PROPOSED UPDATES TO EMM METHODOLOGY

The EMM captures changes in age-related spending patterns through multiple cost categories: CAPEX, O&M, fuel, energy sales, and capacity sales. The updates below relate only to the CAPEX and O&M. The focus of the work scope was to more accurately represent power plant aging impacts on CAPEX and O&M. Detailed derivations of fixed and variable O&M costs for the EMM were not part of the work scope.

Sargent & Lundy's recommended updates to the fixed and variable O&M costs and CAPEX in the EMM for each generating technology are summarized in the tables below. Values are in constant 2017 price levels and are incurred in every year of plant operation, starting from commercial operation through plant retirement. In all cases, the yearly values would increase annually with the inflation rate.

Coal Steam

Sargent & Lundy's analysis of the coal steam dataset (Appendix A) identified two significant variables affecting annual changes in real CAPEX spending (on a constant $/kW-year basis): age and FGD. Variables not having a significant effect on annual changes in real CAPEX spending (on a constant $/kW-year basis) were: plant capacity (kW), fuel type, and regulatory environment. When CAPEX spending was expressed on a constant $/MWh basis, it was significantly related to age, primarily as a result of declining MWh generation with age.

Table ES-3 compares the new CAPEX values derived from the coal steam dataset with the CAPEX values currently used in the EMM. The new CAPEX values are similar in magnitude with the current EMM values over the long term, except that the new values follow a continuous pattern rather than a step pattern. As discussed below, the new values include life extension projects that occur throughout the plant life, including the first 30 years of operation.

Table ES-3 — Coal Steam CAPEX Results – All MW, All Capacity Factors

Net Total CAPEX (2017 $/kW-year)	$/kW-yr (Years 1-10)	$/kW-yr (Years 10-20)	$/kW-yr (Years 20-30)	$/kW-yr (Years 30-40)	$/kW-yr (Years 40-50)	$/kW-yr (Years 50-60)	$/kW-yr (Years 60-70)	$/kW-yr (Years 70-80)
New Value – No FGD*	17.16	18.42	19.68	20.94	22.20	23.46	24.72	25.98
New Value – with FGD*	22.84	24.10	25.36	26.62	27.88	29.14	30.40	31.66
Existing EMM Value	17.55	17.55	17.55	24.62	24.62	24.62	24.62	24.62

*Calculated to the midpoint of the given age band.

"Life extension costs" in the existing CAPEX values are covered by the step increase after year 30. Life extension costs in the new CAPEX values are distributed throughout the plant life. This is a result of discretionary spending, which is a common practice for most coal steam plants. Different plants might incur the same type of expense at different points in time due to differences in plant-specific economic, locational, or operational circumstances.

Typical industry-standard frequencies for repairs and replacement of major equipment within a coal plant are not absolute, but rather indicative of when a coal plant may be required to perform the work, based on manufacturer experience. An owner may choose to perform the work early, if they have an available outage, or defer if, after inspection, the equipment appears to be capable of continued operation without repair.

The new values also account for CAPEX relating to FGD. An FGD system tends to be capital-intensive to own and operate. The corrosive environment of chemicals and reagents significantly reduces the life of equipment such as pumps, mills, nozzles, valves, etc. These components must be replaced more frequently than at plants without FGD.

O&M costs for the coal steam plants include a significant variable component. By definition, variable O&M costs are proportional to plant generation and are typically expressed in $/MWh. As previously mentioned, the variable O&M component cannot be clearly delineated from the total reported O&M in the FERC Form 1 data. For this assessment, the variable component was combined with the fixed component and expressed in $/kW-year. The combined total O&M in the coal steam plant dataset for this analysis was found to be nearly equivalent to the existing combined total O&M representation in the EMM, which already includes the necessary $/MWh variable O&M breakout (see Table ES-4).

Table ES-4 — Coal Steam O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)*	Variable O&M (2017 $/kW-yr)**	Total O&M (2017 $/kW-yr)**
Coal Steam Dataset Results – All Plants	36.81	1.78	9.20	46.01
< 500 MW	44.21	1.78	9.20	53.41
500 MW – 1,000 MW	34.02	1.78	9.20	43.22
1,000 MW – 2,000 MW	28.52	1.78	9.20	37.72
> 2,000 MW	33.27	1.78	9.20	42.47
Existing EMM Value***	40.63	1.78	9.20	49.83

*Fixed and variable split is estimated using the existing EMM variable O&M cost of $1.78/MWh.
**Calculated at the coal steam dataset average capacity factor of 59%.
***Source: Internal communication with EIA, February 2018.

Gas/Oil Steam

The analysis of the gas/oil steam dataset (Appendix B) identified only one significant variable affecting annual changes in real CAPEX spending (on a constant $/kW-year basis): plant capacity (kW). That is, CAPEX was lower on a $/kW-year basis for larger plant sizes due to economies of scale. When CAPEX spending was expressed on a constant $/MWh basis, it was significantly related to age, primarily as a result of declining MWh generation with age.

Table ES-5 compares the new CAPEX values derived from the gas/oil steam dataset with the CAPEX values currently used in the EMM. The new CAPEX values are similar in magnitude with the current EMM values over the long term, except that the new values follow a continuous pattern rather than a step pattern. As discussed below, the new values include life extension projects that occur throughout the plant life, including the first 30 years of operation.

Table ES-5 — Gas/Oil Steam CAPEX Results

Plant Size	Net Total CAPEX (2017 $/kW-year)	
	Years 1-30	Years 30-80
Gas/Oil Steam Dataset Results – All Plants	15.96	15.96
New Value: < 500 MW	18.86	18.86
New Value: 500 MW – 1,000 MW	11.57	11.57
New Value: > 1,000 MW	10.82	10.82
Existing EMM Value	9.14	16.21

"Life extension costs" in the existing CAPEX values are covered by the step increase after year 30. Life extension costs in the new CAPEX values are distributed throughout the plant life. This is a result of discretionary spending, which is a common practice for most gas/oil steam plants. Different plants might incur the same type of expense at different points in time due to differences in plant-specific economic, locational, or operational circumstances.

Typical industry-standard frequencies for repairs and replacement of major equipment within a gas/oil steam plant are not absolute, but rather indicative of when a gas/oil steam plant may be required to perform the work, based on manufacturer experience. An owner may choose to perform the work early, if they have an available outage, or defer if, after inspection, the equipment appears to be capable of continued operation without repair.

Typical industry-standard frequencies for repairs and replacement of major equipment are similar to those of coal units, as presented in the previous section.

The use of a constant annual value on the modeling of annual CAPEX would be similar to representing a major maintenance reserve account (MMRA), which is commonly used for non-recourse financing of power projects. MMRAs are usually required by power project lenders over the tenor of debt as protection against maintenance spending uncertainty. An MMRA is typically funded by annual contributions drawn from a project's cash flow, sometimes as a uniform annual amount. Annual contribution levels are based on estimated long-term maintenance expenditure patterns. Over the long term, annual contributions represent a smoothed version of irregular actual annual values.

The use of a long-term average value also recognizes the inherent variability in long-term spending patterns for any given plant. Since the EMM is a large-scale model, it is conceptually designed to represent plant types as averages rather than as individual plants. When summed across a large number of plants in a utility system, some of the variability in annual expenditure patterns would tend to even out. The level of accuracy between average values and year-specific values for a given plant type is nearly equivalent in large-scale models.

O&M costs for the gas/oil steam plants include a significant variable component, although typically smaller than coal units. The combined total O&M in the gas/oil steam plant dataset for this analysis was found to be somewhat lower than the existing combined total O&M representation in the EMM, which already includes the necessary $/MWh variable O&M breakout (see Table ES-6). However, the variable O&M of $8.23/MWh in the EMM is much higher than values Sargent & Lundy has observed in actual gas/oil steam plants and should not be higher than the variable O&M of $1.78/MWh in the EMM used for the coal units.

Table ES-6 — Gas/Oil Steam O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)*	Variable O&M (2017 $/kW-yr)**	Total O&M (2017 $/kW-yr)**
Gas/Oil Steam Dataset Results – All Plants	24.68	1.00	1.84	26.52
< 500 MW	29.73	1.00	1.84	31.57
500 MW – 1,000 MW	17.98	1.00	1.84	19.82
> 1,000 MW	14.51	1.00	1.84	16.35
Existing EMM Value***	19.68	8.23	15.14	34.82

*Fixed and variable split is estimated using an approximate value for variable O&M of $1.00/MWh based on confidential projects.
**Calculated at the gas/oil steam dataset average capacity factor of 21%.
***Source: Internal communication with EIA, February 2018.

Gas/Oil Combined Cycle and Gas/Oil Combustion Turbine

As with coal steam and gas/oil steam plants, CAPEX spending for gas/oil CC and gas/oil CT plants represents a series of capital projects throughout the plant life, which include projects for "life extension." Most CAPEX spending for gas/oil CC and gas/oil CT plants is for vendor-specified major maintenance events. Other CAPEX spending, other than for emission control retrofits, is relatively minor.

Vendor-specified major maintenance spending is based on cumulative hours of operation and/or cumulative starts. Implicitly, CAPEX spending for CC and CT plants is age-related and vendor-specified, and may be expressed as an equivalent $/MWh value, which covers:

- Major maintenance costs for periodic combustion inspections, hot gas path inspections, and major overhauls account for nearly all of the CAPEX expenditures. Many plant owners choose to capitalize major maintenance expenditures. As these expenditures normally follow the equipment vendor's recommendations, they maintain plant performance and extend the plant life.
- Major one-time costs include rotor replacement, typically at about 150,000 equivalent operating hours, 7,000 equivalent starts, or within the first 30 years of plant operation. These costs are captured within the dataset. As gas turbines age, major maintenance parts often become available from third-party suppliers at a discounted price.

As with MMRAs described in the previous subsection, major maintenance contracts are priced according to smoothed versions of irregular long-term expenditure patterns. Apart from adjustments for operating conditions, major maintenance (and nearly all of the CAPEX) is effectively priced as an equal annual value, expressed in constant $/MWh with annual escalation.

Table ES-7 compares the new CAPEX and O&M values derived from the gas/oil CC and CT datasets with the values currently used in the EMM. As indicated above, the combined CAPEX and O&M values in the datasets would be expected to correspond to the combined CAPEX and O&M in the EMM, with most of the CAPEX in the EMM represented as variable O&M. However, some of the EMM values are higher than values Sargent & Lundy has observed in actual CC and CT plants, as detailed below:

- The EMM fixed and variable O&M costs for CC plants are reasonable for smaller CC installations (< 500 MW) but high for larger plants.
- The EMM CAPEX addition of $7/kW-year after 30 years of operation should not be represented as a fixed cost. As previously mentioned, age-related costs would be built into the $/MWh variable O&M and would be a function of cumulative operating hours rather than operating years.

- The EMM fixed and variable O&M costs for CT plants are high for all plant sizes. Since most CT plants operate as peaking plants with low capacity factors, the variable O&M component is likely to be based on equivalent starts rather than equivalent operating hours.

Table ES-7 — Gas/Oil CC and CT CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)*	Variable O&M (2017 $/kW-yr)*	Total O&M (2017 $/kW-yr)*	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)**
CC Dataset Results (All Plants)	13.08	3.91	(included in CAPEX)	13.08	15.76	28.84
< 500 MW	15.62	4.31	(included in CAPEX)	15.62	17.38	33.00
500 MW – 1,000 MW	9.27	3.42	(included in CAPEX)	9.27	13.78	23.05
> 1,000 MW	11.68	3.37	(included in CAPEX)	11.68	13.57	25.25
Existing EMM Value**	27.52	2.64	10.64	38.16	0.18; 7.25 (after year 30)	38.34; 45.41 (after year 30)
CT Dataset Results (All Plants)	5.33	(starts based)	(included in CAPEX)	5.33	6.90	12.23
< 100 MW	5.96	(starts based)	(included in CAPEX)	5.96	9.00	14.96
100 MW – 300 MW	6.43	(starts based)	(included in CAPEX)	6.43	6.18	12.61
> 300 MW	3.99	(starts based)	(included in CAPEX)	3.99	6.95	10.94
Existing EMM Value***	12.60	14.63	5.13	17.73	1.52	19.25

*Fixed and variable split is estimated, assuming all CAPEX costs are represented as variable O&M, either hours-based ($/MWh) or starts-based ($/start).
**Calculated at the dataset average capacity factor of 46% for CC and 4% for CT.
***Source: Internal communication with EIA, February 2018.

Conventional Hydroelectric

Overall, the conventional hydroelectric dataset does not support any age-related CAPEX spending trend across the full data and on any of the subsets by plant size. The average CAPEX value over all operating years is $22.56/kW-year. The dataset does support age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages). Therefore, O&M spending for this dataset may be estimated by the regression equation:

Annual O&M spending in 2017 $/kW-year = 22.360 + (0.073 × age)

The CAPEX and O&M values derived from the conventional hydroelectric dataset are significantly higher than the existing values used in the EMM (Table ES-8) and outside the range of values published in the AEO[4] and by the International Renewable Energy Agency (IRENA).[5] The reasons for this discrepancy are not known without having the data sample used for the EMM values. It appears that the EMM does not currently account for CAPEX or life extension expenditures for conventional hydroelectric.

Table ES-8 — Hydroelectric CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)
Conventional Hydroelectric Dataset Results – All Plants	22.00	-	22.56	44.56
Existing EMM Value*	14.58	0.00	0.00	14.58

*Source: Internal communication with EIA, February 2018.

Pumped Storage

Overall, the pumped storage dataset does not support any age-related CAPEX or O&M spending trend across the full data and on any of the subsets by plant size. The average value over all operating years is $14.83/kW-year for CAPEX and $23.63/kW-year for O&M (Table ES-9). The existing values used in the EMM are not available.

Table ES-9 — Pumped Storage CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)
Pumped Storage Dataset Results – All Plants	23.63	-	14.83	38.46
Existing EMM Value	N/A	N/A	N/A	N/A

Solar Photovoltaic

The solar PV dataset does not support any age-related CAPEX spending trend across the full data and on any of the subsets by plant size. Sargent & Lundy notes that the average change in the "Total Cost of Plant" (TCP) reported in the FERC data for the limited usable dataset (15 sites not filtered out) is approximately $26/kW-year. However, due to the limited dataset, lack of clarity on what qualifies as a change to the TCP, and general lack of

[4] Energy Information Administration, *Annual Energy Outlook 2018*, Cost and Performance Characteristics (Table 8.2), February 2018.
[5] International Renewable Energy Agency, *Renewable Energy Technologies: Cost Analysis Series, Hydropower*, June 2012.

consistency in the FERC capital cost data provided, Sargent & Lundy advises that caution be taken when trying to establish any definitive solar PV capital cost trends from the FERC data.

The solar PV dataset appears to support age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages). However, based upon closer inspection of the data, a more appropriate predictor of O&M spending for this dataset would be a simple average across all years. This determination is based on the lack of data points for plants over 10 years old.

When considering the average O&M costs per plant as a single data point and then averaging those values, Sargent & Lundy calculated an average O&M cost of $75/kW-year from the FERC data for sites under 5 MW. Using the same method, an average O&M cost of $15/kW-year was calculated from the FERC data for sites over 5 MW.

By comparison, the EMM uses an average O&M value of $28.47/kW-year for all solar PV plants and an average CAPEX value of zero. Neither dataset captures the most recent trends in solar PV technology due to rapid changes in cost, size, and efficiency.

Solar Thermal

There are no solar thermal power plants that report operating data in FERC Form 1. Industry-wide, there are a limited number of solar thermal projects; a majority of which have been constructed within the last 10 years—the exception being small test facilities and the Solar Energy Generating Systems (SEGS) plants built in the 1980s.

Geothermal

Overall, the geothermal dataset does not support any age-related CAPEX spending trend across the full data and on any of the subsets by plant size. Instead, we recommend a simple average be used across the full age range. Sargent & Lundy recommends using the indicated $/kW-year average in Table ES-10 for O&M and CAPEX spending. As shown in the table, it appears the EMM does not currently account for CAPEX or life extension expenditures for geothermal plants.

Table ES-10 — Geothermal CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)
Geothermal Dataset Results – All Plants	157.10	-	40.94	198.04
Existing EMM Value**	91.66	0.00	0.00	91.66

**Source: Internal communication with EIA, February 2018.

Wind

The dataset supports age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages). Therefore, O&M spending for this dataset may be estimated by the regression equations shown in Table ES-11. Age was not a significant predictor of CAPEX spending, although CAPEX was found to vary significantly as a function of capacity (kW). That is, CAPEX was lower on a $/kW-year basis for larger plant sizes due to economies of scale.

The CAPEX and O&M values derived from the wind dataset are significantly higher than the existing values used in the EMM. The reasons for this discrepancy are not known without having the data sample used for the EMM values. Neither data sample is stratified by wind technology or turbine size. Neither dataset captures the most recent trends in wind turbine technology due to rapid changes in cost, size, and efficiency.

Table ES-11 — Wind CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	CAPEX (2017 $/kW-yr)
Wind Dataset Results – All Plants	31.66 + (1.22 × age)	0.00	18.29
< 100 MW	39.08 + (1.12 × age)	0.00	20.48
100 MW – 200 MW	23.80 + (1.17 × age)	0.00	16.93
> 200 MW	26.78 + (0.92 × age)	0.00	13.48
Existing EMM Value*	29.31	0.00	0.00

*Source: Internal communication with EIA, February 2018.

RECOMMENDED AREAS FOR FURTHER STUDY

Based on our analyses performed for the update to the EMM treatment of age-related spending, Sargent & Lundy identified several areas that warrant further study, including:

- Impact of regional labor cost differences versus the effects of a regulated/deregulated environment;
- Compatibility of EMM plant technology and size breakdowns and fixed/variable O&M cost breakdowns with proposed EMM updates;
- Identification of the factors supporting consistently high capacity factors over the plant lives at particular coal units; and
- Impact of aging on plant performance (heat rates, capacity derates, etc.). If capacity factors decline, regardless of the causes, this includes examining the impact of the lower capacity factors on plant costs and performance.

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1. INTRODUCTION

Sargent & Lundy LLC (Sargent & Lundy) was engaged by the Office of Energy Analysis (OEA) of the U.S. Energy Information Administration (EIA), an agency within the U.S. Department of Energy (DOE), to conduct a study to improve the ability of the Electricity Market Module (EMM) to represent the changing landscape of electricity generation and to more accurately represent costs, which will improve projections for generating capacity, generator dispatch, and electricity prices. The EMM is a submodule within the EIA's National Energy Modeling System (NEMS), a computer-based energy supply modeling system that is used for the EIA's *Annual Energy Outlook* (AEO) and other analyses.

In particular, the purpose of this study was to provide information that may enable the EIA to more accurately represent costs associated with operation of the existing fleet of U.S. generators as they age. This includes capital expenditures (CAPEX) related to ongoing operations as well as potential increases in operations and maintenance (O&M) costs attributable to declining performance due to aging.

The primary focus of our analysis was existing fossil fuel generators. The study also included existing wind, solar, hydro, and other renewable generators. The work scope did not include analysis of nuclear units.

The generating capacity types represented in the EMM that were included in our analysis comprised:

- Coal steam plants
- Gas/oil steam plants
- Gas/oil combined-cycle (CC) plants
- Gas/oil combustion turbines (CTs)
- Conventional hydropower
- Pumped storage – hydraulic turbine reversible
- Solar thermal – central tower
- Solar photovoltaic (PV) – single-axis tracking
- Geothermal
- Wind

This final report is the fourth milestone task of the EMM update project, which is organized as follows:

- Task 1 – Analysis of publicly available information for use in estimating capital costs related to ongoing operations for specified plant types.

- Task 2 – Analysis of publicly available information for use in estimating changes in O&M expenditures due to aging for specified plant types.
- Task 3 – Interim report on assembled aging-related capital and O&M costs.
- Task 4 – Final report on modeling aging-related capital and O&M costs.

2. ASSESSMENT METHODOLOGY

2.1 BACKGROUND

The EMM currently accounts for power plant aging through a one-time step increase in annual CAPEX. These added expenditures are intended to extend the life or preserve the performance of an existing generator, including repowering, major repairs or retrofits, and/or covering increases in maintenance required to mitigate the adverse effects of aging, including any decreases in plant performance. The portion of the annual CAPEX associated with the step increase is referred as "life extension costs."

As modeled in the EMM, a generating unit is assumed to retire if the expected revenues from the generator are not sufficient to cover the annual going-forward costs and if the overall cost of producing electricity can be lowered by building new replacement capacity. The going-forward costs include fuel, O&M costs, and annual CAPEX. The average annual CAPEX in the EMM is $0.18 per kilowatt-year (/kW-year) for existing CC plants, $9/kW-year for existing gas/oil steam plants, and $18/kW-year for existing coal plants (in constant 2017 dollars). These amounts are increased to $7.25/kW-year, $16/kW-year, and $25/kW-year, respectively, after a plant reaches 30 years of age.[6] The average annual CAPEX in the EMM for existing CT plants is $1.52/kW-year with no life extension costs. The other generating technologies in the EMM are not currently modeled with either CAPEX or life extension costs.

