the existing Regional Greenhouse Gas Initiative for the plants to which that program applies. Note that many units are currently undergoing environmental retrofits to meet MATS compliance (typically consisting of ACI installations). These "sunk" environmental retrofits that are not yet completed are not accounted for in this analysis.

5 Annual capacity factor refers to the ratio of generation produced by a coal unit to the total possible generation over a year. It is commonly expressed through the formula: Annual Unit Generation / (Unit Capacity x 8760 hours).

(EIA's) reference case—starting at the national 2015 average price of $4.43/MMBtu and increasing by an annual average rate of 2.40 percent.[6]

If a coal unit's marker appears below the market price curves, it is more economic to continue running the unit than to retire it and purchase market power. If the unit's marker appears above the market price curves, it is more economic to retire the unit and purchase market power. Note that 238 units are outlined in red, indicating that their retirements have been announced. Figure 2 shows that, if one does not account for expected retrofit costs, many of the units slated for retirement are economic compared to the energy-only market price, and even more are economic compared to the all-in market price. Only 20 of the retiring units are currently more expensive to operate than the all-in market price; this suggests that decisions about retirements are being made on the basis of expected future environmental costs.[7]

Figure 3 plots the future costs of each coal plant, including required environmental controls,[8] against the same current capacity factors (shown as blue circles). Environmental controls assumed necessary for regulatory compliance in Figure 3 are dry FGD in 2020, SCR in 2019, baghouses in 2025, ACI in 2016, recirculating cooling systems in 2019, coal ash controls in 2019, and effluent controls in 2019. Control costs are assigned to only those units that are currently uncontrolled. The Synapse mid CO_2 price case (starting at $20.00/ton in 2020 and rising to $72.10/ton in 2044) is also assumed.[9] Units currently announced for retirement are again outlined in red. Note that the energy-only and all-in market prices in this figure have also been adjusted to include the Synapse mid CO_2 price case.[10]

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[6] EIA (2014) *Annual Energy Outlook 2014*. Retrieved from http://www.eia.gov/forecasts/aeo/data.cfm.

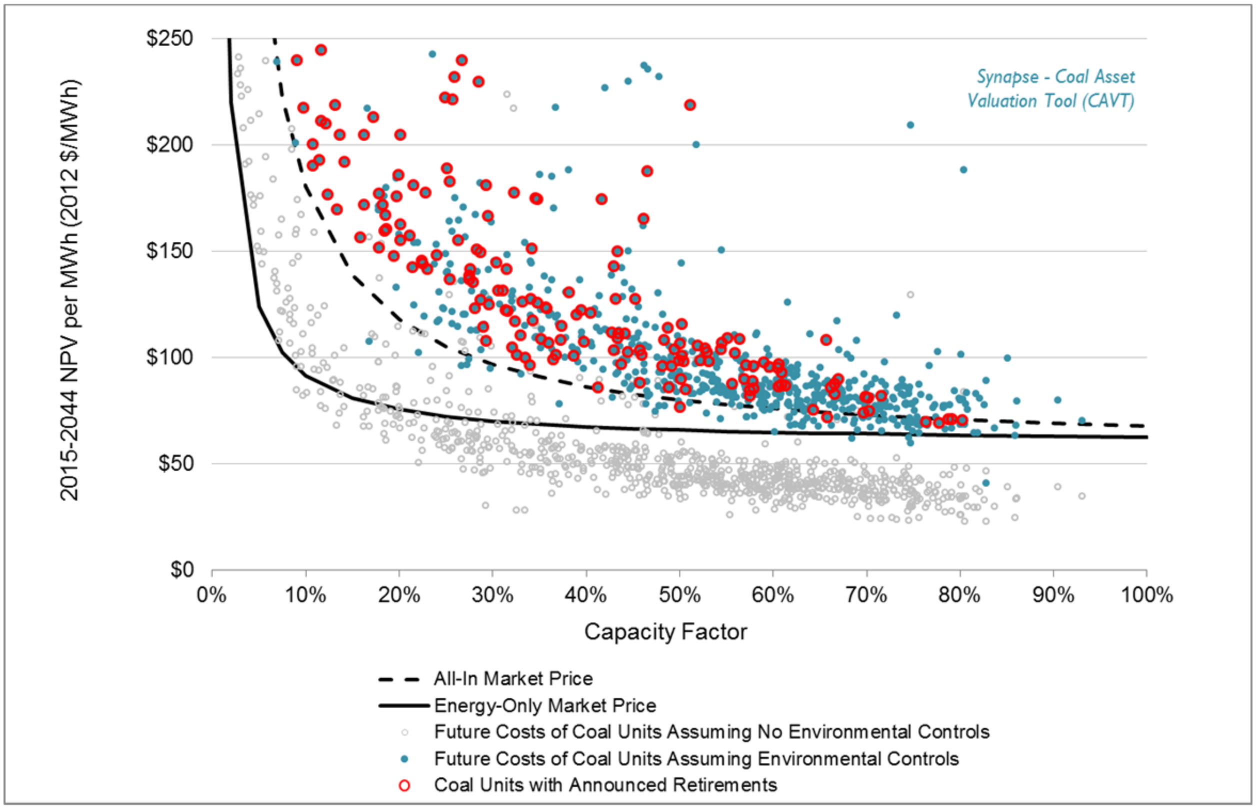
[7] The number of units described as uneconomic in the text of this report is based on comparisons to regionally specific market prices, and therefore may not correspond exactly to unit placement above or below the curves representing illustrative national market prices in Figures 1 and 2.