The existing CAPEX values in the EMM were derived from yearly changes in plant in service accounts reported on the Federal Energy Regulatory Commission (FERC) Form No. 1 ("FERC Form 1").[7] The O&M costs in the EMM are also derived from FERC Form 1. However, FERC Form 1 does not cover merchant power plants or independent power producers (IPPs), leaving a large gap in the data. For example, out of approximately 35,000 generating units in the U.S., roughly 21,000 (60%) are IPPs. The EIA currently extrapolates data from FERC Form 1 to represent all plants covered in the EMM.

Sargent & Lundy's update to the EMM treatment of aging examined the potential adaptation of the EMM to represent changes in age-related spending patterns by various methods. This examination required the following steps:

1. Gathering of in-house data from independent power projects and other plants, in addition to FERC Form 1 data.

[6] Internal communication with EIA, February 2018.
[7] FERC Form 1 is an annual regulatory requirement for major electric utilities, licensees, and others designed to collect non-confidential financial and operational information.

2. Incorporation of O&M and capital spending forecasts by plant owners and operators with firsthand knowledge of plant operating history and future needs, thereby extending the range of plant operating years over which to characterize spending, compared with FERC Form 1 data that is limited to historical data.
3. Removal of capital spending for major modifications relating to environmental compliance, which would be modeled on a case-specific basis.
4. Identification of the most significant variables affecting age-related spending from commonly reported plant data—such as plant capacity (kW), annual generation (megawatt-hours [MWh]), age, fuel type, emission controls, and regulatory environment—using regression analysis.
5. Representation of age-related costs as either fixed ($/kW-year) or variable ($/MWh) according to generating technology and typical maintenance practices.
6. Application of capital spending and/or age-related costs to the EMM representations of long-term fixed O&M, variable O&M, and ongoing capital spending for each generating technology.

The assessment methodology used by Sargent & Lundy for the EMM update included an in-depth process of data validation, data normalization, and statistical testing, which is described in detail in the following subsections.

2.2 SOURCES OF COST INFORMATION

2.2.1 FERC Form 1 Data

Sargent & Lundy reviewed the FERC Form 1 data through 2016, financial information available from other publicly available sources, and detailed in-house project information with which we are familiar. We assembled a sufficient volume of source material for each technology in order to characterize the distribution of capital and O&M expenditures over the life of a plant.

We obtained the FERC Form 1 data via ABB's Velocity Suite EV Power database. Using the available FERC Form 1 data, we assessed and summarized the "Cost of Plant" components of the data by major plant type category. The "Cost of Plant" components include the following categories of "Electric Plant in Service" accounts in FERC Form 1 data, which have been reported annually since the database's inception:

- Steam Power Generation – Cost of Plant
    - 310 Land and land rights.
    - 311 Structures and improvements.

  - 312 Boiler plant equipment.
  - 313 Engines and engine-driven generators.
  - 314 Turbo generator units.
  - 315 Accessory electric equipment.
  - 316 Miscellaneous power plant equipment
  - 317 Asset retirement costs for steam production plant.
- Hydraulic Power Generation – Cost of Plant
  - 330 Land and land rights.
  - 331 Structures and improvements.
  - 332 Reservoirs, dams, and waterways.
  - 333 Water wheels, turbines, and generators.
  - 334 Accessory electric equipment.
  - 335 Miscellaneous power plant equipment.
  - 336 Roads, railroads, and bridges.
  - 337 Asset retirement costs for hydraulic production plant.
- Other Power Generation – Cost of Plant
  - 340 Land and land rights.
  - 341 Structures and improvements.
  - 342 Fuel holders, producers, and accessories.
  - 343 Prime movers.
  - 344 Generators.
  - 345 Accessory electric equipment.
  - 346 Miscellaneous power plant equipment.
  - 347 Asset retirement costs for other production plant.

The sum of these components includes the original construction cost and all ongoing CAPEX. Therefore, each annual FERC Form 1 submittal includes the cumulative additions to the "Total Cost of Plant" (TCP). Annual changes in the TCP between each submittal year give an indication of the amount of CAPEX for the given year. Sargent & Lundy assessed and summarized these annual changes to derive age-related CAPEX, as discussed in the following subsections.

Sargent & Lundy also assessed and summarized the annual O&M expenditures for each technology as reported under the "Electric Operation and Maintenance Expenses" accounts in FERC Form 1:

- Steam Power Generation – O&M
    - 500 Operation supervision and engineering.
    - 502 Steam expenses.
    - 505 Electric expenses.
    - 506 Miscellaneous steam power expenses.
    - 507 Rents.
    - 509 Allowances.
    - 510 Maintenance supervision and engineering.
    - 511 Maintenance of structures.
    - 512 Maintenance of boiler plant.
    - 513 Maintenance of electric plant.
    - 514 Maintenance of miscellaneous steam plant.
- Hydraulic Power Generation – O&M
    - 535 Operation supervision and engineering.
    - 536 Water for power.
    - 537 Hydraulic expenses.
    - 538 Electric expenses.
    - 539 Miscellaneous hydraulic power generation expenses.
    - 540 Rents.
    - 541 Maintenance supervision and engineering.
    - 542 Maintenance of structures.
    - 543 Maintenance of reservoirs, dams, and waterways.
    - 544 Maintenance of electric plant.
    - 545 Maintenance of miscellaneous hydraulic plant.
- Other Power Generation – O&M
    - 546 Operation supervision and engineering.
    - 548 Generation expenses.
    - 549 Miscellaneous other power generation expenses.
    - 550 Rents.
    - 551 Maintenance supervision and engineering.
    - 552 Maintenance of structures.
    - 553 Maintenance of generating and electric plant.
    - 554 Maintenance of miscellaneous other power generation plant.

The above O&M expenditures are reported for individual power plants. Administrative and general (A&G) expenses in FERC accounts 920 through 935 are reported for the entire utility company. A&G expenses in these accounts were not included in this evaluation because of the significant differences in company sizes, mix of resources, and methods of allocating costs to individual power plants. In a similar manner, corporate-level A&G costs were also excluded from Sargent & Lundy's internal data.

The above FERC accounts 500 to 554 correspond to the following fixed and variable O&M components:

- Fixed O&M
  - Labor
  - Maintenance materials
  - Supplies and miscellaneous expenses
- Variable O&M
  - Consumables (chemicals, water, waste disposal, etc.)
  - Other costs proportional to generating output

The FERC accounts do not explicitly break out labor costs, as most of the accounts include both labor and non-labor expenditures. Likewise, the FERC accounts are not categorized according to fixed and variable cost components. The O&M costs in a given account are combined fixed and variable costs at the reported generating output.

2.2.2 Sargent & Lundy Internal Data

In addition, Sargent & Lundy compared publicly available, non-fuel-related financial and cost data with a characterization of proprietary information with which we are familiar, to the extent permissible by applicable confidentiality agreements (information about plant location, equipment type, or plant configuration was never disclosed from the proprietary data). We utilized our knowledge of actual projects to assemble a characterization of life extension/repowering costs from our in-house data.

A large portion of the in-house data used in this report was developed from business plan forecasts that capture actual budgeted costs for scheduled projects as well as longer-term projections. Historical spending data for standalone projects was not usable for this analysis, unless Sargent & Lundy had access to the complete O&M or CAPEX spending totals at a given plant for a given year. For consistent comparisons with other plants over time, each O&M or CAPEX data point needed to represent a comprehensive total of all spending projects.

2.2.3 Other Data Sources

Other publicly available data sources were searched, including regulated utility filings with public utility commissions, routine financial reports for publicly traded companies, utility integrated resource plans, data reported by various municipalities and electric cooperatives, and requests for proposals (RFPs) for plant improvements at public power entities. Cost data from each of these sources was found to be unsuitable for this study for one or more of the following reasons:

- Cost data was for initial capital investment costs only, with no O&M or ongoing CAPEX spending reported;
- Annual O&M or annual CAPEX amounts were for limited purposes and not representative of a complete year; and/or
- Annual O&M and annual CAPEX amounts were aggregated across business units and not assigned to specific plants.

Several publications or studies of power plant aging and life extension costs were used, which are cited herein.

2.3 DATA VALIDATION

Sargent & Lundy's approach to validating the FERC Form 1 data involved the following steps (note that capitalized words are proper FERC Form 1 terms):

1. For each Plant/Prime Mover combination (e.g., steam turbine, CC, simple-cycle CT), determine the difference between the prior and current year TCP reported in the FERC data. Note that a plant can have multiple prime movers on site (e.g., CT units and steam turbine units). Fortunately, that data is reported separately.
2. Flag and invalidate any years where the difference is negative (i.e., a decreasing value of the TCP).
3. Identify if the TCP difference is significantly due to asset retirement costs. If so, flag this plant reporting year consider it invalid, as capital would have been spent on non-aging items.
4. Identify if there has been any year-to-year change in nameplate capacity. If so, flag this plant reporting year and consider it invalid, because the TCP would be assumed to be spent on an expansion or addition.
5. Identify if any sulfur dioxide (SO_2), nitrogen oxide (NO_X), particulate matter (PM), or mercury (Hg) control equipment was installed for the plant reporting year. If so, flag that plant reporting year and consider it invalid, because capital would have been spent on non-aging items. The year

prior to or after the actual emissions control installation date is sometimes flagged as well, because of when the spending occurred (this is usually a judgement call).

6. Identify if any unit at the plant has been retired in a plant reporting year. If so, flag that plant reporting year and consider invalid, because capital would have been spent on non-aging items. Also, if the plant's TCP dropped significantly the last few years before retirement, flag those plant reporting years and consider them invalid.
7. Cross-check if any additional units at the plant site (using the same technology) show too great of time duration between installed dates of the units. If the first unit and the last unit installed is greater than 10 years apart, then flag the data and consider it invalid, because the TCP difference would not reflect the actual age of the plant (considered to be the age of the first unit). This was flagged as "Removed due to non-equal units at site."
8. If any TCP is reported to be zero for most of all of the reporting years of the plant, consider the data invalid.
9. If the TCP difference is highly volatile, flag and invalidate at discretion. For example, if one year TCP drops from $2,000/kW-year to $1,000/kW-year and then back to $2,000/kW-year in the year after, this would be considered highly volatile for those two reporting years.
10. If a reporting plant has only one or two years of reported TCP data, flag the plant and do not use its data.
11. If any plant reports negative Total O&M Costs, flag that year and do not use it.
12. Use only data that is valid for both CAPEX spending and O&M spending in the analysis of combined CAPEX and O&M spending. Otherwise, analyze CAPEX spending and O&M spending separately. Sargent & Lundy found that a large portion of the data points determined to be valid for CAPEX spending were also valid for O&M spending.

The resulting data points from this validation process are summarized in Table 2-1.

For each year of plant data, we also compiled the associated nameplate capacity (MW) and annual generation (MWh). EIA Form 860 was used to confirm the plant technology, environmental equipment, year in service, and other attributes.

Table 2-1 — Summary of Valid Data Points

Technology / (Dataset Identifier)	Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
				O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
Coal (10)	All MW	All	3,713	3,098	3,109	655	615
	< 500 MW	All	1,592	1,274	1,284	318	318
	500 MW – 1,000 MW	All	986	689	689	337	297
	1000 MW – 2,000 MW	All	813	813	814	0	0
	> 2,000 MW	All	322	322	322	0	0
	All MW	< 50%	965	889	896	76	76
	All MW	> 50%	2,748	2,209	2,213	579	539
Gas/Oil Steam (20)	All MW	All	2,220	2,204	2,226	20	16
	< 500 MW	All	1,377	1,361	1,366	20	16
	500 MW – 1,000 MW	All	488	488	489	0	0
	> 1,000 MW	All	355	355	355	0	0
Gas/Oil Combined Cycle (30)	All MW	All	1,367	980	981	408	387
	< 500 MW	All	764	462	463	304	302
	500 MW – 1,000 MW	All	547	462	463	104	85
	> 1,000 MW	All	177	177	177	0	0
	All MW	< 50%	843	661	662	203	182
	All MW	> 50%	524	319	319	205	205
Gas/Oil Combustion Turbine (40)	All MW	All	5,041	4,905	4,949	437	136
	< 100 MW	All	2,873	2,873	2,911	189	0
	100 MW – 300 MW	All	1,341	1,239	1,248	177	102
	> 300 MW	All	901	867	875	71	34
Conventional Hydroelectric (50)	All MW	All	2,179	2,179	2,180	0	0
	< 100 MW	All	1,272	1,272	1,272	0	0
	100 MW – 500 MW	All	924	924	925	0	0
	> 500 MW	All	41	41	41	0	0

Technology / (Dataset Identifier)	Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
				O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
Pumped Storage Hydroelectric (55)	All MW	All	226	226	227	0	0
	< 100 MW	All	12	12	12	0	0
	100 MW – 500 MW	All	88	88	88	0	0
	> 500 MW	All	126	126	126	0	0
Solar Thermal (60)			0				
Solar Photovoltaic (65)	All MW	All	57	410	57	0	0
Geothermal (70)							
Wind Turbine (80)	All MW	All	310	310	310	270	0
	< 100 MW	All	174	174	174	165	0
	100 MW – 200 MW	All	91	91	91	56	0
	> 200 MW	All	51	51	51	73	0

Note: A data point is one reported value for one year by one plant, i.e., a plant that reports values for 25 years will have 25 data points.

2.4 DATA NORMALIZATION

Sargent & Lundy developed a Microsoft Excel model template for compiling and normalizing all of the CAPEX and O&M data, subsequent to the initial review and validation steps outlined in the previous sections. The data normalization consisted of the following steps:

Step 1: Assign data "identifiers" for each plant:

Technology ID:

- 10 = Coal Steam Plants
- 20 = Gas/Oil Steam Plants
- 30 = Gas/Oil CC Plants
- 40 = Gas/Oil CTs
- 50 = Conventional Hydropower; Pumped Storage – Hydraulic Turbine Reversible
- 60 = Solar Thermal – Central Tower;
- 65 = Solar PV – Single-Axis Tracking
- 70 = Geothermal
- 80 = Wind

Data source:

- 1 = FERC Form 1
- 2 = Sargent & Lundy Internal Data
- 3 = Other Public Source

Step 2: Enter basic information for each plant:

- Year of commercial operation date (COD)
- End year of project life or forecast period
- Nameplate capacity (MW)
- Summer net capacity (MW)

Step 3: Adjust pricing basis for raw data:

- If provided in current dollars, adjust to 2017 dollars
- If provided in 2017 dollars, do not adjust
- If provided in constant dollars of another reference year, adjust to 2017 dollars

Step 4: Enter annual data for each plant (any available data from 1980 to 2060, historical or forecasted by plant owner):

- Plant MW (summer)
- Annual MWh
- Annual O&M (from FERC Form 1)
- Annual O&M (from other sources)
- Annual CAPEX (from FERC Form 1)
- Annual CAPEX (from other sources)
- Annual environmental compliance costs

Using the inputs from Steps 1-4 above, the "Normalizer" worksheet derives the following for each plant:

- Annual O&M in 2017 $/kW-year versus age (years from COD)
- Annual CAPEX in 2017 $/kW-year versus age (years from COD)
- Annual O&M + CAPEX in 2017 $/kW-year versus age (years from COD)

The output worksheets ("O&M," "CAPEX," and "O&M + CAPEX") each have the following user-selected filters:

- Technology ID (10, 20, 30, etc.)

- Data source (1,2, or 3)
- MW range (low, high)
- Outlier maximum $/kW
- Annual O&M + CAPEX in 2017 $/kW-year versus age (years from COD)

Each output worksheet ("O&M," "CAPEX," and "O&M + CAPEX") calculates the following for a given user-defined set of filters:

- $/kW-year (2017 dollars) versus age
- Statistical tests of linear curve fit: annual spending in 2017 $/kW-year = $/kW-year (y-intercept) + [constant × age (years from COD)]
- Average $/kW-year (2017 dollars) for age bands (10-year bands, 30-year bands, and all-years band)

In all cases, the yearly values are expressed in constant 2017 price levels and increase annually with the inflation rate.

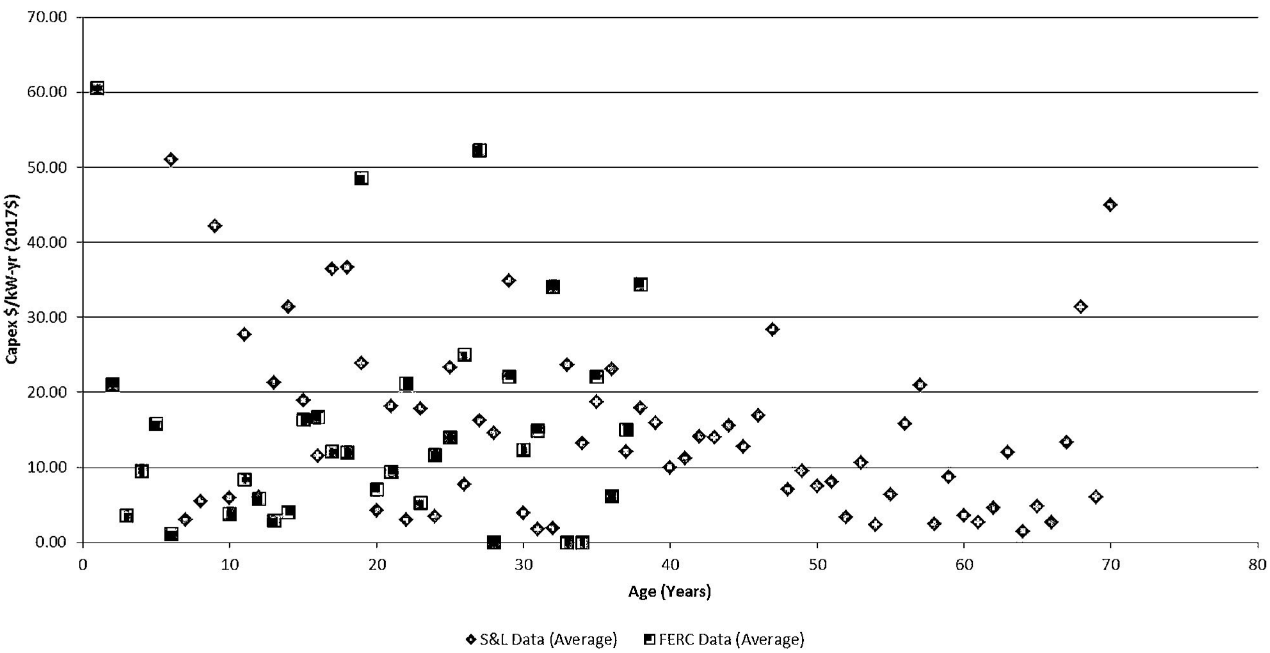
2.5 STATISTICAL TESTS

2.5.1 Consistency of FERC Form 1 and Sargent & Lundy Internal Data

FERC Form 1 data only covers historical data for utilities that are required to file and does not include the owners' projected expenditures or any data for merchant plants and independent power plants. Most of Sargent & Lundy's proprietary data, on the other hand, covers the owners' projected expenditures for utility plants and includes both historical and projected expenditures for merchant plants and independent power plants. The data points from both data sources were judged to be complementary and combined as a single dataset.

The compatibility of the FERC data and Sargent & Lundy internal data is illustrated by the CAPEX spending for a sample of 500-MW coal plants (Figure 2-1). This example is based on a sample of 11 plants from the Sargent & Lundy data and 12 plants from the FERC data, each sample having an average plant capacity of approximately 500 MW and an average age of approximately 30 years. Each data point in the figure is the average value for all the plants that have a valid data point at the given plant age. There are a total of 175 valid data points for the FERC plants and 200 valid data points for the Sargent & Lundy plants. In this particular sample, all of the FERC data is historical and all of the Sargent & Lundy data is owners' projected expenditures.