[8] Environmental control costs include capital costs, fixed and variable operating cost, and balance of plant impacts associated with parasitic load.

[9] Synapse Energy Economics (March 2015) *2015 Carbon Dioxide Price Forecast*.

[10] After levelization over 2015-2034, and assuming a heat rate of 7,050 Btu/kWh, this mid CO2 price can be translated into an $10/MWh adder to the cost of new or existing operating NGCC units.

Figure 3. Projected net present value of coal units assuming environmental retrofits, compared to typical national market electricity prices, 2015-2044



After accounting for environmental retrofit costs, 112 units are still economic compared to the all-in market price of electricity (i.e., below the dashed line), and only 31 units are still economic compared to the lower, energy-only market price (i.e., below the solid line).[11] Announced retirements tend to confirm Synapse's results. Out of 238 coal units with announced retirement dates (circled in red), only 10 units are identified by CAVT as being economic compared to the all-in market price in Figure 3 (i.e., below the dashed line). Table 1 indicates what these numbers mean in terms of capacity and generation.

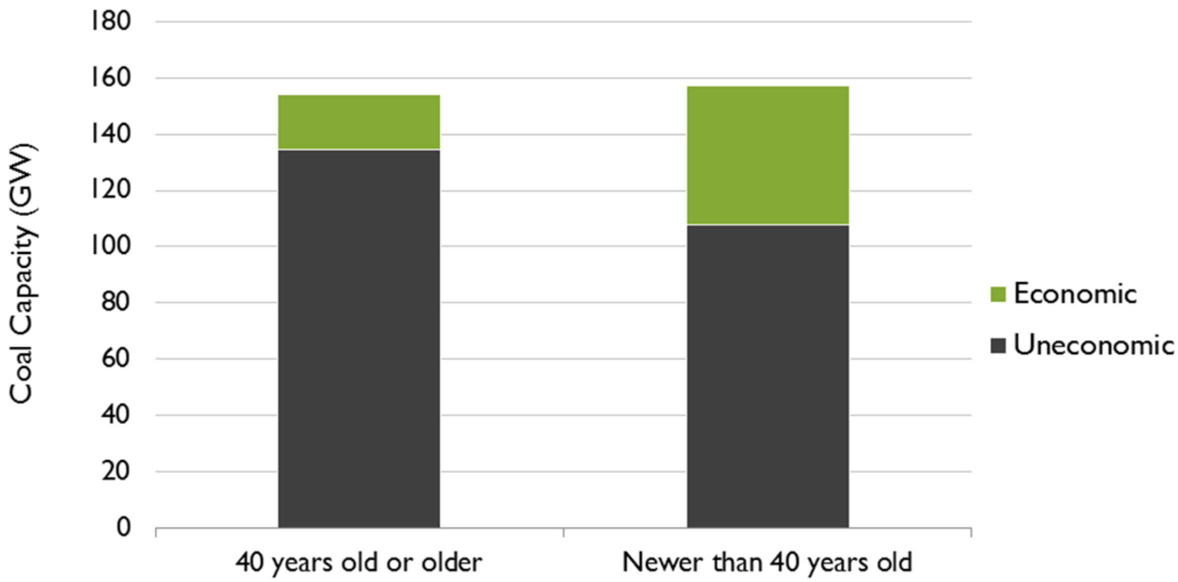
Table 1. Coal units, coal capacity, and coal generation uneconomic compared to market replacements under a mid-case environmental retrofit scenario

	Uneconomic Coal Compared to All-in Market Price Replacement		Uneconomic Coal Compared to Energy-only Market Price Replacement	
Number of Units	771	87%	852	96%
Capacity (GW)	242	77%	296	94%
Generation (TWh)	1,096	74%	1,371	92%

[11] The number of units described as uneconomic in the text of this report is based on comparisons to regionally specific market prices, and therefore may not correspond exactly to unit placement above or below the curves representing illustrative national market prices in Figures 1 and 2.

Figure 4 indicates how uneconomic coal capacity is distributed across different age cohorts. As stated earlier in this report, in 2015, approximately half of all the nationwide coal capacity is 40 years old or older. Of this old coal capacity, 87 percent is uneconomic. However, uneconomic coal plants are not restricted to being just the oldest in the fleet; of the coal capacity that is newer than 40 years old, 32 percent is uneconomic.

Figure 4. Uneconomic coal by age cohort



If all 771 coal units that are projected to be more expensive than the cost of purchasing all-in energy were to retire, Synapse estimates that the savings between installing and operating environmental controls on uneconomic coal plants and purchasing all-in market energy would result in present value savings of about $262 billion between 2015 and 2044. Of course, as numerous coal units retire, there will likely be changes in the markets for coal and natural gas that will influence the comparative economics of the remaining units. The analysis presented in this paper should be interpreted as a snapshot based on current market conditions and expectations.

2.2. Testing the effects of key assumptions

The forecasted economics of operating coal units compared to purchasing wholesale market power depend on underlying CAVT modeling assumptions regarding the costs of market replacements and environmental controls. To investigate the impact of differing assumptions on the results of the analysis, Synapse tested the model's sensitivity to a range of natural gas prices and environmental retrofit scenarios (see Appendix A for detailed descriptions of these assumptions.) While natural gas prices used in the energy-only and all-in market prices shown in Figure 1 and 2 are U.S. averages (and, therefore, only representative) in CAVT's unit-specific statistical analysis each plant's economics are compared to regional market prices based on Annual Energy Outlook's (AEO's) regional natural gas price projections.

Figure 5 displays the amount of capacity that is uneconomic compared to the cost of all-in market purchases for the reference case and a set of sensitivities. Using the mid natural gas price as well as the mid environmental retrofit scenario (the first column in Figure 5), 242 GW or 77 percent of the existing coal fleet is uneconomic compared to the cost of all-in market purchases. Moving from left to right across Figure 5, the figure shows that lower gas prices and more stringent environmental control requirements result in more coal capacity rendered uneconomic. Conversely, in sensitivities with high gas prices and less stringent environmental control requirements, less coal capacity is uneconomic. In an extreme sensitivity, with both strict environmental control requirements and low natural gas prices, 100 percent of coal capacity is rendered uneconomic. At the other end of the spectrum, with both lenient environmental control requirements and high natural gas prices, just 15 percent of existing coal capacity is uneconomic compared to all-in market purchases.

Figure 5. Coal capacity uneconomic compared to the cost of all-in market purchases in the reference case scenario, along with various sensitivities

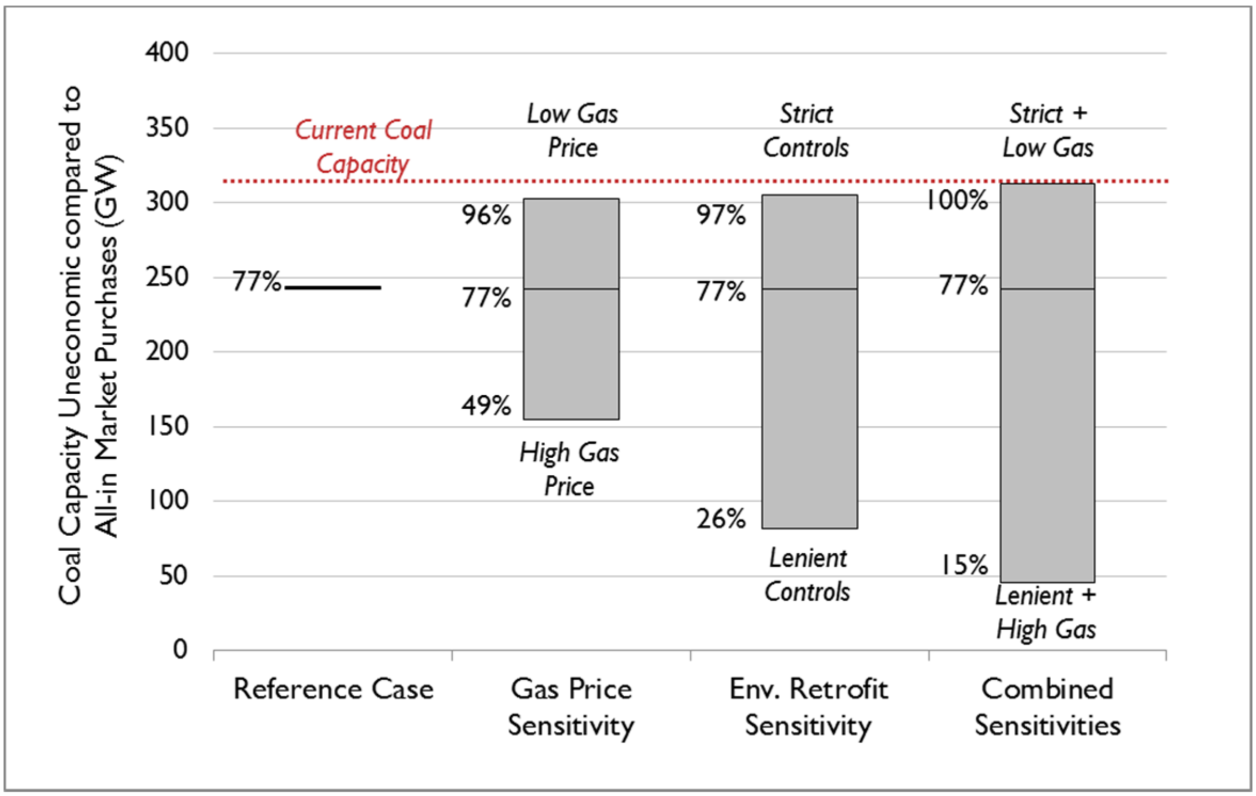
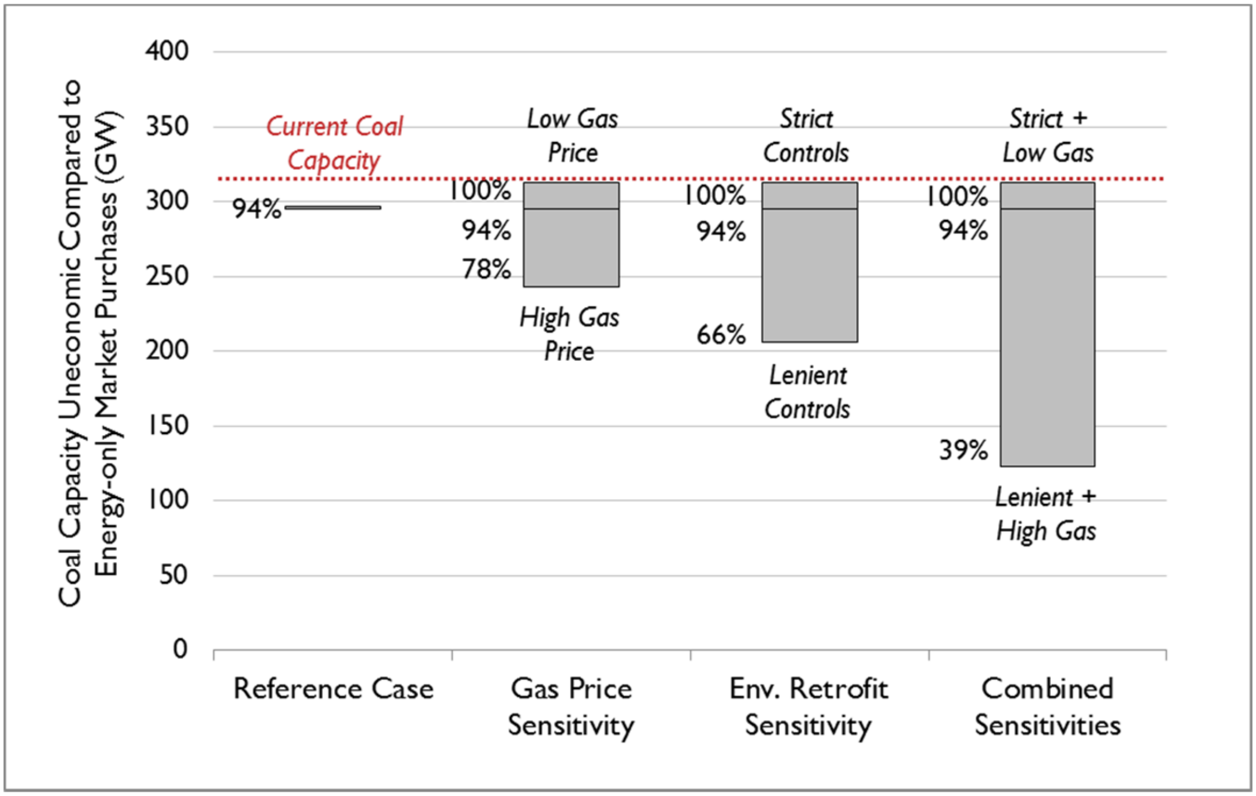