Figure 2-1 — CAPEX vs. Age for 500-MW Coal Plants – FERC and Sargent & Lundy Data



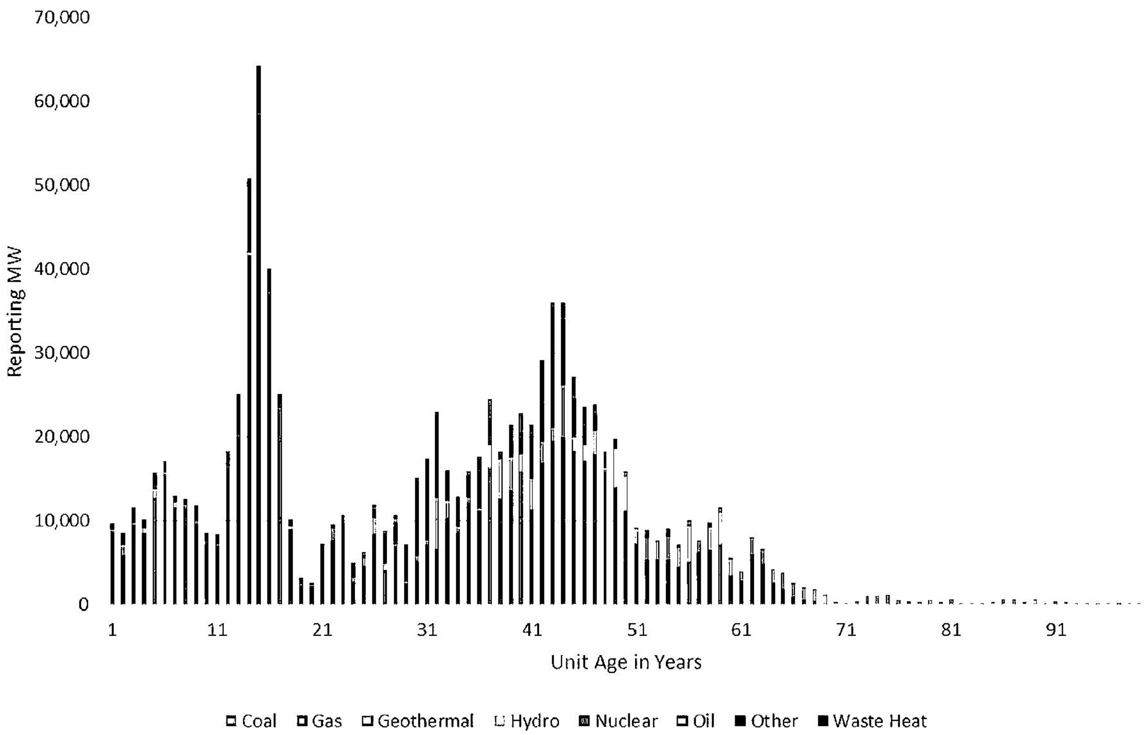
As discussed in Section 0, CAPEX spending for coal plants does not follow a uniform pattern for all plants. For example, different plants might incur the same type of expense at different points in time due to differences in plant-specific economic, locational, or operational circumstances.

For some utility plants, data was available from both FERC Form 1 and proprietary data. The historical O&M and CAPEX spending for these plants were examined in each year to verify their consistency.

The distribution of valid data points for each technology versus age (years from COD in which the spending occurs) was examined to verify consistency with typical plant ages nationwide. Figure 2-2 shows a recent distribution of the U.S. power plant fleet by unit age and fuel type as reported by FERC[8]. This distribution indicates a large portion of coal-fired capacity with ages of 30-50 years, and a large portion of gas-fired capacity (mostly CT or CC) with ages under 20 years. The valid data points assembled in this report were found to be representative of these major age and technology cohorts.

[8] North American Electric Reliability Corporation, *State of Reliability 2017*, June 2017 (p.116)

Figure 2-2 — U.S. Power Plant Fleet Capacity by Age and Fuel Type



A recent study found that the average age of the U.S. generator fleet has increased significantly over time, due in part to regulatory uncertainty in a deregulated market environment. At the same time, the average expected physical life of the fleet has been decreasing as a result of new investments in smaller, shorter-lived capacity. This has been a means of mitigating the regulatory risk of more limited stranded cost recovery mechanisms.[9] In another recent study, this one on the causes of power plant retirements, the strongest predictors of retirements were found to be SO_2 emission rates, planning reserve margins, variations in load growth or contraction, the age of older thermal plants, the ratio of coal to gas prices, and delivered natural gas prices. The impacts of annual CAPEX and O&M spending on retirement decisions were not specifically identified.[10]

2.5.2 Significance of Plant Age on Annual Capital and O&M Expenditures

For each technology group, Sargent & Lundy performed a regression analysis on the O&M spending, CAPEX spending, and combined O&M plus CAPEX spending using the following linear equation:

- Annual spending in 2017 \$/kW-year = \$/kW-year (y-intercept) + (constant × age)

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[9] Rode, D., Fischbeck, P., and Paez, A., "Power Plant Lives and their Policy Implications," *Energy Policy*, 106 (2017) 222-232, April 1, 2017.

[10] Mills, A., Wiser, R., and Seel, J, "Power Plant Retirements: Trends and Possible Drivers," Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Laboratory, November 2017.

The purpose of the regression analysis was to determine whether plant age is a statistically significant predictor of annual spending. The regression coefficient for age measures the change (+ or -) in annual spending as a function of plant age, measured as the number of years from the COD. Its statistical significance is measured by the p-value, which tests the null hypothesis that the coefficient is equal to zero (i.e., has no effect on spending).

The R-squared (R^2) statistic ("coefficient of determination") is an indication of the goodness of fit of the regression equation to the real data points. A low R^2 indicates that the regression equation explains a relatively small amount of the variability of the data around its mean. A low p-value (< 0.05) indicates that the age coefficient is statistically significant, regardless of the R^2 statistic. A low p-value corresponds approximately to a t-value that is greater than 2 or less than -2. For higher p-values, the simple average $/kW-year per year may be a more appropriate estimation for a given age band (e.g., 20-year bands and all-years band). Depending on the characteristics of the dataset, especially the number of data points, Sargent & Lundy applied engineering judgement (as further described in each section that follows) in our recommendations.

2.5.3 Autocorrelation of Time Series Data

In addition to the correlation between annual spending and plant age, an autocorrelation may also exist between spending in a given year and spending in previous years. Autocorrelation commonly occurs with time series data. If statistical tests verify the presence of autocorrelation, a lagged (autoregressive) variable may be added to improve the goodness of fit (R^2) of the regression model. Models with this functional form are referred to as "autoregressive integrated moving average" (ARIMA) models.

ARIMA models are typically constructed for the purpose of predicting the future from a given point in time, based on correlations with historical values and other exogenous variables. The functional form of an ARIMA model may better capture curvilinear or cyclical data trends and therefore improve the goodness of fit. For the purposes of this study, an ARIMA model was not necessary or appropriate. The datasets in this analysis already capture plant O&M and CAPEX spending patterns throughout a typical plant lifespan. The purpose of this study was to represent costs for generators as they age, and not to predict future spending from a given point in time.

3. COAL STEAM

3.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for coal steam plants were compiled using the assessment methodology described in Section 2. The valid data points derived from this process were distributed as follows:

- O&M expenditures:
  - 456 plants in FERC data and 32 plants from Sargent & Lundy internal data
  - 3,098 valid data points in FERC data, 655 valid data points in Sargent & Lundy internal data
- CAPEX:
  - 457 plants in FERC data and 29 plants from Sargent & Lundy internal data
  - 3,109 valid data points in FERC data, 615 valid data points in Sargent & Lundy internal data

The coal steam data was broken down by plant MW capacity and average capacity factor—as summarized in Table 3-1—for the regression analysis shown in Appendix A.

Table 3-1 — Coal Steam Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	3,713	3,098	3,109	655	615
< 500 MW	All	1,592	1,274	1,284	318	318
500 MW – 1,000 MW	All	986	689	689	337	297
1,000 MW – 2,000 MW	All	813	813	814	0	0
> 2,000 MW	All	322	322	322	0	0
All MW	< 50%	965	889	896	76	76
All MW	> 50%	2,748	2,209	2,213	579	539

Table 3-2 below identifies the relative effects in the data validation process of the top three data filters on the number of valid data points. These filters are described as follows:

- Change in Capacity: A change in nameplate capacity of 20% or more during the reported time of the unit. Data points prior to the change in capacity are no longer comparable to the data points after the change in capacity, so the entire unit was filtered out.
- Negative Change in Total Cost: Any year with a decrease in the cumulative historical capital cost reported in the FERC data was not included.
- Environmental Retrofit: Data points in years where SO_2, NO_X, PM, or Hg removal equipment was installed were filtered out.

Table 3-2 — Effect of Data Validation Filters on Coal Data Points

Coal Steam – FERC Dataset	Data Points
Total Data Points, Unfiltered	6,699
Total Data Points, Filtered Out	3,774
Top Three Filters	
Change in Capacity	1,659
Negative Change in Total Cost	889
Environmental Retrofit	599
Total Data Points, Valid (FERC Only)	**2,925**

3.2 SUMMARY OF RESULTS

3.2.1 Recommended CAPEX Values

The analysis of the coal steam dataset (Appendix A) identified two significant variables affecting annual changes in real CAPEX spending (on a constant \$/kW-year basis): age and flue gas desulfurization (FGD). Variables not having a significant effect on annual changes in real CAPEX spending (on a constant \$/kW-year basis) were: plant capacity (kW), fuel type, and regulatory environment. When CAPEX spending was expressed on a constant \$/MWh basis, it was significantly related to age, primarily as a result of declining MWh generation with age.

Table 3-3 below compares the new CAPEX values derived from the coal steam dataset with the CAPEX values currently used in the EMM. The new CAPEX values are similar in magnitude with the current EMM values over the long term, except the new values follow a continuous pattern rather than a step pattern. As discussed below, the new values include life extension projects that occur throughout the plant life, including the first 30 years of operation.

Table 3-3 — Coal Steam CAPEX Results – All MW, All Capacity Factors

Net Total CAPEX (2017 $/kW-year)	$/kW-yr (Years 1-10)	$/kW-yr (Years 10-20)	$/kW-yr (Years 20-30)	$/kW-yr (Years 30-40)	$/kW-yr (Years 40-50)	$/kW-yr (Years 50-60)	$/kW-yr (Years 60-70)	$/kW-yr (Years 70-80)
New Value – No FGD*	17.16	18.42	19.68	20.94	22.20	23.46	24.72	25.98
New Value – with FGD*	22.84	24.10	25.36	26.62	27.88	29.14	30.40	31.66
Existing EMM Value	17.55	17.55	17.55	24.62	24.62	24.62	24.62	24.62

*Calculated from the following regression equation to the midpoint of the given age band:

Annual CAPEX spending in 2017 $/kW-year = 16.53 + (0.126 × age) + (5.68 × FGD)
Where FGD = 1 if a plant has FGD; zero otherwise

"Life extension costs" in the existing CAPEX values are covered by the step increase after year 30. Life extension costs in the new CAPEX values are distributed throughout the plant life. This is a result of discretionary spending, which is a common practice for most coal steam plants. Different plants might incur the same type of expense at different points in time due to differences in plant-specific economic, locational, or operational circumstances.

Typical industry-standard frequencies for repairs and replacement of major equipment within a coal plant are not absolute, but rather indicative of when a coal plant may be required to perform the work, based on manufacturer experience. An owner may choose to perform the work early, if they have an available outage, or defer if, after inspection, the equipment appears to be capable of continued operation without repair.

The new values also account for CAPEX relating to FGD. An FGD system tends to be capital-intensive to own and operate. The corrosive environment of chemicals and reagents significantly reduces the life of equipment such as pumps, mills, nozzles, valves, etc. These components must be replaced more frequently compared with plants without FGD.

Table 3-4 below provides indicative typical industry-standard frequencies for repairs and replacement of major equipment within a coal plant.

Table 3-4 — Coal Plant Indicative Typical CAPEX Projects and Intervals

Project Description	Typical Frequency of Repairs/Replacement from COD (Years)
Boiler	
Coal mills and exhausters, burner tips and ignitors	5
Lower nose tube, burner panels, economizer banks, air heater tubes, and baskets	15
Lower and upper waterwalls, superheater and reheater horizontal sections and pendants, economizer header, coal feeders, mill motors	20
Superheater and reheater header, feedwater supply piping	25
Mud and steam drums	30
Turbine and Generator	
Control valves, nozzle block	12
Electro-hydraulic control system (EHC), governor, turbine controls, generator rotor, turbine lubrication pumps	15
Stop valves, low-pressure (LP) turbine and blades, LP casing/diaphragms,	20
Steam chest, high-pressure/intermediate-pressure (HP/IP) turbine with blades, HP/IP casing/diaphragm, generator stator, exciter	25
HP/IP rotor, LP rotor, isophase	30
Balance of Plant	
Condensate pumps, cooling tower fill, cooling tower fan drives and blades, conveyor belts, conveyer idlers/pulleys/motors, coal crushing equipment	10
Slag conveyors and tanks	12
Induced draft (ID) fans, electrostatic precipitator (ESP) casing, ESP plates/wires, deaerator, circulating water pumps, boiler feed pumps, distributed control system (DCS)/unit controls, boiler master/combustion controls, coal handling dust control system	15
Forced draft (FD) fans, primary air (PA) fans, fan motors, windbox and ductwork, ESP transformer/rectifier (TR) sets and rappers, condenser valves and cleaner system, LP feedwater heaters, HP feedwater heaters, gland coolers, conveyor structures, coal unloading equipment, fuel oil heaters, and delivery pumps	20
Condenser retube, deaerator storage tank, vacuum pumps/steam air ejectors, pump motors	25
Main power transformer, auxiliary transformer	30

3.2.2 Recommended O&M Values

The analysis required an understanding of the cost breakdowns in the reported data between 1) capitalized (CAPEX) and expensed (O&M) cost components and 2) fixed O&M and variable O&M cost components. From a system modeling perspective, CAPEX and fixed O&M costs are typically expressed in $/kW-year, while variable O&M is typically expressed in $/MWh. Normalized cost breakdowns in these units are necessary for compatibility with the EMM.

O&M costs for the coal steam plants include a significant variable component. By definition, variable O&M costs are proportional to plant generation and are typically expressed in $/MWh. As previously mentioned, the variable O&M component cannot be clearly delineated from the total reported O&M in the FERC Form 1 data. For this assessment, the variable component was combined with the fixed component and expressed in $/kW-year. The combined total O&M in the coal steam plant dataset for this analysis was found to be nearly equivalent to the existing combined total O&M representation in the EMM, which already includes the necessary $/MWh variable O&M breakout (Table 3-5).

Table 3-5 — Coal Steam O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)*	Variable O&M (2017 $/kW-yr)**	Total O&M (2017 $/kW-yr)**
Coal Steam Dataset Results – All Plants	36.81	1.78	9.20	46.01
< 500 MW	44.21	1.78	9.20	53.41
500 MW – 1,000 MW	34.02	1.78	9.20	43.22
1,000 MW – 2,000 MW	28.52	1.78	9.20	37.72
> 2,000 MW	33.27	1.78	9.20	42.47
Existing EMM Value***	40.63	1.78	9.20	49.83

*Fixed and variable split is estimated using the existing EMM variable O&M cost of $1.78/MWh.
**Calculated at the coal steam dataset average capacity factor of 59%.
***Source: Internal communication with EIA, February 2018.

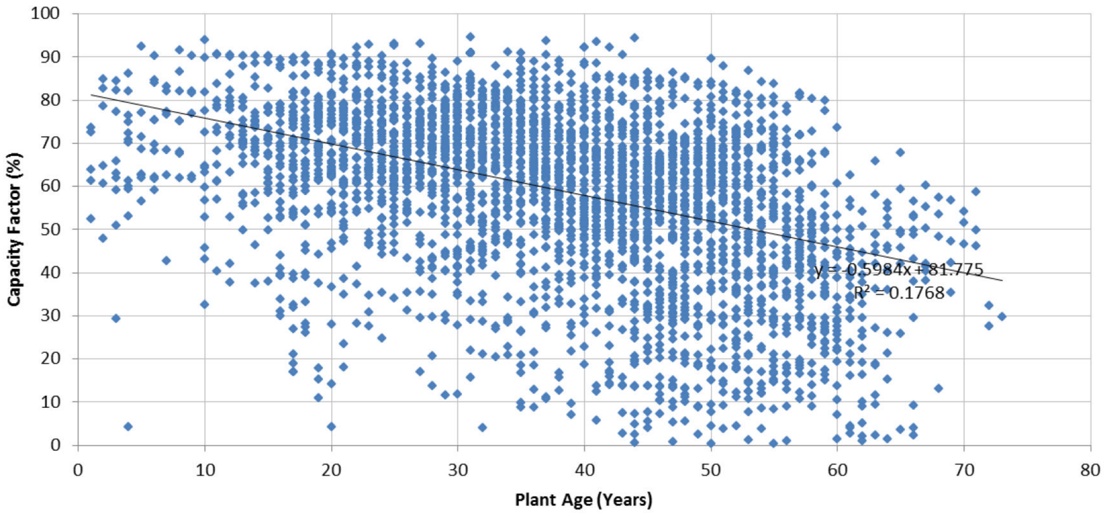
CAPEX and O&M spending have a relatively minor effect on future non-fuel O&M spending, on average, compared with plant performance-related economic benefits not captured in this analysis, such as:

- Reduced fuel expenditures due to improved heat rates
- Reduced capacity degradation and higher capacity sales
- Reduced outage costs due to reduced replacement power expenses or higher power sales
- Increased power sales due to increased net capacity or reduced forced outages

3.2.3 Effect of Plant Capacity Factor

CAPEX and O&M spending for the coal steam plants increased significantly with age when expressed on a $/MWh basis. This was primarily a result of significant declines in plant capacity factors over time, as shown in Figure 3-1.

Figure 3-1 — Capacity Factor vs. Age for All Coal Plants



3.2.4 Effect of External Market Conditions

The declining capacity factors with age may have been a result of external market conditions and/or declining plant performance. These are areas for further exploration.

External market conditions over the same time period that may have contributed to lower capacity factors for coal steam plants include:

- Competition with lower gas prices and more efficient gas turbines
- Competition with renewable energy having lower dispatch costs
- Lower load growth due to increased amounts of energy efficiency and distributed resources

For some coal steam plants, the decline in capacity factor was also a result of less efficient heat rates, increased component failures, and increased outage rates over time. A major contributor to this decline in performance is often a result of increased cycling operation. Increased cycling leads to higher O&M and CAPEX spending over time.[11]

External market conditions may have also reduced the number of data points with higher age-related spending, due to plant retirements. The least efficient coal steam plants would likely retire under the following circumstances:

[11] Kumar, N., Besuner, P., Lefton, S., and Agan, D., *Power Plant Cycling Costs*, National Renewable Energy Laboratory, April 2012.

- Lower efficiency may contribute to less frequent dispatch and more cycling, leading to more component failures and higher spending
- Less frequent dispatch reduces hours of operation and power sales
- Lower power sales income may not adequately cover plant fixed costs

Some of the older coal steam plants (23 in this data sample) maintained consistently high capacity factors throughout their lives, with no real increase in spending. These high capacity factor plants had an installed capacity ranging from 70 MW to 2,400 MW, with an average of 850 MW and an average COD of 1961. These plants are slightly larger and older, on average, than the entire dataset of coal steam plants, which have an average installed capacity of 720 MW and an average COD of 1964. Table 3-6 shows the average capacity factors and O&M and CAPEX spending for the entire dataset of coal steam plants compared with the older consistently high capacity factor plants.

Table 3-6 — High Capacity Factor Coal Plants – Spending Comparison

	Average – All Years	Years 1-20	Years 20-40	Years 40-80
Capacity Factor – All Plants	59.1%	66.8%	64.5%	52.9%
Capacity Factor – High CF Plants	74.0%	-	72.8%	74.4%
O&M – All Plants (2017 $/kW-yr)	46.01	53.90	40.06	48.77
CAPEX – All Plants (2017 $/kW-yr)	22.78	17.92	26.20	21.25
Total – All Plants (2017 $/kW-yr)	68.67	71.86	66.25	69.82
O&M – High CF Plants (2017 $/kW-yr)	36.65	-	31.07	38.78
CAPEX – High CF Plants (2017 $/kW-yr)	20.26	-	23.13	19.16
Total – High CF Plants (2017 $/kW-yr)	57.02	-	54.20	58.10

Market conditions at the older, high capacity factor plants may have led to fewer competing resources, which would support higher levels of dispatch and higher capacity factors. In addition, lower cycling requirements at those plants would have reduced spending requirements.

3.2.5 Effect of Regulatory Environment

Owners of coal steam plants in deregulated states were found to have no aversion to capital spending compared to plant owners in regulated states (see Appendix A). Some of the difference may be due to higher labor costs in many of the deregulated states. This is the opposite of what would be expected, whereby plant owners in a deregulated environment would have a greater incentive to reduce O&M costs that cannot be passed through to ratepayers. The higher O&M spending is likely a result of other factors, such as higher average labor costs in deregulated states, which tend to have a higher percentage of union labor compared with regulated states. Therefore, the net effect of regulatory status on average O&M spending was not apparent at this level of detail.

3.2.6 Effect of Fuel Characteristics

Sargent & Lundy's regression analysis compared CAPEX spending for coal steam plants with bituminous and subbituminous coal types (Appendix A). The results indicate that average CAPEX spending is not likely affected by coal type at a high-level designation (i.e., bituminous/subbituminous) without more detailed coal specifications.

4. GAS/OIL STEAM

4.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for gas/oil steam plants were compiled using the assessment methodology described in Section 2. The valid data points derived from this process were distributed as follows:

- O&M Expenditures
  - 283 plants in FERC data and four plants from Sargent & Lundy internal data
  - 2,204 valid data points in FERC data, 20 valid data points in Sargent & Lundy internal data
- CAPEX
  - 283 plants in FERC data and four plants from Sargent & Lundy internal data
  - 2,226 valid data points in FERC data, 16 valid data points in Sargent & Lundy internal data

The gas/oil steam data was broken down by plant MW capacity, as summarized below in Table 4-1, for the regression analysis shown in Appendix B.

Table 4-1 — Gas/Oil Steam Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	2,220	2,204	2,226	20	16
< 500 MW	All	1,377	1,361	1,366	20	16
500 MW – 1,000 MW	All	488	488	489	0	0
> 1,000 MW	All	355	355	355	0	0

4.2 SUMMARY OF RESULTS

4.2.1 Recommended CAPEX Values

Sargent & Lundy's analysis of the gas/oil steam dataset (Appendix B) identified only one significant variable affecting annual changes in real CAPEX spending (on a constant $/kW-year basis): plant capacity (kW). That is, CAPEX was lower on a $/kW-year basis for larger plant sizes due to economies of scale. When CAPEX spending was expressed on a constant $/MWh basis, it was significantly related to age, primarily as a result of declining MWh generation with age.

Table 4-2 compares the new CAPEX values derived from the gas/oil steam dataset with the CAPEX values currently used in the EMM. The new CAPEX values are similar in magnitude with the current EMM values over the long term, except that the new values follow a continuous pattern rather than a step pattern. As discussed below, the new values include life extension projects that occur throughout the plant life, including the first 30 years of operation.

Table 4-2 — Gas/Oil Steam CAPEX Results

Plant Size	Net Total CAPEX (2017 $/kW-year)	
	Years 1-30	Years 30-80
Gas/Oil Steam Dataset Results – All Plants	15.96	15.96
New Value: < 500 MW	18.86	18.86
New Value: 500 MW – 1,000 MW	11.57	11.57
New Value: > 1,000 MW	10.82	10.82
Existing EMM Value	9.14	16.21

"Life extension costs" in the existing CAPEX values are covered by the step increase after year 30. Life extension costs in the new CAPEX values are distributed throughout the plant life. This is a result of discretionary spending, which is a common practice for most gas/oil steam plants. Different plants might incur the same type of expense at different points in time due to differences in plant-specific economic, locational, or operational circumstances.

Typical industry-standard frequencies for repairs and replacement of major equipment within a gas/oil steam plant are not absolute, but rather indicative of when a gas/oil steam plant may be required to perform the work, based on manufacturer experience. An owner may choose to perform the work early, if they have an available outage, or defer if, after inspection, the equipment appears to be capable of continued operation without repair. Typical industry-standard frequencies for repairs and replacement of major equipment are similar to those of coal units, as presented in the previous section.

The use of a constant annual value on the modeling of annual CAPEX would be similar to representing a major maintenance reserve account (MMRA), which is commonly used for non-recourse financing of power projects. MMRAs are usually required by power project lenders over the tenor of debt as protection against maintenance spending uncertainty. An MMRA is typically funded by annual contributions drawn from a project's cash flow, sometimes as a uniform annual amount. Annual contribution levels are based on estimated long-term maintenance expenditure patterns. Over the long term, annual contributions represent a smoothed version of irregular actual annual values.

The use of a long-term average value also recognizes the inherent variability in long-term spending patterns for any given plant. Since the EMM is a large-scale model, it is conceptually designed to represent plant types as averages rather than as individual plants. When summed across a large number of plants in a utility system, some of the variability in annual expenditure patterns would tend to even out. The level of accuracy between average values and year-specific values for a given plant type is nearly equivalent in large-scale models.

4.2.2 Recommended O&M Values

The analysis required an understanding of the cost breakdowns in the reported data between 1) capitalized (CAPEX) and expensed (O&M) cost components and 2) fixed O&M and variable O&M cost components. From a system modeling perspective, CAPEX and fixed O&M costs are typically expressed in $/kW-year, while variable O&M is typically expressed in $/MWh. Normalized cost breakdowns in these units are necessary for compatibility with the EMM.

O&M costs for the gas/oil steam plants include a significant variable component, although typically smaller than coal units. The combined total O&M in the gas/oil steam plant dataset for this analysis was found to be somewhat lower than the existing combined total O&M representation in the EMM, which already includes the necessary $/MWh variable O&M breakout (see Table 4-3). However, the variable O&M of $8.23/MWh in the EMM is much higher than values Sargent & Lundy has observed in actual gas/oil steam plants and should not be higher than the variable O&M of $1.78/MWh in the EMM used for the coal units.

Table 4-3 — Gas/Oil Steam O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)*	Variable O&M (2017 $/kW-yr)**	Total O&M (2017 $/kW-yr)**
Gas/Oil Steam Dataset Results – All Plants	24.68	1.00	1.84	26.52
< 500 MW	29.73	1.00	1.84	31.57
500 MW – 1,000 MW	17.98	1.00	1.84	19.82
> 1,000 MW	14.51	1.00	1.84	16.35
Existing EMM Value***	19.68	8.23	15.14	34.82

*Fixed and variable split is estimated using an approximate value for variable O&M of $1.00/MWh based on confidential projects.
**Calculated at the gas/oil steam dataset average capacity factor of 21%.
***Source: Internal communication with EIA, February 2018.

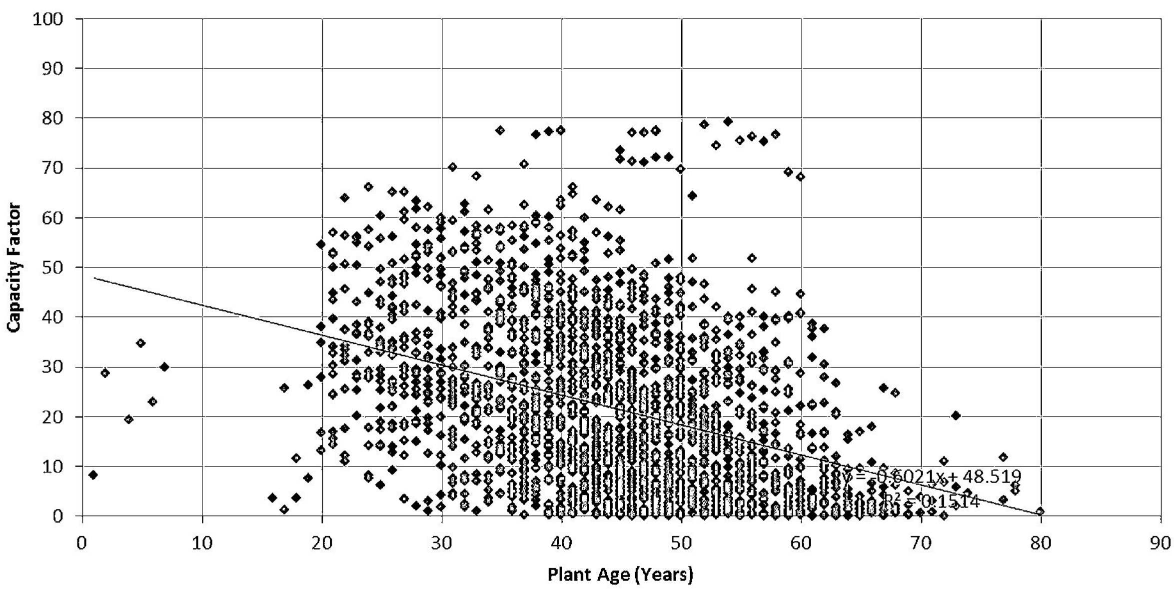
CAPEX and O&M spending have a relatively minor effect on future non-fuel O&M spending, on average, compared with plant performance-related economic benefits not captured in this analysis, such as:

- Reduced fuel expenditures due to improved heat rates
- Reduced capacity degradation and higher capacity sales
- Reduced outage costs due to reduced replacement power expenses or higher power sales
- Increased power sales due to increased net capacity or reduced forced outages

4.2.3 Effect of Plant Capacity Factor

CAPEX and O&M spending for the gas/oil steam plants increased significantly with age when expressed on a $/MWh basis. This was primarily a result of significant declines in plant capacity factors over time, as shown in Figure 4-1.

Figure 4-1 — Capacity Factor vs. Age for All Gas/Oil Steam Plants



4.2.4 Effect of External Market Conditions

The declining capacity factors with age may have been a result of external market conditions and/or declining plant performance. These are areas for further exploration.

External market conditions over the same time period that may have contributed to lower capacity factors for gas/oil steam plants include:

- Competition with more efficient gas turbines

- Competition with renewable energy having lower dispatch costs
- Lower load growth due to increased amounts of energy efficiency and distributed resources

For some gas/oil steam plants, the decline in capacity factor was also a result of less efficient heat rates, increased component failures, and increased outage rates over time. A major contributor to this decline in performance is often a result of increased cycling operation. Increased cycling leads to higher O&M and CAPEX spending over time.

External market conditions may have also reduced the number of data points with higher age-related spending, due to plant retirements. The least efficient gas/oil steam plants would likely retire under the following circumstances:

- Lower efficiency may contribute to less frequent dispatch and more cycling, leading to more component failures and higher spending
- Less frequent dispatch reduces hours of operation and power sales
- Lower power sales income may not adequately cover plant fixed costs

5. GAS/OIL COMBINED CYCLE

5.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for gas/oil CC plants were compiled using the assessment methodology described in Section 2. The valid data points derived from this process were distributed as follows:

- O&M Expenditures
  - 144 plants in FERC data and 20 plants from Sargent & Lundy internal data
  - 980 valid data points in FERC data, 408 valid data points in Sargent & Lundy internal data
- CAPEX
  - 142 plants in FERC data and 17 Sargent & Lundy proprietary plants with valid data
  - 981 valid data points in FERC data, 387 valid data points in Sargent & Lundy internal data

The gas/oil CC data was broken down by plant MW capacity and average capacity factor, as summarized below in Table 5-1, for the regression analysis shown in Appendix C.

Table 5-1 — Gas/Oil CC Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	1,367	980	981	408	387
< 500 MW	All	764	462	463	304	302
500 MW – 1,000 MW	All	547	462	463	104	85
> 1,000 MW	All	177	177	177	0	0
All MW	< 50%	843	661	662	203	182
All MW	> 50%	524	319	319	205	205

5.2 SUMMARY OF RESULTS

As with coal steam and gas/oil steam plants, CAPEX spending for gas/oil CC plants represents a series of capital projects throughout the plant life, which includes projects for "life extension." Most CAPEX spending for gas/oil CC plants is for vendor-specified major maintenance events. Other CAPEX spending, other than for emission control retrofits, is relatively minor.

Vendor-specified major maintenance spending is based on cumulative hours of operation and/or cumulative starts. Implicitly, CAPEX spending for CC plants is age-related and vendor-specified, and may be expressed as an equivalent $/MWh value, which covers:

- Major maintenance costs for periodic combustion inspections, hot gas path inspections, and major overhauls account for nearly all of the CAPEX expenditures. Many plant owners choose to capitalize major maintenance expenditures. As these expenditures normally follow the equipment vendor's recommendations, they maintain plant performance and extend the plant life.
- Major one-time costs include rotor replacement, typically at about 150,000 equivalent operating hours, 7,000 equivalent starts, or within the first 30 years of plant operation. These costs are captured within the dataset. As gas turbines age, major maintenance parts often become available from third-party suppliers at a discounted price.

As with MMRAs (described in Section 4.2.1), major maintenance contracts are priced according to smoothed versions of irregular long-term expenditure patterns. Apart from adjustments for operating conditions, major maintenance (and nearly all of the CAPEX) is effectively priced as an equal annual value, expressed in constant $/MWh with annual escalation.

Table 5-2 compares the new CAPEX and O&M values derived from the gas/oil CC dataset with the values currently used in the EMM. As previously mentioned, the combined CAPEX and O&M in the dataset would be expected to correspond to the combined CAPEX and O&M in the EMM, with most of the CAPEX in the EMM represented as variable O&M. However, some of the EMM values are higher than values Sargent & Lundy has observed in actual CC plants, as detailed below:

- The EMM fixed and variable O&M costs for CC plants are reasonable for smaller CC installations (< 500 MW) but high for larger plants.
- The EMM CAPEX addition of $7/kW-year after 30 years of operation should not be represented as a fixed cost. As previously mentioned, age-related costs would be built into the $/MWh variable O&M and would be a function of cumulative operating hours rather than operating years.

Table 5-2 — Gas/Oil CC CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	Variable O&M (2017 $/kW-yr)*	Total O&M (2017 $/kW-yr)*	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)*
CC Dataset Results – All Plants	13.08	3.91	(included in CAPEX)	13.08	15.76	28.84
< 500 MW	15.62	4.31	(included in CAPEX)	15.62	17.38	33.00
500 MW – 1,000 MW	9.27	3.42	(included in CAPEX)	9.27	13.78	23.05
> 1,000 MW	11.68	3.37	(included in CAPEX)	11.68	13.57	25.25
Existing EMM Value**	27.52	2.64	10.64	38.16	0.18; 7.25 (after year 30)	38.34; 45.41 (after year 30)

*Calculated at the gas/oil CC dataset average capacity factor of 46%. Fixed and variable O&M split is estimated.
**Source: Internal communication with EIA, February 2018.

CAPEX and O&M spending have a relatively minor effect on future non-fuel O&M spending, on average, compared with plant performance-related economic benefits not captured in this analysis, such as:

- Reduced fuel expenditures due to improved heat rates
- Reduced capacity degradation and higher capacity sales
- Reduced outage costs due to reduced replacement power expenses or higher power sales
- Increased power sales due to increased net capacity or reduced forced outages

6. GAS/OIL COMBUSTION TURBINE

6.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for gas/oil CT plants were compiled using the assessment methodology described in Section 2. The valid data points derived from this process were distributed as follows:

- O&M Expenditures
  - 625 plants from FERC data and 27 plants from Sargent & Lundy internal data
  - 4,905 valid data points in FERC data, 437 valid data points in Sargent & Lundy internal data
- CAPEX
  - 579 plants from FERC data and five plants from Sargent & Lundy internal data
  - 4,949 valid data points in FERC data, 136 valid data points in Sargent & Lundy internal data

The CT data was broken down by plant MW capacity, as summarized below in Table 6-1, for the regression analysis shown in Appendix D.

Table 6-1 — Gas/Oil Combustion Turbine Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	5,041	4,905	4,949	437	136
< 100 MW	All	2,873	2,873	2,911	189	0
100 MW – 300 MW	All	1,341	1,239	1,248	177	102
> 300 MW	All	901	867	875	71	34

6.2 SUMMARY OF RESULTS

As with coal steam and gas/oil steam plants, CAPEX spending for gas/oil CT plants represents a series of capital projects throughout the plant life, which includes projects for "life extension." Most CAPEX spending for gas/oil CT plants is for vendor-specified major maintenance events. Other CAPEX spending, other than for emission control retrofits, is relatively minor.

Vendor-specified major maintenance spending is based on cumulative hours of operation and/or cumulative starts. Implicitly, CAPEX spending for CTs is age-related and vendor-specified, and may be expressed as an equivalent $/MWh value, which covers:

- Major maintenance costs for periodic combustion inspections, hot gas path inspections, and major overhauls account for nearly all of the CAPEX expenditures. Many plant owners choose to capitalize major maintenance expenditures. As these expenditures normally follow the equipment vendor's recommendations, they maintain plant performance and extend the plant life.
- Major one-time costs include rotor replacement, typically at about 150,000 equivalent operating hours, 7,000 equivalent starts, or within the first 30 years of plant operation. These costs are captured within the dataset. As gas turbines age, major maintenance parts often become available from third-party suppliers at a discounted price.

As with MMRAs (described in Section 4.2.1), major maintenance contracts are priced according to smoothed versions of irregular long-term expenditure patterns. Apart from adjustments for operating conditions, major maintenance (and nearly all of the CAPEX) is effectively priced as an equal annual value, expressed in constant $/MWh with annual escalation.

Table 6-2 compares the new CAPEX and O&M values derived from the gas/oil CT datasets with the values currently used in the EMM. As previously mentioned, the combined CAPEX and O&M in the datasets would be expected to correspond to the combined CAPEX and O&M in the EMM, with most of the CAPEX in the EMM represented as variable O&M. However, EMM fixed and variable O&M costs across all plant sizes are higher than values Sargent & Lundy has observed in actual CT plants. Since most CT plants operate as peaking plants with low capacity factors, the variable O&M component is likely to be based on equivalent starts rather than equivalent operating hours.

Table 6-2 — Gas/Oil Combustion Turbine CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	Variable O&M (2017 $/kW-yr)*	Total O&M (2017 $/kW-yr)*	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)*
CT Dataset Results – All Plants	5.33	(starts based)	(included in CAPEX)	5.33	6.90	12.23
< 100 MW	5.96	(starts based)	(included in CAPEX)	5.96	9.00	14.96
100 MW – 300 MW	6.43	(starts based)	(included in CAPEX)	6.43	6.18	12.61
> 300 MW	3.99	(starts based)	(included in CAPEX)	3.99	6.95	10.94
Existing EMM Value**	12.60	14.63	5.13	17.73	1.52	19.25

*Calculated at the gas/oil CC dataset average capacity factor of 4%.
**Source: Internal communication with EIA, February 2018.

CAPEX and O&M spending have a relatively minor effect on future non-fuel O&M spending, on average, compared with plant performance-related economic benefits not captured in this analysis, such as:

- Reduced fuel expenditures due to improved heat rates
- Reduced capacity degradation and higher capacity sales
- Reduced outage costs due to reduced replacement power expenses or higher power sales
- Increased power sales due to increased net capacity or reduced forced outages

7. CONVENTIONAL HYDROELECTRIC

7.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for conventional hydroelectric plants were compiled using the assessment methodology described in Section 2. The valid data points derived from this process were distributed as follows:

- O&M Expenditures
  - 348 plants in FERC data
  - 2,179 valid data points in FERC data
- CAPEX
  - 348 plants in FERC data
  - 2,180 valid data points in FERC data

The conventional hydroelectric data was broken down by plant MW capacity, as summarized below in Table 7-1, for the regression analysis shown in Appendix E.

Table 7-1 — Conventional Hydroelectric Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	2,179	2,179	2,180	0	0
< 100 MW	All	1,272	1,272	1,272	0	0
100 MW – 500 MW	All	924	924	925	0	0
> 500 MW	All	41	41	41	0	0

7.2 SUMMARY OF RESULTS

Sargent & Lundy's linear regression analysis of the dataset for conventional hydroelectric plants (Appendix E) supports age as a statistically significant predictor of CAPEX spending (on a linear trend across all plant ages). CAPEX spending for this dataset may be estimated by the regression equation:

Annual CAPEX spending in 2017 $/kW-year = 7.269 + (0.296 × age)

The dataset also supports age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages). Therefore, O&M spending for this dataset may be estimated by the regression equation:

Annual O&M spending in 2017 $/kW-year = 22.360 + (0.073 × age)

The CAPEX and O&M values derived from the conventional hydroelectric dataset are significantly higher than the existing values used in the EMM (Table 7-2) and outside the range of values published in the AEO[12] and by the International Renewable Energy Agency (IRENA).[13] The reasons for this discrepancy are not known without having the data sample used for the EMM values. It appears that the EMM does not currently account for CAPEX or life extension expenditures for conventional hydroelectric.

Table 7-2 — Hydroelectric CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)
Conventional Hydroelectric Dataset Results – All Plants	22.00	-	22.56	44.56
Existing EMM Value*	14.58	0.00	0.00	14.58

*Source: Internal communication with EIA, February 2018.

[12] Energy Information Administration, *Annual Energy Outlook 2018*, Cost and Performance Characteristics (Table 8.2), February 2018.
[13] International Renewable Energy Agency, *Renewable Energy Technologies: Cost Analysis Series, Hydropower*, June 2012.

8. PUMPED HYDROELECTRIC STORAGE

8.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for pumped storage plants were compiled using the assessment methodology described in Section 2. The valid data points derived from this process were distributed as follows:

- O&M Expenditures
  - 37 plants in FERC data
  - 226 valid data points in FERC data
- CAPEX
  - 37 plants in FERC data
  - 227 valid data points in FERC data

The pumped storage data was broken down by plant MW capacity, as summarized below in Table 8-1, for the regression analysis shown in Appendix F.