Figure 6 mirrors the results for Figure 5, except that the costs of retrofitting coal units are compared to the costs of energy-only market purchases. Here, 94 percent of existing coal capacity is projected to be uneconomic compared to energy-only market costs.

Figure 6. Coal capacity uneconomic compared to the cost of energy-only market purchases in the reference case scenario, along with various sensitivities



3. Recent Applications of CAVT

Synapse regularly uses CAVT to assist in analysis of coal plant economics. Typically, Synapse applies the data in CAVT to analyze utilities' control cost assumptions. Over the past year Synapse has leveraged the tool to perform increasingly complex analysis.

3.1. Retrofit costs: Determination of likely coal units to be retired in Florida

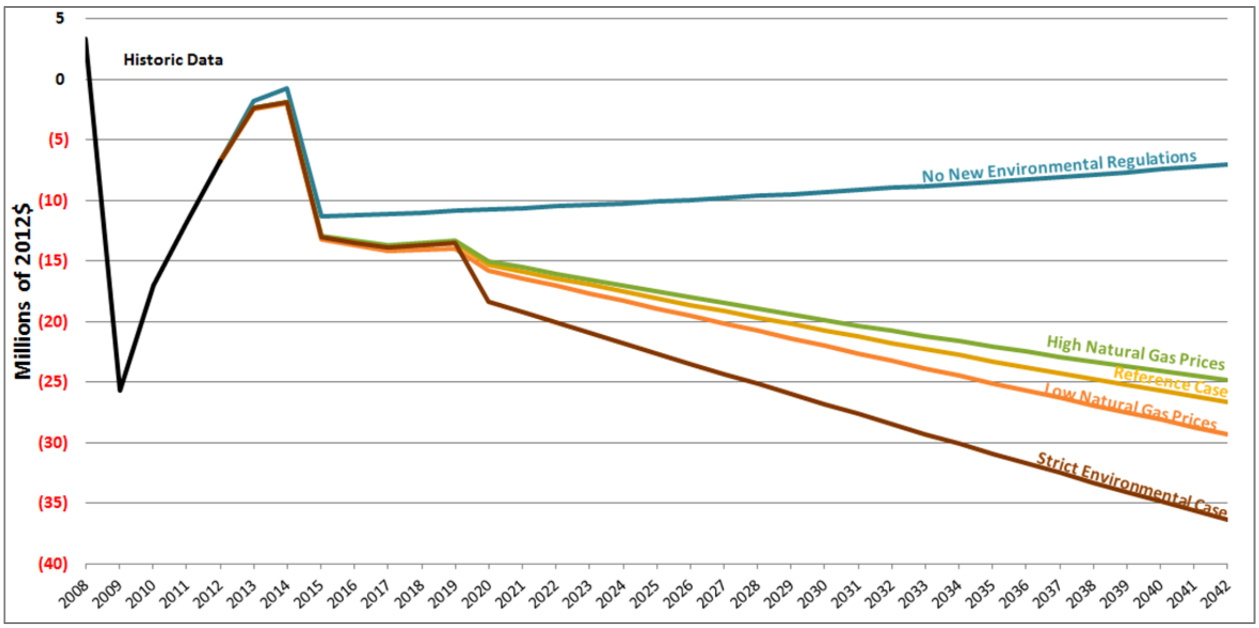
On behalf of the Sierra Club, Synapse used CAVT to estimate the cost of retrofitting the Lansing Smith and Crystal River coal units to sufficiently control for various pollutants. In the Florida Public Service Commission's final 10-year site plan review, the commission repeatedly referred to CAVT results to point out that the Lansing Smith and Crystal River plants may well be uneconomic and hence may be retirement targets.[12]

[12] Florida Public Service Commission (December 2012) *Review of the 2012 Ten-year Site Plans for Florida's Electric Utilities.* Available at http://www.psc.state.fl.us/publications/pdf/electricgas/TYSP2012.pdf.