Table 8-1 — Pumped Storage Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	226	226	227	0	0
< 100 MW	All	12	12	12	0	0
100 MW – 500 MW	All	88	88	88	0	0
> 500 MW	All	126	126	126	0	0

8.2 SUMMARY OF RESULTS

Overall, the pumped storage dataset does not support any age-related CAPEX or O&M spending trend across the full data and on any of the subsets by plant size. The average value over all operating years is $14.83/kW-year for CAPEX and $23.63/kW-year for O&M (Table 8-2). The existing values used in the EMM are not available.

Table 8-2 — Pumped Storage CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)
Pumped Storage Dataset Results – All Plants	23.63	-	14.83	38.46
Existing EMM Value	N/A	N/A	N/A	N/A

9. SOLAR PHOTOVOLTAIC

9.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for solar PV storage plants were compiled using the assessment methodology described in Section 2. The FERC data includes 105 solar PV installations ranging in capacity from 10 kW to 36 MW.

The solar PV data, summarized below in Table 9-1, was used for the regression analysis shown in Appendix G.

Table 9-1 — Solar Photovoltaic Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	57	410	57	0	0

9.2 SUMMARY OF RESULTS

The solar PV dataset does not support any age-related CAPEX spending trend across the full data and on any of the subsets by plant size (see Appendix G). Sargent & Lundy determined that a significant portion of the data needed to be filtered out, resulting in a limited dataset of 15 sites. The average annual CAPEX (i.e., change in TCP) for these sites was approximately $26/kW-year. However, due to the limitations of the solar PV dataset, described in Appendix G, Sargent & Lundy advises that caution be taken when trying to establish any definitive solar PV capital cost trends from the FERC data.

The solar PV dataset appears to support age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages). However, based on a closer inspection of the data, a more appropriate predictor of O&M spending for this dataset would be a simple average across all years. This determination is based on the lack of data points for plants over 10 years old and the fact that nearly all data points for plants over 10 years old are reported as having zero O&M expenses. Additionally, many of these plants also reported zero O&M expenses for all years of operation.

Solar PV O&M activities include a variety of work scopes, including administrative work, monitoring, cleaning, preventative maintenance, and corrective maintenance. Some specific examples of O&M activities may include cleaning modules, monitoring system voltage and current, inspecting and cleaning electrical equipment, inspecting modules for damage, inspecting mounting systems, and checking invertor settings. The cost of O&M is dependent on several factors, including the number of components, the type of system (e.g., roof, tracking, ground mount, fixed, etc.), warranty coverage, and location. Environmental conditions, such as hail, sand/dust, snow, salt in air, high winds, etc., also play a significant role in O&M costs. For these reasons, a higher level of variation is expected when compared to traditional generating technologies.

An average O&M cost of $75/kW-year was calculated from the FERC data for sites under 5 MW, and $15/kW-year for sites over 5 MW. Sargent & Lundy notes that, compared to other industry metrics shown in Appendix G, the FERC data averages are similar for the sites over 5 MW but much higher for the sites under 5 MW.

If the results of the regression analysis are used, the average O&M costs are reduced to $41/kW-year for sites under 5 MW and $10/kW-year for sites over 5 MW. The regression analysis uses each year of plant data as a unique data point, which captures the years in which zero O&M costs were reported.

By comparison, the EMM uses an average O&M value of $28.47/kW-year for all solar PV plants and an average CAPEX value of zero.[14] Neither dataset captures the most recent trends in solar PV technology due to rapid changes in cost, size, and efficiency.

[14] Internal communication with EIA, February 2018.

10. SOLAR THERMAL

10.1 DATA DESCRIPTION

There are no solar thermal power plants that report operating data in FERC Form 1. Industry-wide, there are a limited number of solar thermal projects; a majority of which have been constructed within the last 10 years—the exception being small test facilities and the Solar Energy Generating Systems (SEGS) plants built in the 1980s.

10.2 SUMMARY OF RESULTS

The U.S. National Renewable Energy Laboratory (NREL) published an Annual Technology Baseline (ATB) in 2017 that estimates the capital and O&M cost of a 100-MWnet solar power tower plant with 10 hours of thermal storage, based on cost models benchmarked with industry data.[15] The estimate includes future projections based on possible reductions in costs (high, mid, or low). The 2017 ATB includes a 2015 baseline. An update is expected to be made available in 2018.

[15] NREL 2017 Annual Technology Baseline (https://atb.nrel.gov/electricity/2017/index.html?t=sc)

11. GEOTHERMAL

11.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for geothermal plants were compiled using the assessment methodology described in Section 2. The FERC data includes five geothermal installations ranging in capacity from 23 MW to 1,224 MW.

The geothermal data summarized in Table 11-1 was used for the regression analysis shown in Appendix I.

Table 11-1 — Geothermal Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	36	38	36	0	0

11.2 SUMMARY OF RESULTS

Overall, the geothermal dataset does not support any age-related CAPEX spending trend across the full data and on any of the subsets by plant size. Instead, we recommend a simple average be used across the full age range. Sargent & Lundy recommends using the indicated $/kW-year average in Table 11-2 for O&M and CAPEX spending. As shown in the table, it appears the EMM does not currently account for CAPEX or life extension expenditures for geothermal plants.

Table 11-2 — Geothermal CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	CAPEX (2017 $/kW-yr)	Total O&M and CAPEX (2017 $/kW-yr)
Geothermal Dataset Results – All Plants	157.10	-	40.94	198.04
Existing EMM Value*	91.66	0.00	0.00	91.66

*Source: Internal communication with EIA, February 2018.

12. WIND

12.1 DATA DESCRIPTION

Annual O&M and CAPEX expenditures for wind plants were compiled using the assessment methodology described in Section 2. The valid data points derived from this process were distributed as follows:

- O&M Expenditures
  - 73 plants in FERC and 24 from Sargent & Lundy proprietary plants with valid data
  - 310 valid data points in FERC, 270 valid data points in Sargent & Lundy proprietary plants
- CAPEX
  - 97 plants in FERC with valid data
  - 310 valid data points in FERC

Sargent & Lundy's dataset includes both actual historical cost reporting from operating wind projects as well as forecasted budgetary cost projections prepared by project developers and operators with large project portfolios.

Operating costs are assumed to include all expenses related to the maintenance of the wind project, such as planned and unplanned maintenance of the wind turbines and electrical balance of plant (including labor, parts, materials, and consumables) as well as operating expenses (such as facility monitoring and management fees, utilities, land lease and royalty payments, professional service fees, taxes, and insurance).

The wind data was broken down by plant MW capacity, as summarized below in Table 12-1, for the regression analysis shown in Appendix J.

Table 12-1 — Wind Cost Data Distribution

Plant Size	Average Net Capacity Factor (%)	Valid Data Points	FERC Data		Sargent & Lundy Internal Data	
			O&M Data Points	CAPEX Data Points	O&M Data Points	CAPEX Data Points
All MW	All	310	310	310	270	0
< 100 MW	All	174	174	174	165	0
100 MW – 200 MW	All	91	91	91	56	0
> 200 MW	All	51	51	51	73	0

12.2 SUMMARY OF RESULTS

The dataset supports age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages). Therefore, O&M spending for this dataset may be estimated by the regression equations shown in Table 12-2. Age was not a significant predictor of CAPEX spending, although CAPEX was found to vary significantly as a function of capacity (kW). That is, CAPEX was lower on a $/kW-year basis for larger plant sizes due to economies of scale.

The CAPEX and O&M values derived from the wind dataset are significantly higher than the existing values used in the EMM. The reasons for this discrepancy are not known without having the data sample used for the EMM values. Neither data sample is stratified by wind technology or turbine size. Neither dataset captures the most recent trends in wind turbine technology due to rapid changes in cost, size, and efficiency.

Table 12-2 — Wind CAPEX and O&M Comparison with Existing EMM

	Fixed O&M (2017 $/kW-yr)	Variable O&M (2017 $/MWh)	CAPEX (2017 $/kW-yr)
Wind Dataset Results – All Plants	31.66 + (1.22 × age)	0.00	18.29
< 100 MW	39.08 + (1.12 × age)	0.00	20.48
100 MW – 200 MW	23.80 + (1.17 × age)	0.00	16.93
> 200 MW	26.78 + (0.92 × age)	0.00	13.48
Existing EMM Value*	29.31	0.00	0.00

*Source: Internal communication with EIA, February 2018.

Sargent & Lundy Consulting

Appendix A. Regression Analysis – Coal Steam

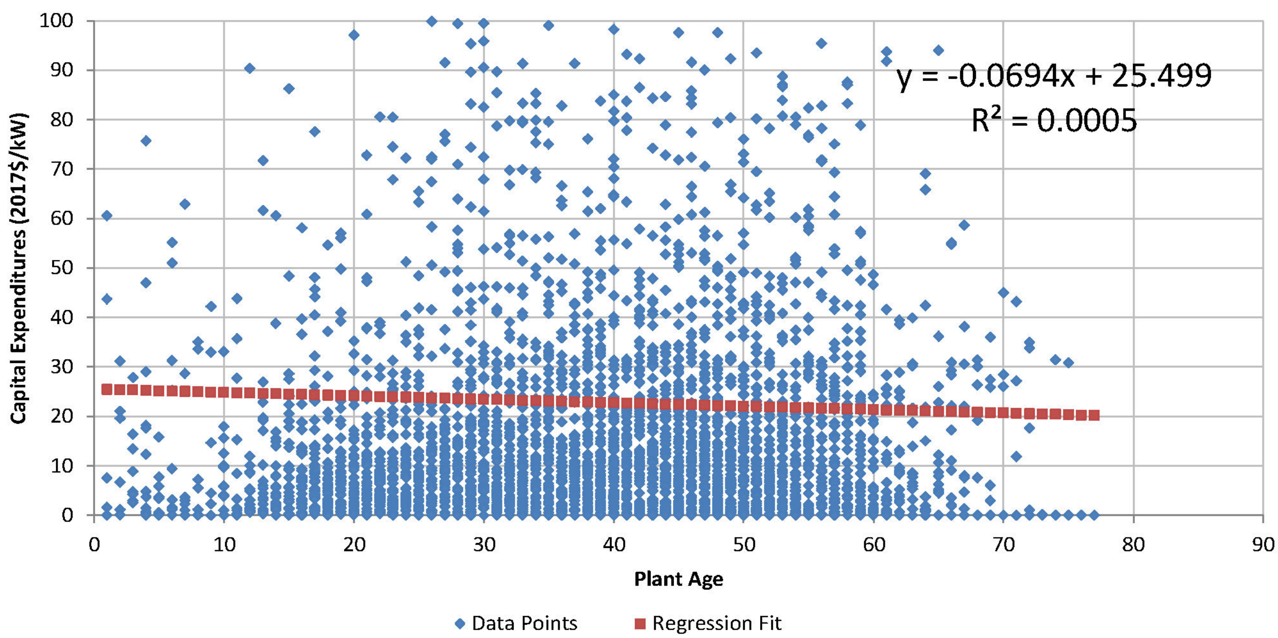
CAPITAL EXPENDITURES – ALL PLANT SIZES

The results of the linear regression analysis of CAPEX spending for coal steam plants of all MW sizes (full dataset) are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.19, which is greater than 0.05, the dataset does not support age as a statistically significant predictor of CAPEX spending (on a linear trend across all plant ages). However, age and FGD are significant variables when an FGD variable is added to the regression equation (see below).

Table A-1 — Regression Statistics – Coal CAPEX for All MW

		t statistic	*p-value*
Observations	3,724		
Simple Average ($/kW)	22.782		
Intercept	25.499	11.4859	4.95E-30
Slope	-0.069	-1.3054	1.92E-01
R^2	0.00046		

Figure A-1 — Coal Steam Dataset – CAPEX for All MW Plant Sizes



Note: Age coefficient in above regression equation is not statistically significant.

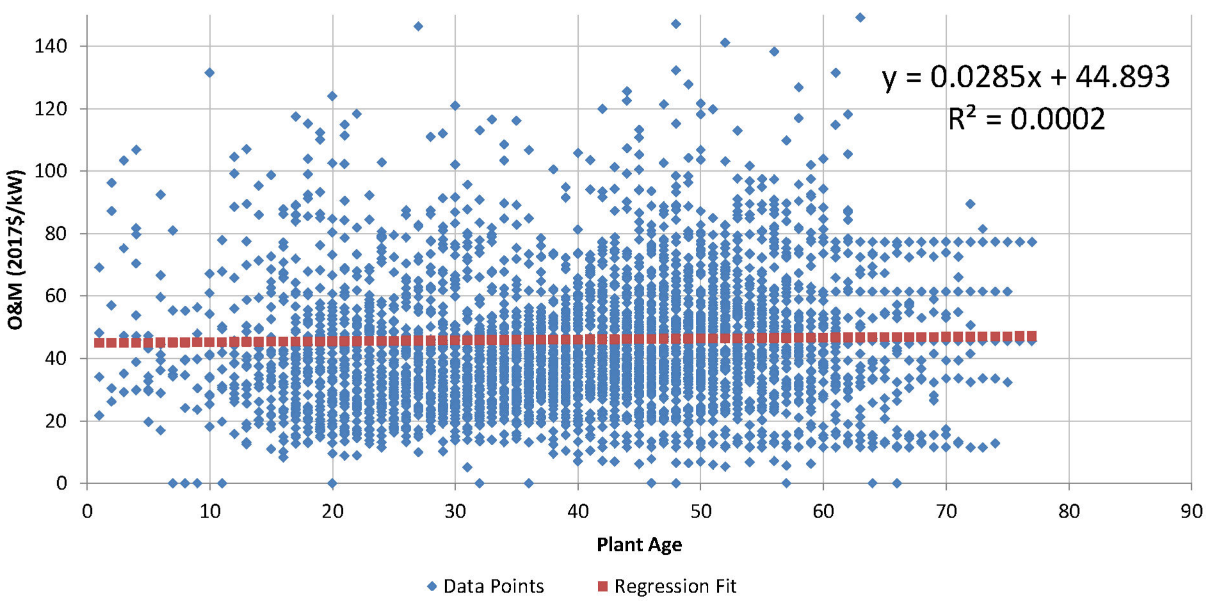
OPERATIONS & MAINTENANCE EXPENDITURES – ALL PLANT SIZES

The results of the linear regression analysis of O&M spending for coal steam plants of all MW sizes (full dataset) are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.38, which is greater than 0.05, the dataset does not support age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages).

Table A-2 — Regression Statistics – Coal O&M for All MW

		t statistic	*p-value*
Observations	3,753		
Simple Average ($/kW)	46.013		
Intercept	44.893	33.2097	3.08E-212
Slope	0.028	0.8843	3.77E-01
R^2	0.00021		

Figure A-2 — Coal Steam Dataset – O&M for All MW Plant Sizes



Notes: Age coefficient in above regression equation is not statistically significant.
Sequential data points with identical values are forecasted values for the same plant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

`	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
All MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	53.90	40.06	48.77	**46.01**	440	1,448	1,865	**3,753**
Net Total Capex - 2017 $/kW	17.92	26.20	21.25	**22.78**	441	1,450	1,833	**3,724**
Net Total O&M and Capex - 2017 $/kW	71.86	66.25	69.82	**68.67**	440	1,448	1,825	**3,713**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing coal steam plants are described in Section 3.

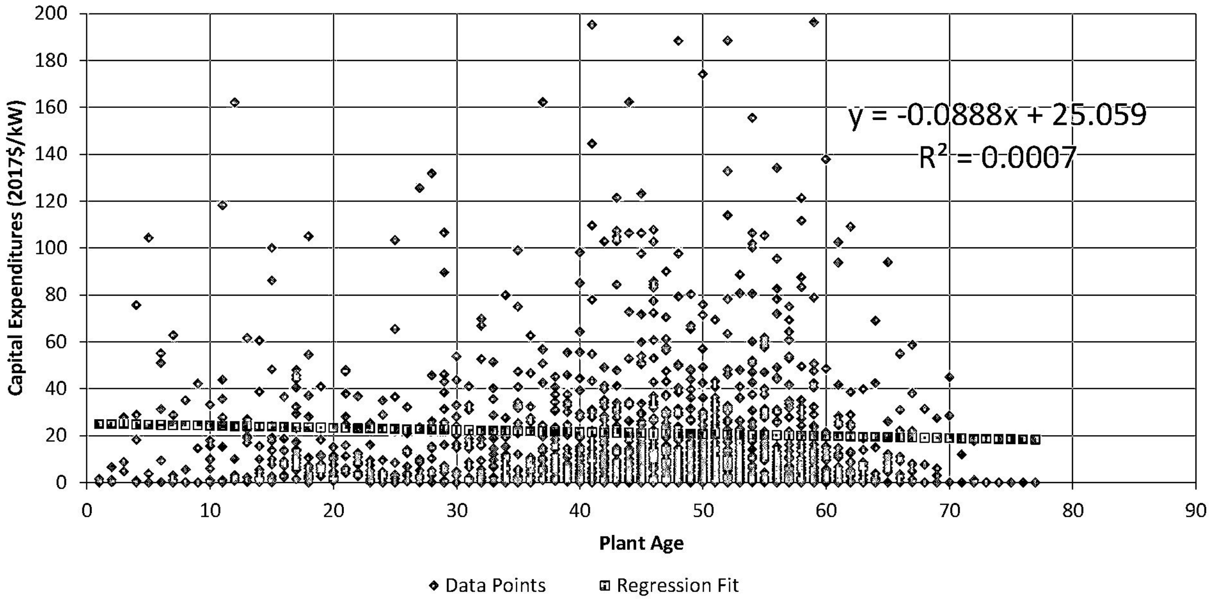
CAPITAL EXPENDITURES – LESS THAN 500 MW

The results of the linear regression analysis of CAPEX spending for coal steam plants less than 500 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.28, which is greater than 0.05, the dataset does not support age as a statistically significant predictor of CAPEX spending (on a linear trend across all plant ages).

Table A-3 — Regression Statistics – Coal CAPEX < 500 MW

		t statistic	*p-value*
Observations	1,602		
Simple Average ($/kW)	21.187		
Intercept	25.059	6.5593	7.28E-11
Slope	-0.089	-1.0685	2.85E-01
R^2	0.00071		

Figure A-3 — Coal Steam Dataset – CAPEX for Less than 500-MW Plant Size



Note: Age coefficient in above regression equation is not statistically significant.

OPERATIONS & MAINTENANCE EXPENDITURES – LESS THAN 500 MW

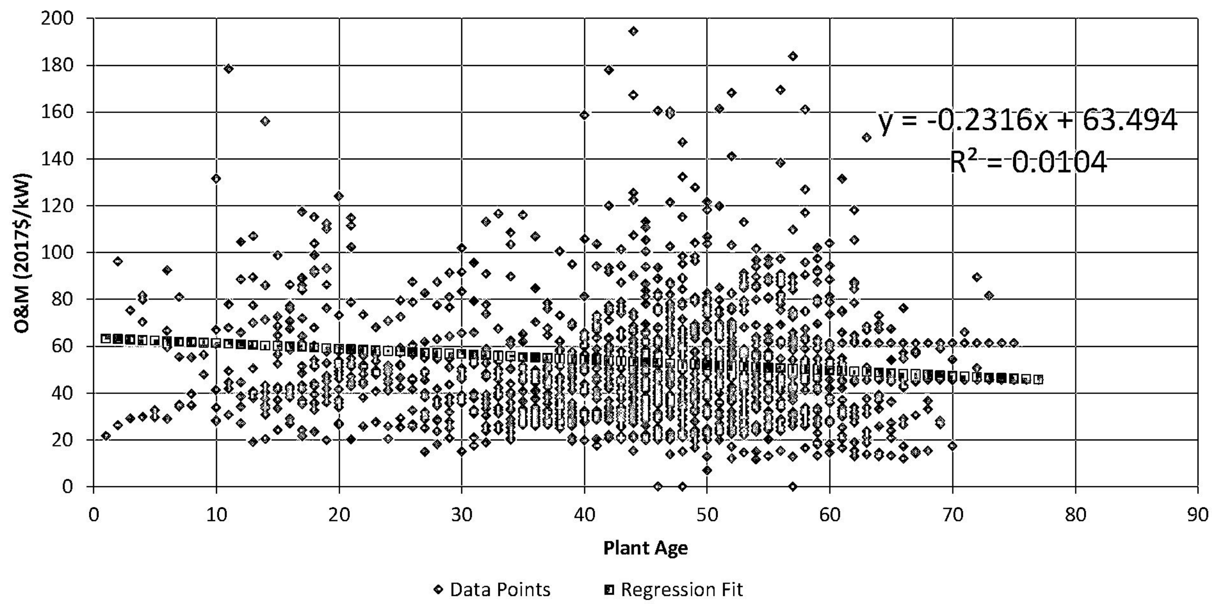
The results of the regression analysis of O&M spending for coal steam plants less than 500 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of O&M spending (on a linear trend across all plant ages). Therefore, O&M spending for this dataset may be estimated by the following regression equation:

Annual spending in 2017 $/kW-year = 63.494 + (-0.232 × age)

Table A-4 — Regression Statistics – Coal O&M < 500 MW

		t statistic	*p-value*
Observations	1,592		
Simple Average ($/kW)	53.406		
Intercept	63.494	24.4603	2.03E-112
Slope	-0.232	-4.0977	4.38E-05
R^2	0.01045		

Figure A-4 — Coal Steam Dataset – O&M for Less than 500-MW Plant Size



The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

`	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
< 500 MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	68.13	47.13	53.16	**53.41**	169	355	1,068	**1,592**
Net Total Capex - 2017 $/kW	21.01	22.83	20.67	**21.19**	169	357	1,076	**1,602**
Net Total O&M and Capex - 2017 $/kW	89.14	69.91	73.93	**74.65**	169	355	1,068	**1,592**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing coal steam plants are described in Section 3.

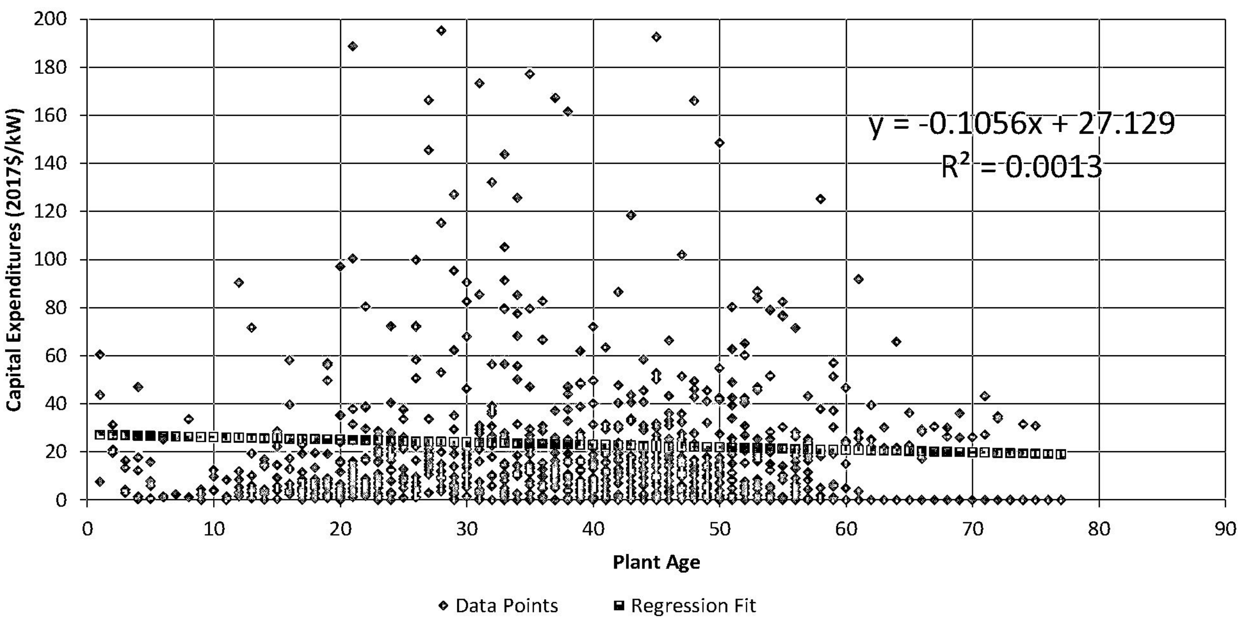
CAPITAL EXPENDITURES – BETWEEN 500 MW AND 1,000 MW

The results of the linear regression analysis of CAPEX spending for coal steam plants between 500 MW and 1,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.26, which is greater than 0.05, the dataset does not support age as a statistically significant predictor of CAPEX spending (on a linear trend across all plant ages).

Table A-5 — Regression Statistics – Coal CAPEX 500 MW to 1,000 MW

		t statistic	*p-value*
Observations	986		
Simple Average ($/kW)	23.021		
Intercept	27.129	6.8576	1.24E-11
Slope	-0.106	-1.1195	2.63E-01
R^2	0.00127		

Figure A-5 — Coal Steam Dataset – CAPEX for 500-MW to 1,000-MW Plant Size



Note: Age coefficient in above regression equation is not statistically significant.

OPERATIONS & MAINTENANCE EXPENDITURES – BETWEEN 500 MW AND 1,000 MW

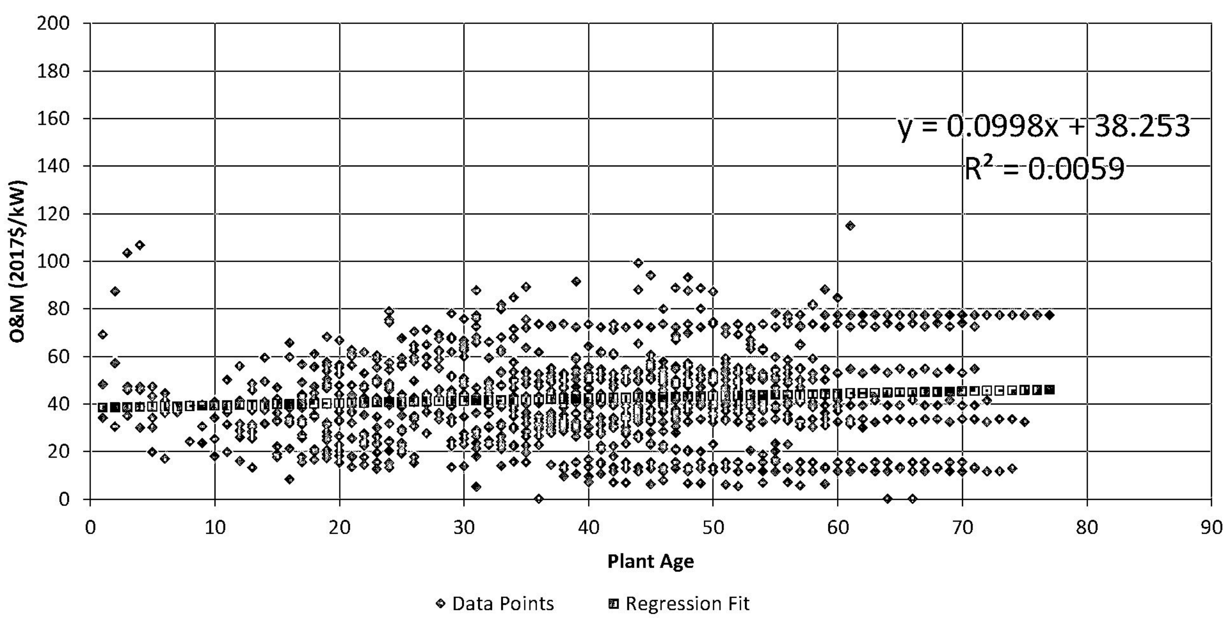
The results of the linear regression analysis of O&M spending for coal steam plants between 500 MW and 1,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of CAPEX spending (on a linear trend across all plant ages). Therefore, O&M spending for this dataset may be estimated by the regression equation:

Annual spending in 2017 $/kW-year = 38.253 + (0.100 × age)

Table A-6 — Regression Statistics – Coal O&M 500 MW to 1,000 MW

		t statistic	*p-value*
Observations	1,026		
Simple Average ($/kW)	42.223		
Intercept	38.253	22.0915	9.54E-89
Slope	0.100	2.4710	1.36E-02
R^2	0.00593		

Figure A-6 — Coal Steam Dataset – O&M for 500-MW to 1,000-MW Plant Size



Note: Sequential data points with identical values are forecasted values for the same plant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

`	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
500 MW - 1000 MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	38.15	42.09	43.40	**42.22**	138	369	519	**1,026**
Net Total Capex - 2017 $/kW	12.27	32.63	18.71	**23.02**	138	369	479	**986**
Net Total O&M and Capex - 2017 $/kW	50.41	74.72	60.65	**64.49**	138	369	479	**986**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing coal steam plants are described in Section 3.

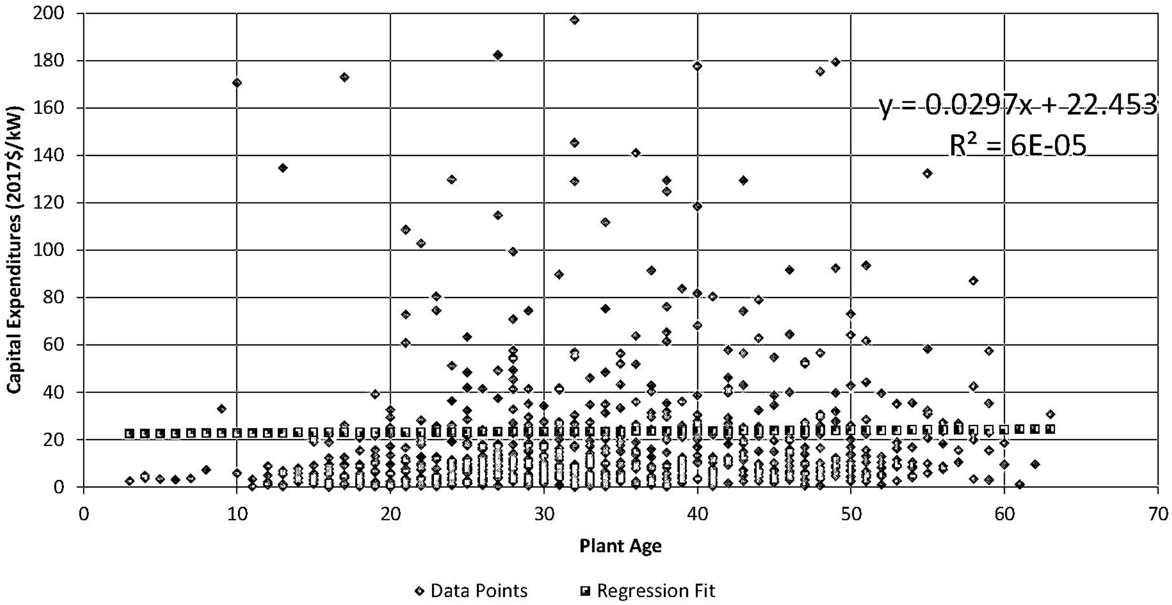
CAPITAL EXPENDITURES – BETWEEN 1,000 MW AND 2,000 MW

The results of the regression analysis of CAPEX spending for coal steam plants between 1,000 MW and 2,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient (“slope”) is 0.83, which is greater than 0.05, the dataset does not support age as a statistically significant predictor of CAPEX spending (on a linear trend across all plant ages).

Table A-7 — Regression Statistics – Coal CAPEX 1,000 MW to 2,000 MW

		t statistic	*p-value*
Observations	814		
Simple Average ($/kW)	23.448		
Intercept	22.453	4.6325	4.21E-06
Slope	0.030	0.2174	8.28E-01
R^2	0.00006		

Figure A-7 — Coal Steam Dataset – CAPEX for 1,000-MW to 2,000-MW Plant Size



Note: Age coefficient in above regression equation is not statistically significant.

OPERATIONS & MAINTENANCE EXPENDITURES – BETWEEN 1,000 MW AND 2,000 MW

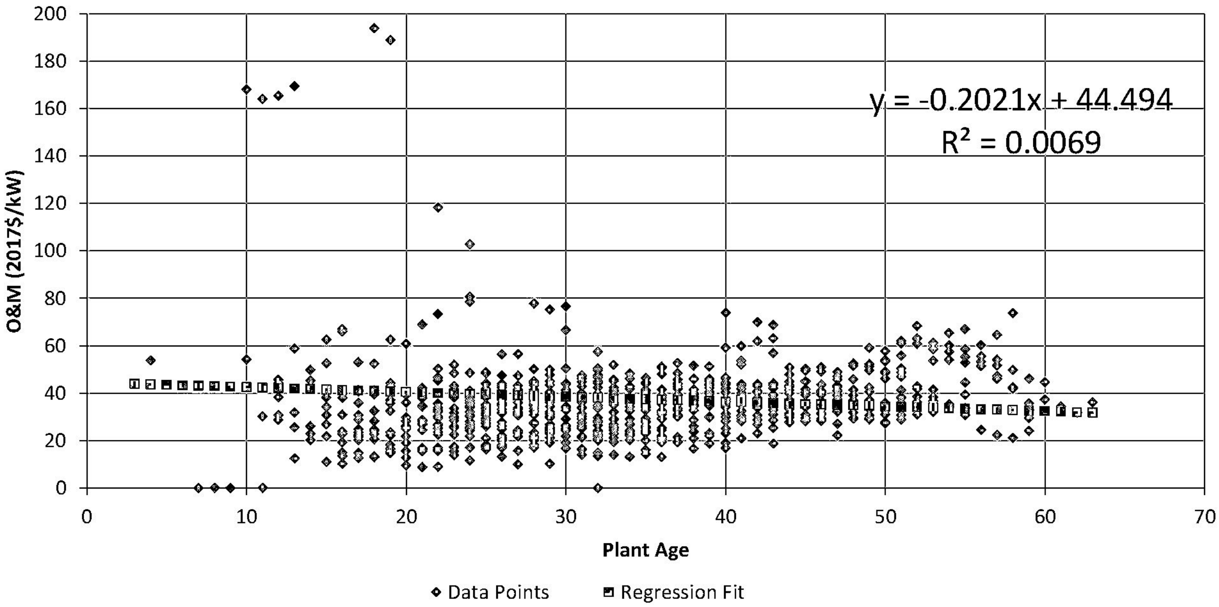
The results of the regression analysis of O&M spending for coal steam plants between 1,000 MW and 2,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of O&M spending (on a linear trend across all plant ages). Therefore, O&M spending for this dataset may be estimated by the regression equation:

Annual spending in 2017 $/kW-year = 44.494 + (-0.202 × age)

Table A-8 — Regression Statistics – Coal O&M 1,000 MW to 2,000 MW

		t statistic	*p-value*
Observations	813		
Simple Average ($/kW)	37.722		
Intercept	44.494	14.7620	7.42E-44
Slope	-0.202	-2.3785	1.76E-02
R^2	0.00693		

Figure A-8 — Coal Steam Dataset – O&M for 1,000-MW to 2,000-MW Plant Size



The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

`	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
1000 MW - 2000 MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	53.51	32.80	40.62	**37.72**	107	478	228	**813**
Net Total Capex - 2017 $/kW	22.56	23.31	24.16	**23.45**	108	478	228	**814**
Net Total O&M and Capex - 2017 $/kW	76.28	56.11	64.78	**61.20**	107	478	228	**813**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing coal steam plants are described in Section 3.

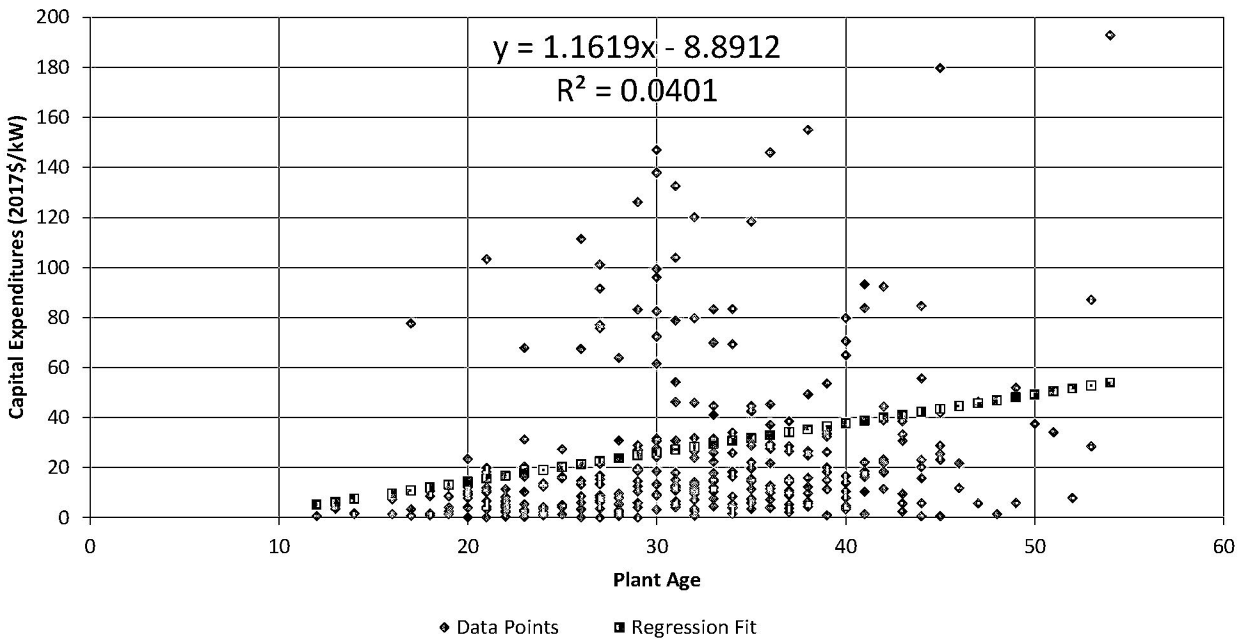
CAPITAL EXPENDITURES – GREATER THAN 2,000 MW

The results of the regression analysis of CAPEX spending for coal steam plants greater than 2,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of CAPEX spending. However, the linear regression analysis shows the intercept value (i.e., the CAPEX cost during the first year) to be less than zero. This is because of the lack of data for plant ages up to 20 years—the limited amount of data causes the regression analysis to be distorted and unrealistic.

Table A-9 — Regression Statistics – Coal CAPEX > 2,000 MW

		t statistic	*p-value*
Observations	322		
Simple Average ($/kW)	28.303		
Intercept	-8.891	-0.8468	3.98E-01
Slope	1.162	3.6556	3.00E-04
R^2	0.04009		

Figure A-9 — Coal Steam Dataset – CAPEX for Greater than 2,000-MW Plant Size



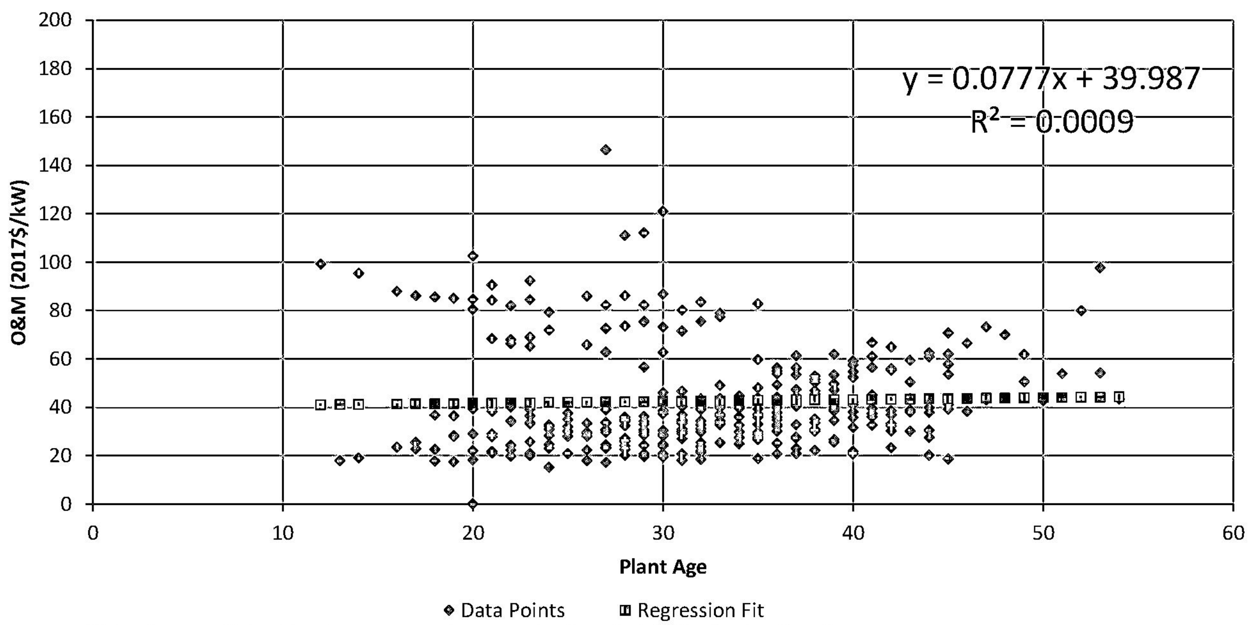
OPERATIONS & MAINTENANCE EXPENDITURES – GREATER THAN 2,000 MW

The results of the regression analysis of O&M spending for coal steam plants greater than 2,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.59, which is greater than 0.05, the dataset does not support age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages).