3.2. Economic forecasting analysis: Updated financial analysis of the Schiller units

In February of 2014, the Conservation Law Foundation commissioned Synapse to update a previous economic analysis of two coal units owned by Public Service of New Hampshire, Schiller 4 and Schiller 6.[13] Three years prior, Synapse had conducted a similar study, which correctly projected that Schiller 4 & 6 would continue to lose money each year. As shown in Figure 7, the updated CAVT analysis was able to include a much wider range of possible scenarios. The analysis showed that, even in a scenario where no new environmental regulations were promulgated, Schiller 4 & 6 appear likely to continue posting losses each year out to 2042.

Figure 7. Annual Net Revenue (Losses) for Schiller 4 & 6 Combined



3.3. Capacity market revenues: Brayton Point capacity payment requirement analysis for the New Hampshire OCA, the Maine OPA, and the Connecticut OCC

In April of 2014, Synapse analyzed the expected financial position of the three coal units at the Brayton Point station.[14] The goal was to determine an expected price at which the power plant would be willing to participate in the Eighth Forward Capacity Auction, which had occurred six weeks earlier, and from which the station chose to retire. Figure 8 displays the capacity payments required by each unit, as

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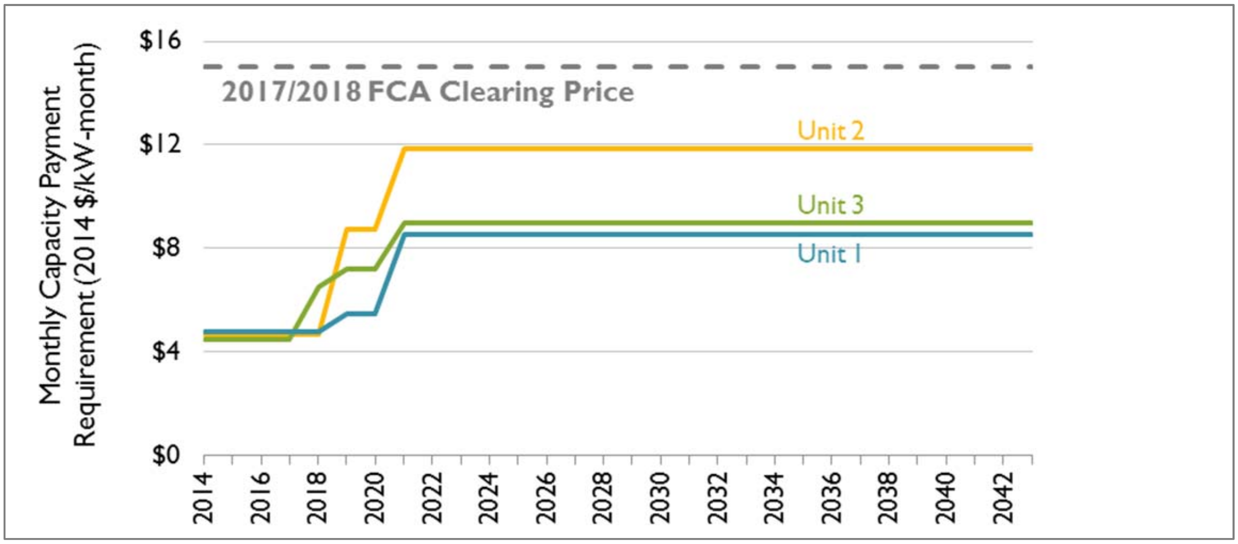
[13] Hurley, Doug, et al. (February 2014) *Update of Schiller Units 4 & 6 Economic Analysis*. Available at http://www.synapse-energy.com/sites/default/files/SynapseReport.2014-02.CLF_.Schiller-Economics.14-023.pdf.

[14] Hurley, Doug, et al. (April 2014) *Brayton Point Capacity Payment Requirement Analysis*. Available at http://www.synapse-energy.com/sites/default/files/SynapseReport.2014-04.0.Brayton-Analysis.14-049.pdf.

calculated in CAVT. As monthly capacity payments are the payment price at which a unit "breaks even," these prices can serve as proxies for the price at which the unit will exit the capacity market.

Figure 8. Future estimated monthly capacity payment requirement for the Brayton Point units

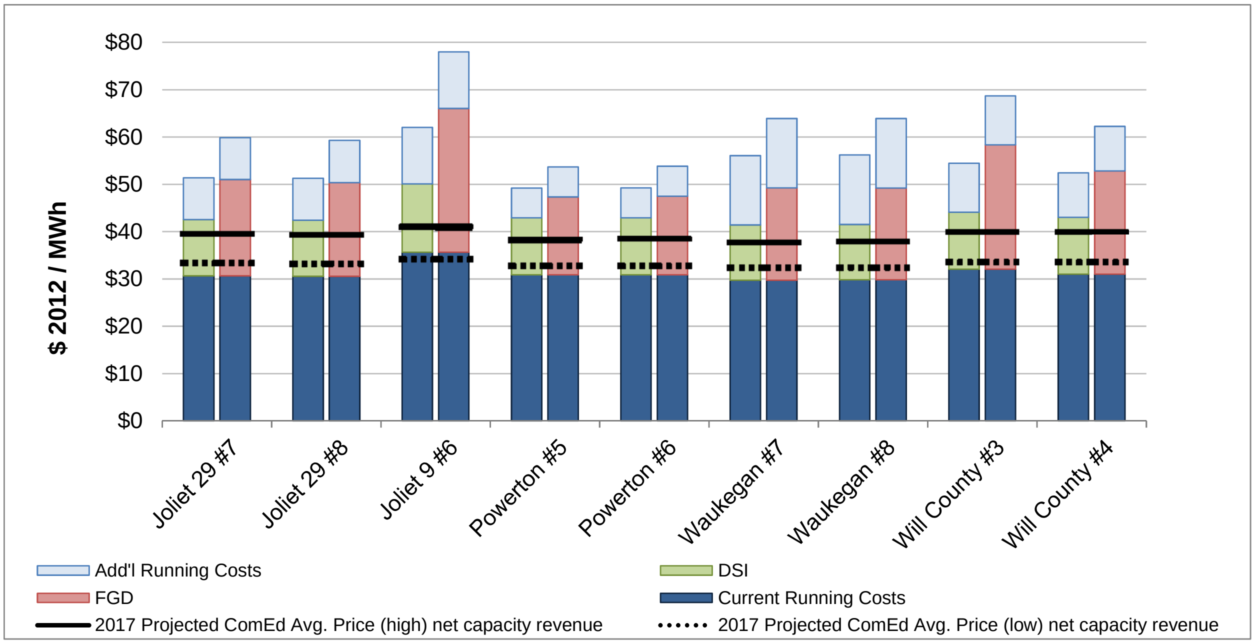


3.4. Fleet analysis: Comparing forward going costs of Ameren's coal fleet versus the PJM market

Synapse assisted the Sierra Club in evaluating the future economic viability of a group of Edison Mission Energy coal plants that was subsequently purchased by NRG.[15] This analysis included estimates of forward-going costs, capacity revenue, and system reliability. Synapse used CAVT to compare the forward-going costs of the Edison Mission Energy fleet against projected PJM market revenues. As shown in Figure 9, analysis showed that for every one of the coal plants, the forward-going costs exceeded the expected future revenues.

[15] Sierra Club (April 2013) *Midwest Generation's Illinois Coal Plants: Too Expensive to Compete?* Available at http://synapse-energy.com/sites/default/files/SynapseReport.2013-04.SC_.Midwest-Gen-Report-Update.13-039.pdf.

Figure 9. Economic viability of Illinois coal plants proposed to be purchased by Dynegy



APPENDIX A: METHODOLOGY, DATA SOURCES, AND ASSUMPTIONS

A.1 CAVT methodology

Synapse's Coal Asset Valuation Tool (CAVT) is a spreadsheet-based database and model that aggregates publicly available data (such as capacity, generated power, and heat rate) on non-cogenerating coal units and combines this with publicly available cost methodologies to calculate the cost of complying with environmental regulations. Compliance technologies include Wet FGD, Dry FGD, DSI, SCR, SNCR, ACI, baghouse, recirculating cooling, coal combustion residual controls, effluent controls, and carbon prices.

Capital, operating, and maintenance costs of each new environmental control are added to each unit's expected operating costs without additional environmental controls (including unit-specific fixed and variable operating and maintenance costs, coal fuel costs, and fixed and variable operating and maintenance costs associated with existing environmental controls) beginning in the year the control is assumed to come into effect. These dollar-per-MWh costs are then multiplied by the unit's assumed generation in each year to determine total dollars spent on plant operations and capital in each year from 2015 through 2044. The net present value of each unit's lifetime cost is then calculated using a 4.71 percent real discount rate. A similar calculation is performed for both the energy-only market price and the all-in market price (using the cost of operating an existing natural gas-fired combined cycle unit and the cost of constructing and operating a new natural gas-fired combined cycle unit, respectively). The "future" coal unit cost is then compared with the two market prices to determine each unit's individual economic viability.

A.2 Data sources

Source data for coal unit characteristics include the U.S. Energy Information Agency (EIA's) Form 860[16] and Form 923,[17] and the U.S. Environmental Protection Agency's (EPA's) Air Markets Dataset.[18]

Market price data are developed using the EIA's Annual Energy Outlook 2014 Electricity Market Module Assumptions.[19] See the "Natural Gas Forecast" section, below, for more information.

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16 U.S. Energy Information Agency (2014) *Form EIA-860 detailed data*. Retrieved from http://www.eia.gov/electricity/data/eia860/index.html.

17 U.S. Energy Information Agency (2014) *Form EIA-923 detailed data*. Retrieved from http://www.eia.gov/electricity/data/eia923/.

18 U.S. Environmental Protection Agency (2014) *Air Markets Program Data.* Retrieved from http://ampd.epa.gov/ampd/.

19 U.S. Energy Information Agency (2014) *AEO 2014* Electricity Market Module. Retrieved from http://www.eia.gov/forecasts/aeo/assumptions/pdf/electricity.pdf.

Cost methodologies for environmental controls are based on Sargent & Lundy costs developed as inputs for EPA's assumptions in their version of ICF's Integrated Planning Model (IPM) v.4.10, technical documentation for the proposed 316(b) rule, and analysis of cost compliance with the Resource Conservation and Recovery Act, among other sources. See Table A1, below, for more detailed citations.