Table A-10 — Regression Statistics – Coal O&M > 2,000 MW

		t statistic	*p-value*
Observations	322		
Simple Average ($/kW)	42.474		
Intercept	39.987	8.3303	2.39E-15
Slope	0.078	0.5348	5.93E-01
R^2	0.00089		

Figure A-10 — Coal Steam Dataset – O&M for Greater than 2,000-MW Plant Size



Note: Age coefficient in above regression equation is not statistically significant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

`	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
> 2000 MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	46.55	40.91	48.04	**42.47**	26	246	50	**322**
Net Total Capex - 2017 $/kW	8.65	27.06	44.64	**28.30**	26	246	50	**322**
Net Total O&M and Capex - 2017 $/kW	55.20	67.97	92.67	**70.78**	26	246	50	**322**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing coal steam plants are described in Section 3.

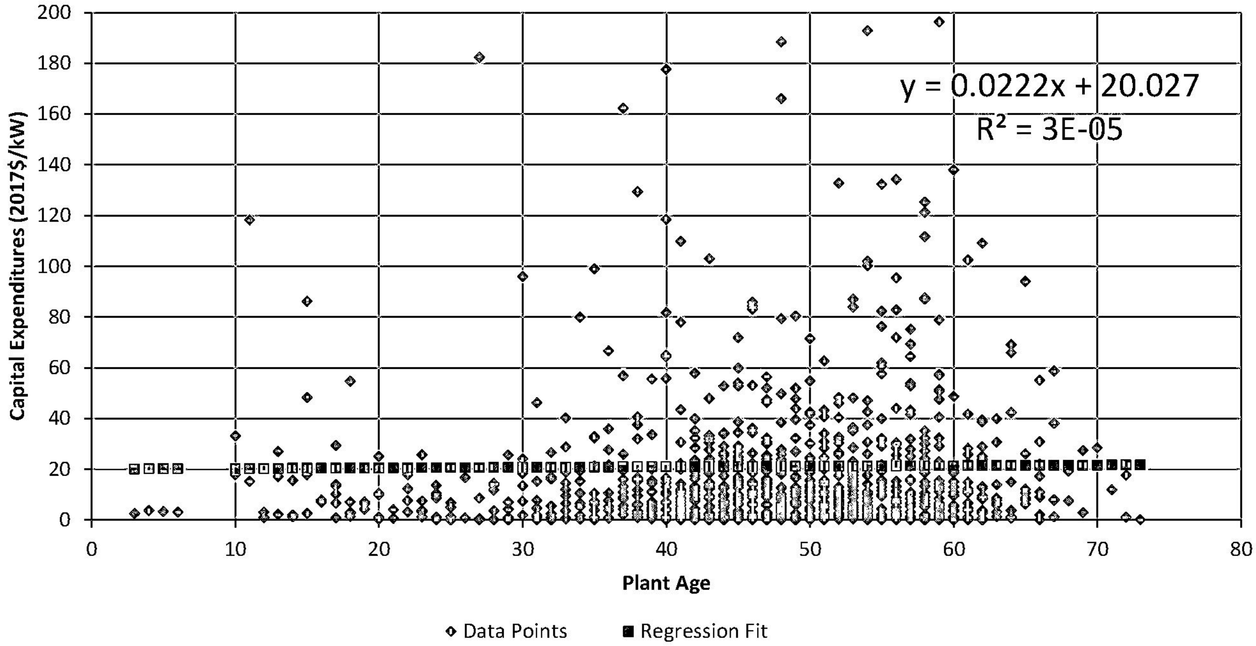
CAPITAL EXPENDITURES – CAPACITY FACTOR LESS THAN 50%

The results of the regression analysis of CAPEX spending for coal steam plants of all MW sizes and with capacity factors less than 50% are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient (“slope”) is 0.87, which is greater than 0.05, age is not a statistically significant predictor of CAPEX spending.

Table A-11 — Regression Statistics – Coal CAPEX for Capacity Factor < 50%

		t statistic	*p-value*
Observations	972		
Simple Average ($/kW)	21.063		
Intercept	20.027	3.1188	1.87E-03
Slope	0.022	0.1663	8.68E-01
R^2	0.00003		

Figure A-11 — Coal Steam Dataset – CAPEX for All Plants with Avg. Net Capacity Factor < 50%



Note: Age coefficient in above regression equation is not statistically significant.

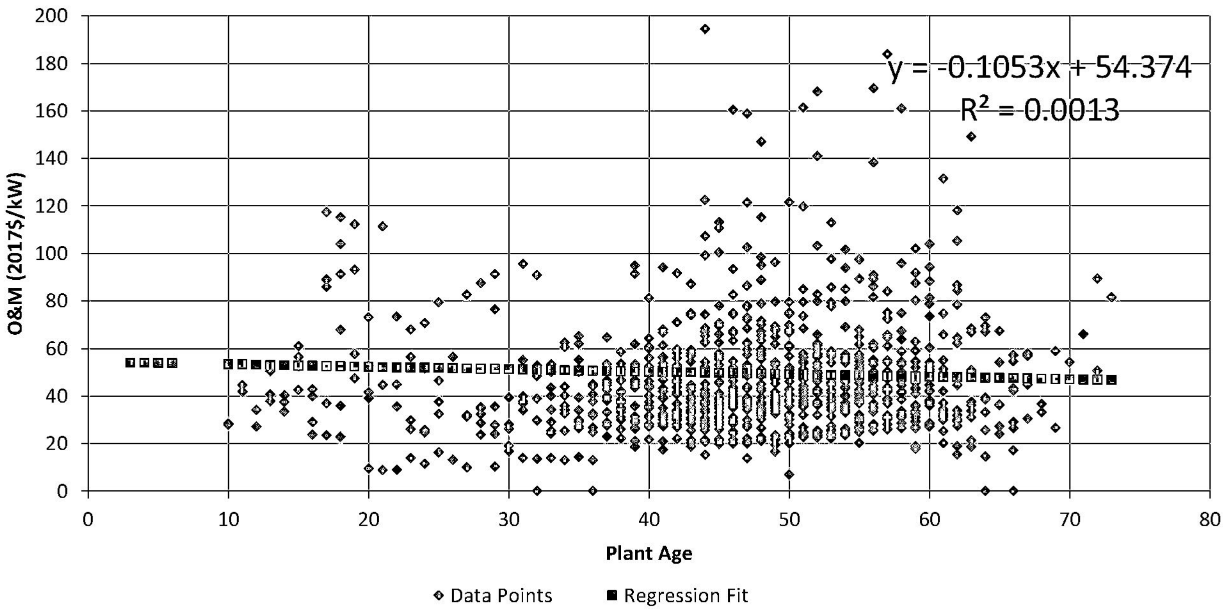
OPERATIONS & MAINTENANCE EXPENDITURES – CAPACITY FACTOR LESS THAN 50%

The results of the regression analysis of O&M spending for coal steam plants of all MW sizes and with capacity factors less than 50% are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.26, which is greater than 0.05, age is not a statistically significant predictor of O&M spending.

Table A-12 — Regression Statistics – Coal O&M for Capacity Factor < 50%

		t statistic	*p-value*
Observations	965		
Simple Average ($/kW)	49.454		
Intercept	54.374	12.0380	3.43E-31
Slope	-0.105	-1.1234	2.62E-01
R^2	0.00131		

Figure A-12 — Coal Steam Dataset – O&M for All Plants with Avg. Net Capacity Factor < 50%



Note: Age coefficient in above regression equation is not statistically significant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

`	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
All MW, Capacity Factors 0 - 50%								
Net Total O&M- 2017 $/kW	76.43	40.01	50.07	**49.45**	45	177	743	**965**
Net Total Capex - 2017 $/kW	19.62	23.74	20.51	**21.06**	45	179	748	**972**
Net Total O&M and Capex - 2017 $/kW	96.04	63.66	70.63	**70.54**	45	177	743	**965**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing coal steam plants are described in Section 3.

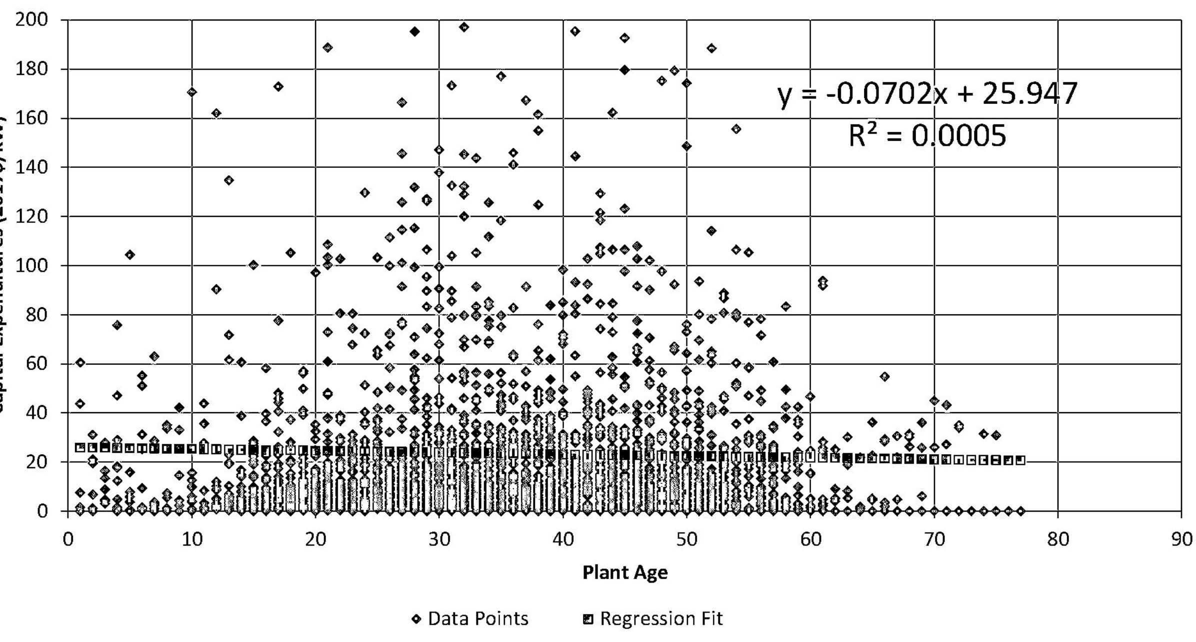
CAPITAL EXPENDITURES – CAPACITY FACTOR GREATER THAN 50%

The results of the regression analysis of CAPEX spending for coal steam plants of all MW sizes and with capacity factors greater than 50% are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.25, which is greater than 0.05, age is not a statistically significant predictor of CAPEX spending.

Table A-13 — Regression Statistics – Coal CAPEX for Capacity Factor > 50%

		t statistic	*p-value*
Observations	2752		
Simple Average ($/kW)	23.389		
Intercept	25.947	10.7905	1.29E-26
Slope	-0.070	-1.1446	2.52E-01
R^2	0.00048		

Figure A-13 — Coal Steam Dataset – CAPEX for All Plants with Avg. Net Capacity Factor > 50%



Note: Age coefficient in above regression equation is not statistically significant.

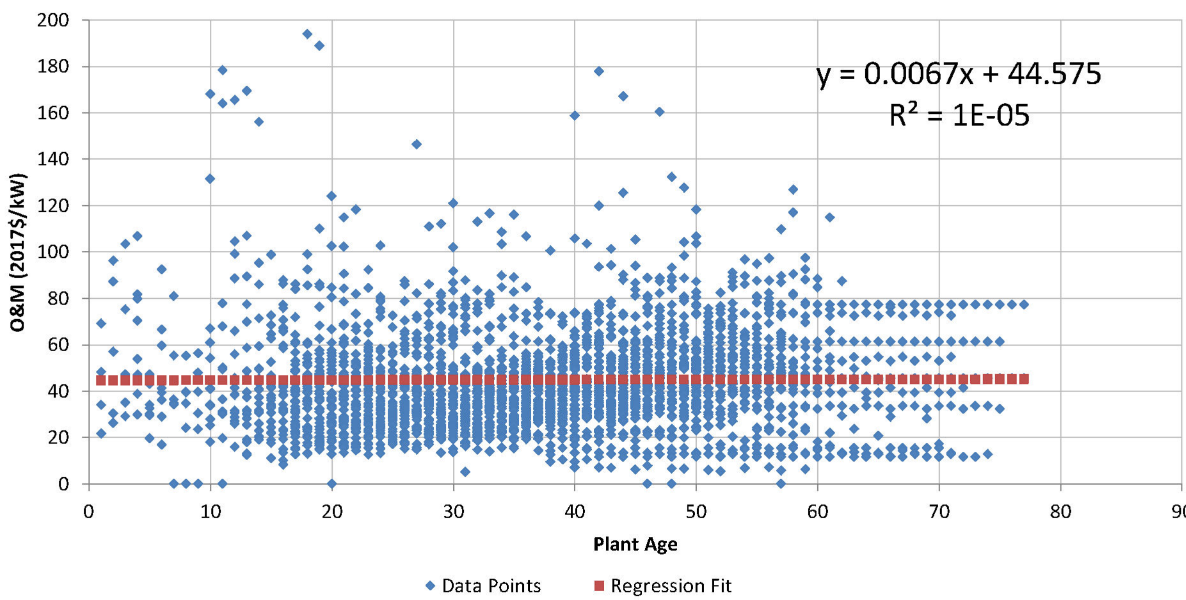
OPERATIONS & MAINTENANCE EXPENDITURES – CAPACITY FACTOR GREATER THAN 50%

The results of the regression analysis of O&M spending for coal steam plants of all MW sizes and with capacity factors greater than 50% are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient (“slope”) is 0.85, which is greater than 0.05, age is not a statistically significant predictor of O&M spending.

Table A-14 — Regression Statistics – Coal O&M for Capacity Factor > 50%

		t statistic	*p-value*
Observations	2788		
Simple Average ($/kW)	44.822		
Intercept	44.575	32.6995	8.78E-199
Slope	0.007	0.1954	8.45E-01
R^2	0.00001		

Figure A-14 — Coal Steam Dataset – O&M for All Plants with Avg. Net Capacity Factor > 50%



Notes: Age coefficient in above regression equation is not statistically significant.
Sequential data points with identical values are forecasted values for the same plant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

`	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
All MW, Capacity Factors 50% - 100%								
Net Total O&M- 2017 $/kW	51.33	40.07	47.92	**44.82**	395	1,271	1,122	**2,788**
Net Total Capex - 2017 $/kW	17.73	26.55	21.75	**23.39**	396	1,271	1,085	**2,752**
Net Total O&M and Capex - 2017 $/kW	69.11	66.62	69.25	**68.01**	395	1,271	1,082	**2,748**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing coal steam plants are described in Section 3.

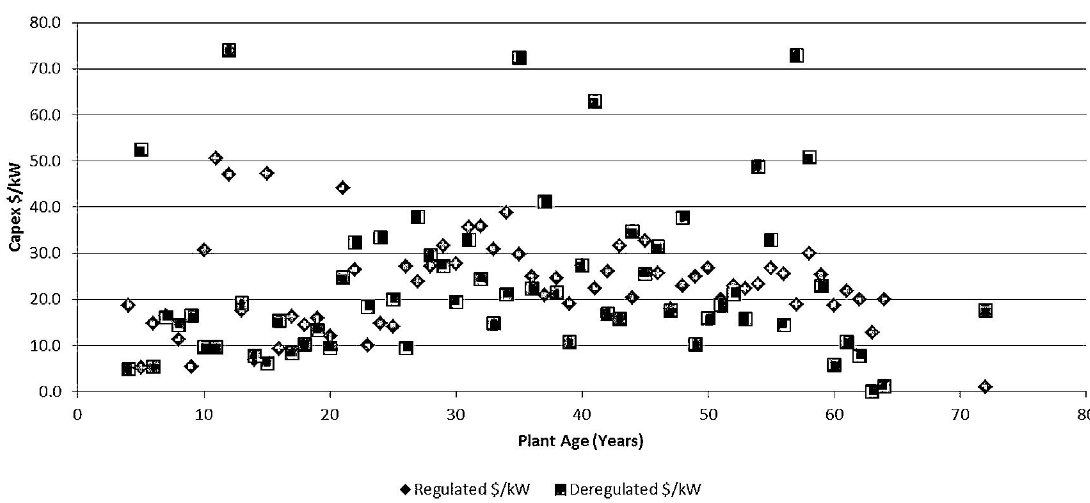
CAPITAL EXPENDITURES – REGULATED VS. DEREGULATED

The results of the regression analysis of CAPEX spending for coal steam plants of all MW sizes (full dataset) in regulated versus deregulated locations are summarized in the table below. Since the p-value for the age ("slope") and regulation/deregulation coefficients are much greater than 0.05, age and regulatory status are not statistically significant predictors of CAPEX spending.

Table A-15 — Regression Statistics – Coal CAPEX for Regulated/Deregulated

	Coefficients	Standard Error	t Stat	P-Value
Intercept	23.22826383	2.9645403	7.835367875	6.36821E-15
Age	0.097334249	0.064355791	1.512439626	0.130523796
Reg./Dereg. (1/0)	-2.479225741	2.148990587	-1.153669893	0.248724297

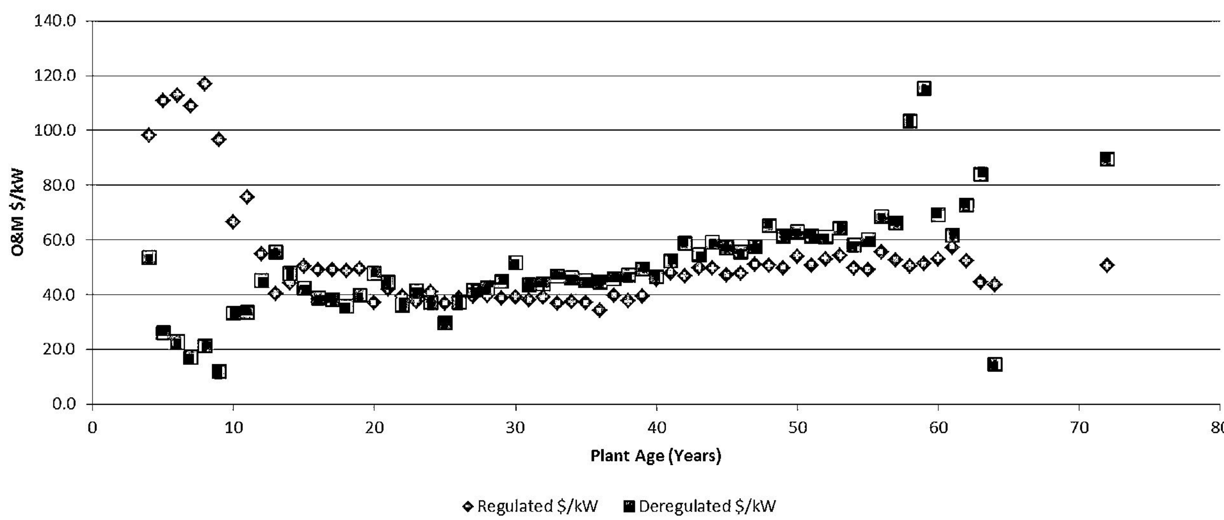
Figure A-15 — Coal Steam Dataset – CAPEX for Regulated/Deregulated



OPERATIONS & MAINTENANCE EXPENDITURES – REGULATED VS. DEREGULATED

The regression analysis of O&M expenditures indicates that the p-value for the age ("slope") and regulated/deregulated coefficients are much less than 0.05 (i.e., statistically significant). However, the outliers before year 20 may tend to distort the regression analysis. After year 20, a visual inspection of the data points indicates higher O&M spending in deregulated states compared with regulated states (Figure A-16). This is the opposite of what would be expected, whereby plant owners in a deregulated environment would have a greater incentive to reduce O&M costs that cannot be passed through to ratepayers. The higher O&M spending is likely a result of other factors, such as higher average labor costs in deregulated states, which tend to have a higher percentage of union labor compared with regulated states. Therefore, the net effect of regulatory status on average O&M spending is not apparent at this level of detail.