A.3 Assumptions

Table A1 presents the underlying assumptions used in this report regarding natural gas prices and environmental control requirements. Section 2.1 is based on the mid natural gas price and mid environmental retrofit assumptions. Section 2.2 presents results based on combinations of the high and low natural gas prices, and lenient and strict retrofit assumptions.

Table A1. Environmental retrofit and natural gas assumptions

Natural Gas Price	**High**	Natural gas prices grow at the AEO 2014 High Economic Growth Case rate of change
	Mid	Natural gas prices grow at the AEO 2014 Reference Case rate of change
	Low	Natural gas prices grow at the AEO 2014 Low Economic Growth Case rate of change
Environmental Control Requirements	**Strict**	Dry FGD, SCR, Baghouse, ACI, Impingement Controls and Recirculating Cooling on all units, Coal Combustion Residual (Subtitle D), Effluent Regulatory Option "4a," "Synapse High" CO_2 Price
	Mid	Dry FGD, SCR, Baghouse, ACI, Impingement Controls and Recirculating Cooling on units with intakes > 125 MGD, Coal Combustion Residual (Subtitle D), Effluent Regulatory Option "3," "Synapse Mid" CO_2 Price
	Lenient	DSI, SNCR, Baghouse, ACI, Impingement Controls, Effluent Regulatory Option "3a," "Synapse Low" CO_2 Price

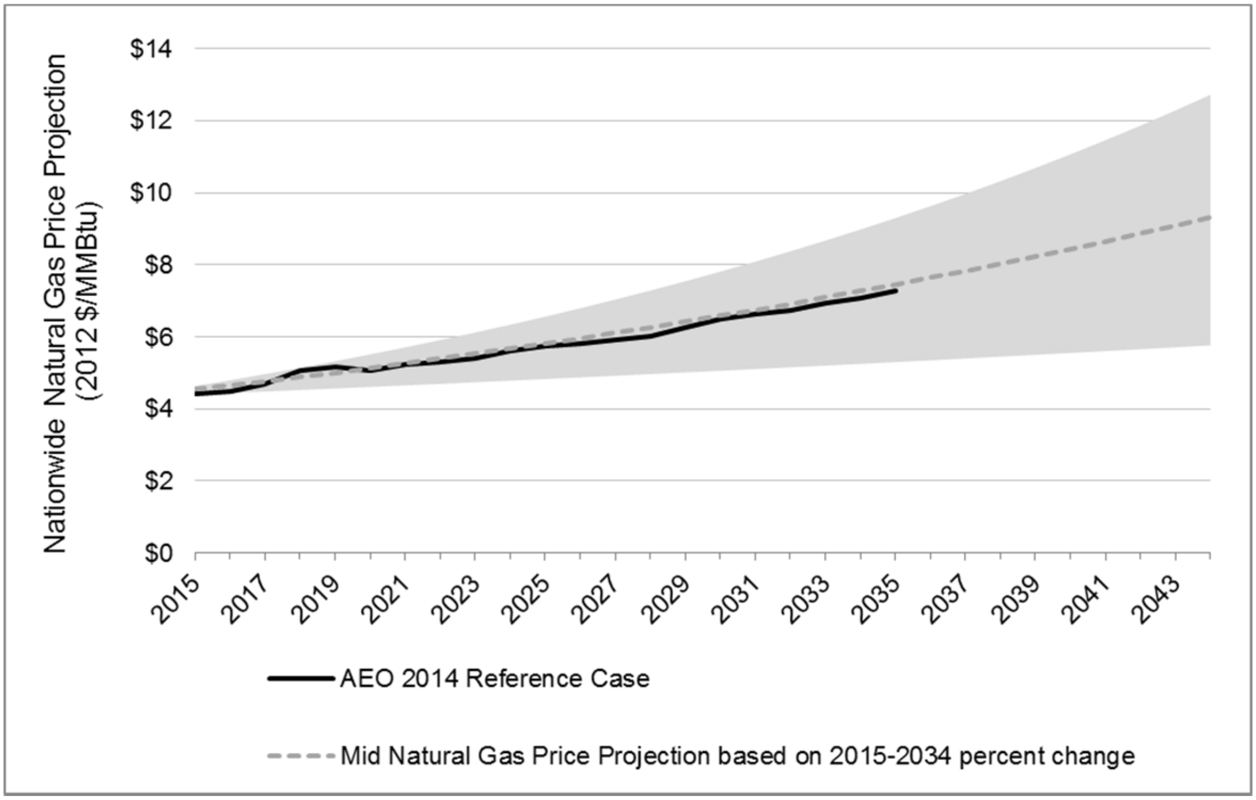
Natural gas forecast

CAVT uses regional natural gas price data from the EIA's 2014 Annual Energy Outlook to inform projections of future natural gas price changes.[20] The mid natural gas prices are the EIA's 2014 reference case price escalated over time using the EIA's 2015-2034 percent change in its reference case natural gas prices. Figure A1 shows the EIA reference case forecast and the mid natural gas price used in this report, as well as the natural gas price sensitivities (shown as a gray wedge). The high and low natural gas price sensitivities are estimated using the same starting price and the rates of change used in EIA's 2012-2035 Low and High Oil and Gas Resource Cases, respectively.[21]

[20] EIA (2014) *2014 Annual Energy Outlook*, supplemental tables 11-20. Retrieved from http://www.eia.gov/forecasts/aeo/data.cfm

[21] Ibid.

Figure A1. Natural gas price projections



Note: The low and high natural gas price projections used in the sensitivity analyses are shown as the lower and upper edges of the shaded area. AEO 2014 only estimates prices out to 2040; the CAVT levelization is a 20-year period through 2034.

Environmental control requirement scenarios

CAVT models the costs and year of implementation of a number of common environmental controls (see Table A2). For the purposes of this analysis, Synapse assumes that each environmental control will be implemented in the years indicated in Table A2 at every coal unit that does not currently have it. Many units may become controlled before these dates, while other plants may obtain extensions that allow them to continue operating without controls after these dates. Control requirement assumptions are representative. Each coal unit is a unique case—some units may not require the level of retrofit CAVT assumes, while other units may require more extensive retrofits. The choice of environmental control requirements and dates of implementation are internal assumptions by Synapse staff; the data sources for the environmental control cost assumptions used in CAVT are shown in Table A2.

Table A2. Environmental control requirement assumptions

Environmental Control	Control Requirement Year			Source of Environmental Control Cost Data
	Lenient	*Mid*	*Strict*	
Wet Flue Gas Desulphurization (Wet FGD)	n/a	n/a	n/a	Sargent & Lundy (2013) *IPM Model – Updates to Cost and Performance for APC Technologies: Wet FGD Cost Development Methodology*. Retrieved from http://www.epa.gov/airmarkets/documents/ipm/attachment5_1.pdf
Dry Flue Gas Desulphurization (Dry FGD)	n/a	2020	2018	Sargent & Lundy (2013) *IPM Model – Updates to Cost and Performance for APC Technologies: SDA FGD Cost Development Methodology*. Retrieved from http://www.epa.gov/airmarkets/documents/ipm/attachment5_2.pdf
Dry Sorbent Injection (DSI)	2020	n/a	n/a	Sargent & Lundy (2013) *IPM Model – Updates to Cost and Performance for APC Technologies: DSI Cost Development Methodology*. Retrieved from http://www.epa.gov/airmarkets/documents/ipm/attachment5_5.pdf
Selective Catalytic Reduction (SCR)	n/a	2021	2019	Sargent & Lundy (2013) *IPM Model – Updates to Cost and Performance for APC Technologies: SCR Cost Development Methodology*. Retrieved from http://www.epa.gov/airmarkets/documents/ipm/attachment5_3.pdf
Selective Non-Catalytic Reduction (SNCR)	2021	n/a	n/a	Sargent & Lundy (2013) *IPM Model – Updates to Cost and Performance for APC Technologies: SNCR Cost Development Methodology*. Retrieved from http://www.epa.gov/airmarkets/documents/ipm/attachment5_4.pdf
Activated Carbon Injection (ACI)	2016	2016	2015	Sargent & Lundy (2013) *IPM Model – Updates to Cost and Performance for APC Technologies: Hg Cost Development Methodology*. Retrieved from http://www.epa.gov/airmarkets/documents/ipm/attachment5_6.pdf
Baghouse	n/a	2025	2018	Sargent & Lundy (2013) *IPM Model – Updates to Cost and Performance for APC Technologies: PM Cost Development Methodology*. Retrieved from http://www.epa.gov/airmarkets/documents/ipm/attachment5_7.pdf
Cooling	2021 (Impingement Controls)	2019 (Impingement Controls, Recirc. cooling for units with >125 MGD intake)	2017 (Impingement Controls, Recirc. cooling for all units)	EPA (March 2011) *Technical Development Document for the Proposed Section 316(b) Phase II Existing Facilities Rule*. Retrieved from: http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100B63C.txt

Table A2 (continued). Environmental control requirement assumptions

Environmental Control	Control Requirement Year *Lenient*	 *Mid*	 *Strict*	Source of Environmental Control Cost Data
Coal Combustion Residuals (CCR)	2021 (Subtitle D)	2019 (Subtitle D)	2017 (Subtitle D)	EPA (April 2013) *Regulatory Impact Analysis for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*. Tables 9-4, 9-3, 9-5, 9-7. Retrieved from: http://water.epa.gov/scitech/wastetech/guide/steam-electric/upload/Steam-Electric_RIA_Proposed-rule_2013.pdf; EPA (April 2013) *Technical Development Document for the Proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category*. Tables 9-9. Retrieved from: http://water.epa.gov/scitech/wastetech/guide/steam-electric/upload/Steam-Electric_TDD_Proposed-rule_2013.pdf
Effluent	2021 (EPA regulatory option 3a)	2019 (EPA regulatory option 3)	2017 (EPA regulatory option 4a)	EPRI. (2010) *Engineering and Cost Assessment of Listed Special Waste Designation of Coal Combustion Residuals Under Subtitle C of the Resource Conservation and Recovery Act, Chapter 4.*
Carbon Price (RGGI)	RGGI prices used through 2019 for coal units in RGGI states			Regional Greenhouse Gas Initiative (2013) *Regional Greenhouse Gas Initiative Summary of Model Rule Changes*. Retrieved from http://www.rggi.org/docs/ProgramReview/_FinalProgramReviewMaterials/Model_Rule_Summary.pdf
Carbon Price (Synapse)	Synapse "Low" Carbon price beginning in 2020	Synapse "Mid" Carbon price beginning in 2020	Synapse "Mid" Carbon price beginning in 2020	Synapse Energy Economics (2015) *2015 Carbon Dioxide Price Forecast*. Retrieved from http://www.synapse-energy.com/sites/default/files/2015%20Carbon%20Dioxide%20Price%20Report.pdf