Figure A-16 — Coal Steam Dataset – O&M for Regulated vs. Deregulated



CAPITAL EXPENDITURES – FGD VS. NO FGD

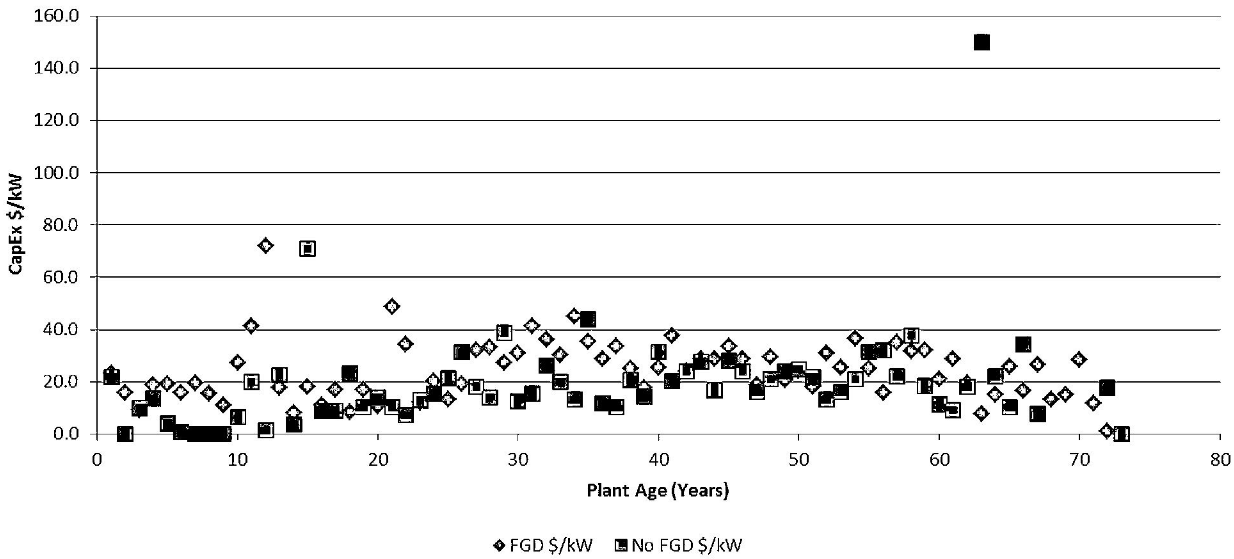
The results of the regression analysis of CAPEX spending for coal steam plants of all MW sizes (full dataset) with and without FGD are summarized in the table below. The p-value for the age ("slope") coefficient is slightly greater than 0.05 (nearly statistically significant) while the p-value for the FGD/no-FGD coefficient is much less than 0.05 (statistically significant). A visual inspection of the difference between the FGD and no-FGD data points in Figure A-17 shows a similarity in CAPEX spending amounts across all ages. Therefore, average CAPEX spending may be represented by the following regression equation:

Annual CAPEX spending in 2017 $/kW-year = 16.53 + (0.126 × age) + (5.68 × FGD)
Where FGD = 1 if plant has FGD; zero otherwise

Table A-16 — Regression Statistics – Coal CAPEX for FGD/No FGD

	Coefficients	Standard Error	t Stat	P-Value
Intercept	16.52586075	3.06139723	5.39814323	7.2399E-08
Age	0.126266024	0.065143952	1.93826166	0.05268181
FGD/No FGD (1/0)	5.6788887	1.913609818	2.96763146	0.00302395

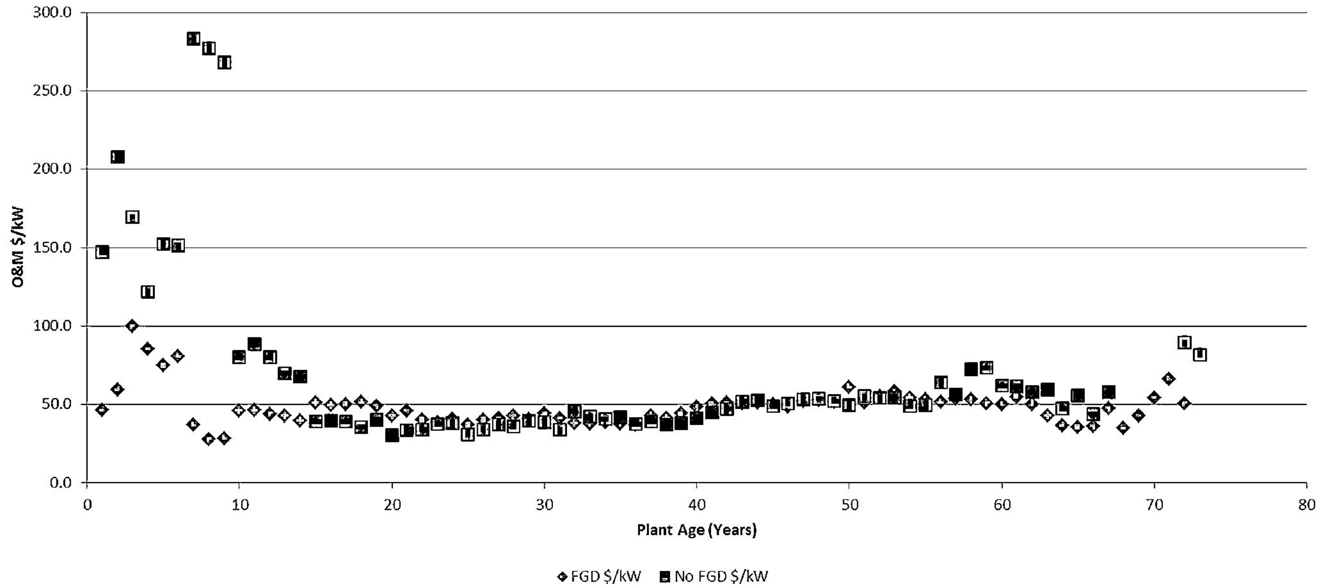
Figure A-17 — Coal Steam Dataset – CAPEX for FGD/No FGD



OPERATIONS & MAINTENANCE EXPENDITURES – FGD VS. NO FGD

The regression analysis of O&M expenditures indicates that the p-value for the age ("slope") and FGD/no-FGD coefficients are much less than 0.05 (i.e., statistically significant). However, outliers before year 15 may tend to distort the regression analysis. A visual inspection of the difference between the FGD and no-FGD data points in Figure A-18 shows a similarity in O&M spending amounts across all ages after year 15. The differences in annual coal plant spending due to having FGD is more significant in the CAPEX accounts, as shown in the previous subsection, rather than the O&M accounts.

Figure A-18 — Coal Steam Dataset – O&M for FGD vs. No FGD



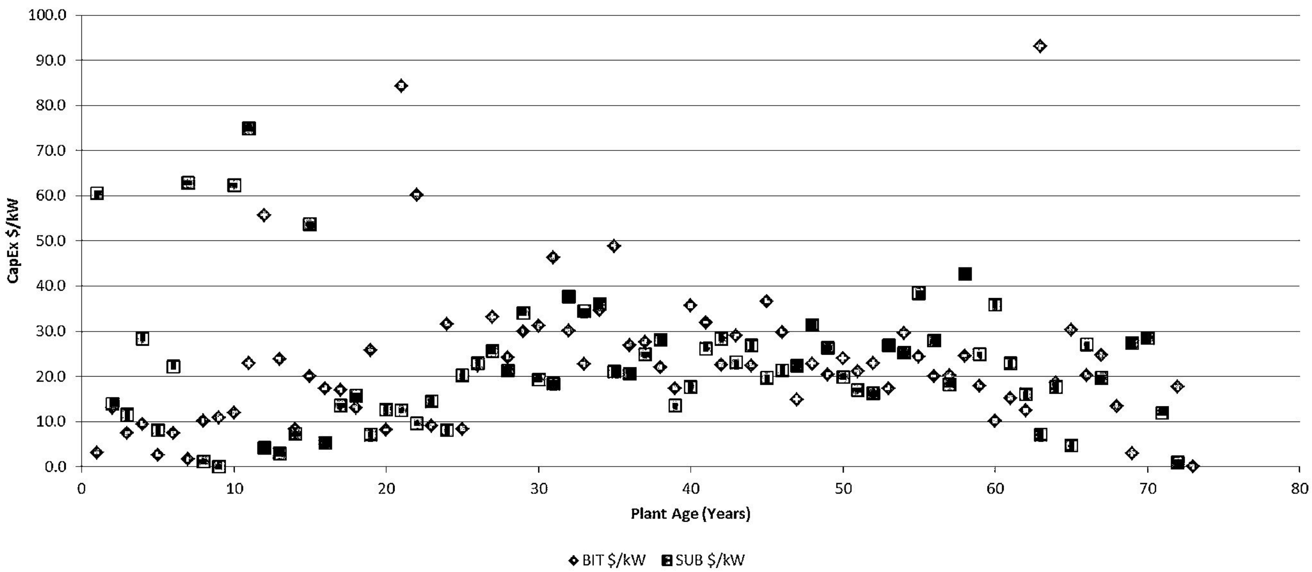
CAPITAL EXPENDITURES – BITUMINOUS VS. SUBBITUMINOUS

The results of the regression analysis of CAPEX spending for coal steam plants of all MW sizes (full dataset) in bituminous versus subbituminous coal types are summarized in the table below. The p-value for the age ("slope") coefficient is much greater than 0.05 (not statistically significant), while the p-value for the bituminous/subbituminous coefficient is much less than 0.05 (statistically significant). However, the outliers before year 20 may tend to distort the regression analysis. Further, a visual inspection of the difference between the bituminous and subbituminous data points in Figure A-19 shows a similarity in CAPEX spending amounts across all ages. Therefore, average CAPEX spending is not likely affected by coal type at a high-level designation (i.e., bituminous/subbituminous) without more detailed coal specifications.

Table A-17 — Regression Statistics – Coal CAPEX for Bituminous/Subbituminous

	Coefficients	Standard Error	t Stat	P-Value
Intercept	15.39252046	2.257695952	6.817800442	1.08205E-11
Age	-0.00350504	0.054578287	-0.064220408	0.948798346
Bit./Sub. (1/0)	10.93481186	1.525466511	7.168175624	9.20398E-13

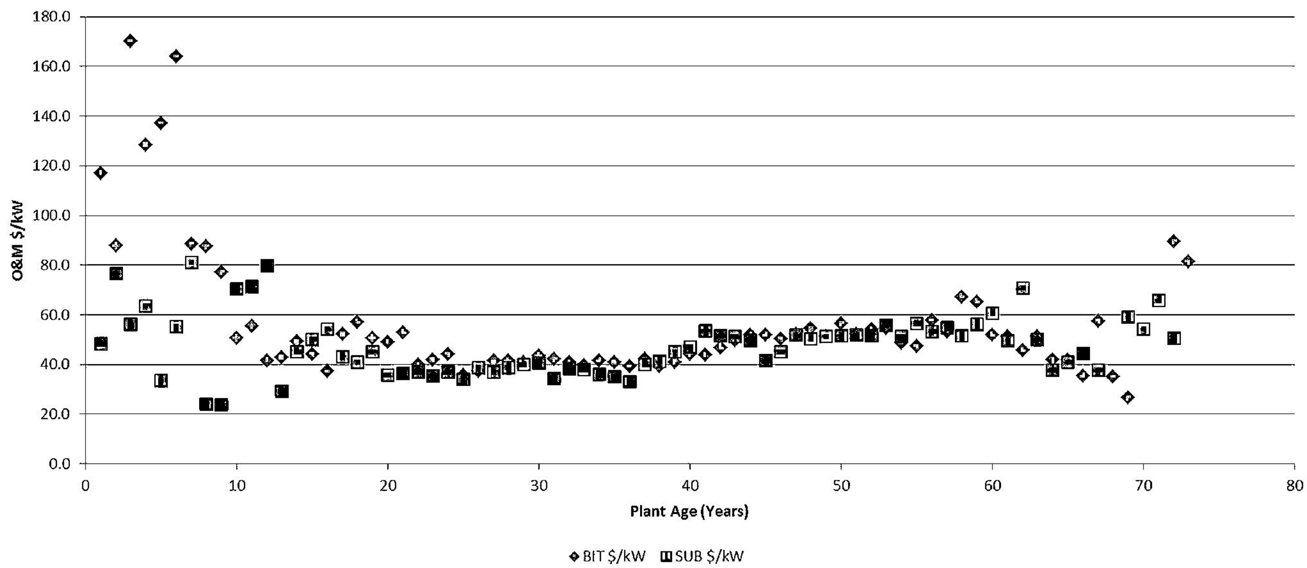
Figure A-19 — Coal Steam Dataset – CAPEX for Bituminous/Subbituminous



OPERATIONS & MAINTENANCE EXPENDITURES – BITUMINOUS VS. SUBBITUMINOUS

The regression analysis of O&M expenditures indicates that the p-value for the age ("slope") and bituminous/subbituminous coefficients are much less than 0.05 (statistically significant). However, as with CAPEX spending, the outliers before year 20 may tend to distort the regression analysis. Further, a visual inspection of the difference between the bituminous and subbituminous data points in Figure A-20 shows a similarity in O&M spending amounts across all ages. Therefore, average O&M spending is not likely affected by coal type at a high-level designation (i.e., bituminous/subbituminous) without more detailed coal specifications.

Figure A-20 — Coal Steam Dataset – O&M for Bituminous vs. Subbituminous



EFFECT OF PLANT CAPACITY FACTOR

CAPEX and O&M spending for the coal steam plants increased significantly with age when expressed on a $/MWh basis. This was primarily a result of significant declines in plant capacity factors over time. Figure A-21 and Figure A-22 indicate real annual increases in CAPEX and O&M spending for the coal steam plants in constant 2017 $/MWh versus plant age, with linear regression results as follows:

- Annual CAPEX in 2017 $/MWh = 3.27 + (0.0426 × age)
- Annual O&M in 2017 $/MWh = 5.44 + (0.133 × age)

Figure A-21 — CAPEX vs. Age for All MW Coal Plants (2017 $/MWh)

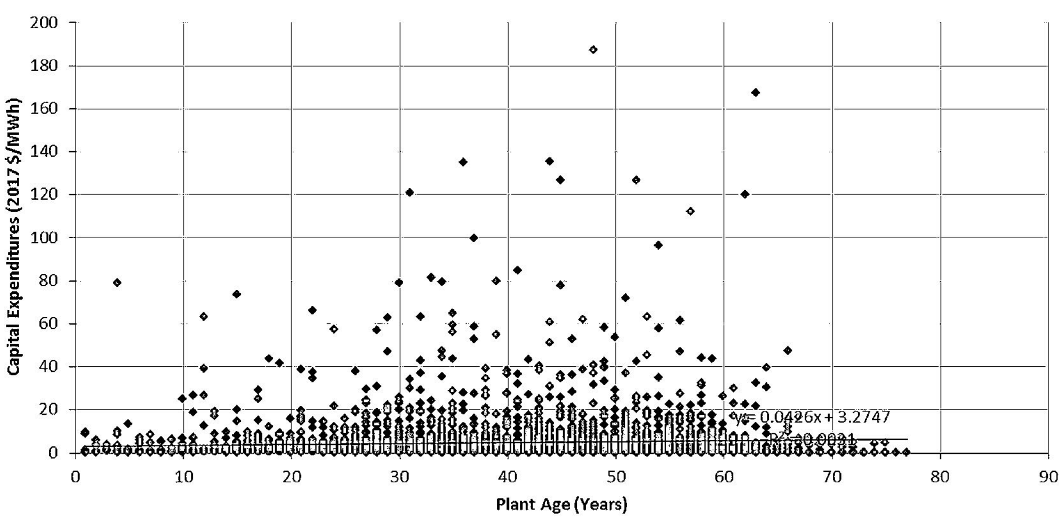
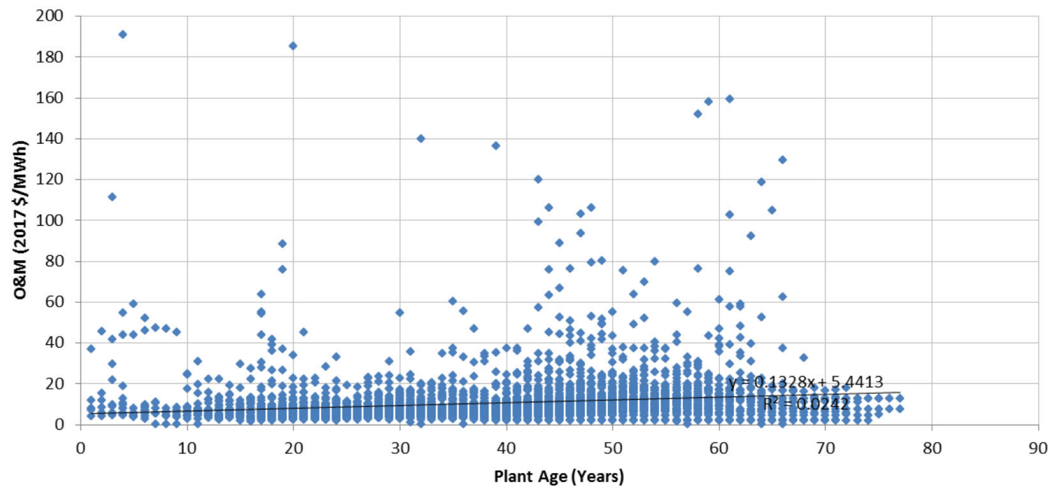


Figure A-22 — O&M vs. Age for All Coal Plants (2017 $/MWh)



In both of the above regression results, the age coefficient was found to be statistically significant. This was determined to be a result of the average decline in capacity factors for the coal steam plants, as shown in Figure A-23. A similar decline also occurred with the gas/oil steam plants, as shown in Figure A-24.

Figure A-23 — Capacity Factor vs. Age for All Coal Plants

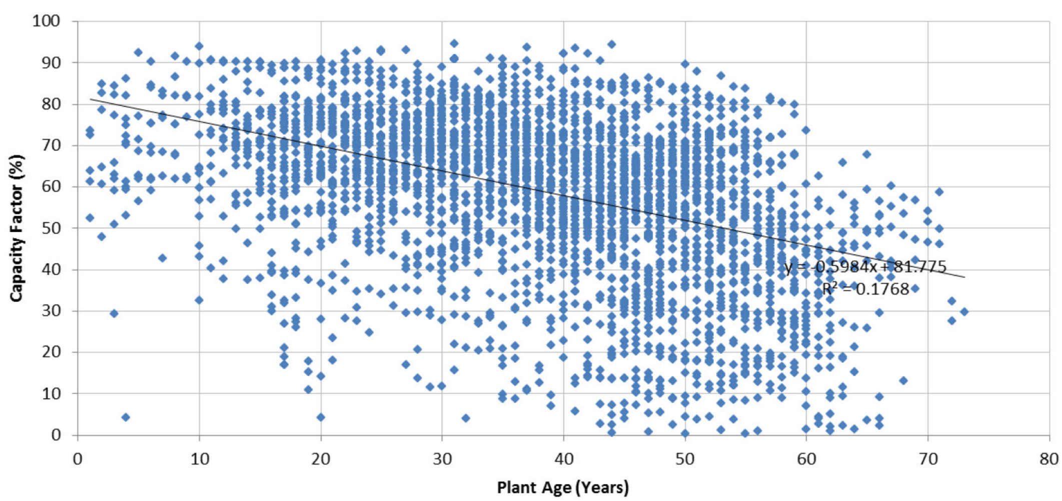


Figure A-24 — Capacity Factor vs. Age for All Gas/Oil Steam Plants

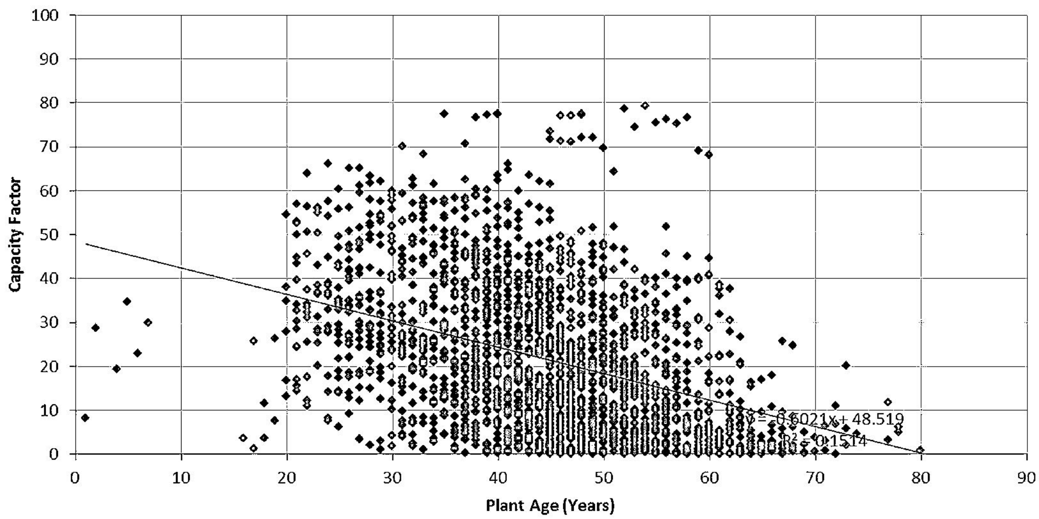


Exhibit DG-6

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Appendix B. Regression Analysis – Gas/Oil Steam

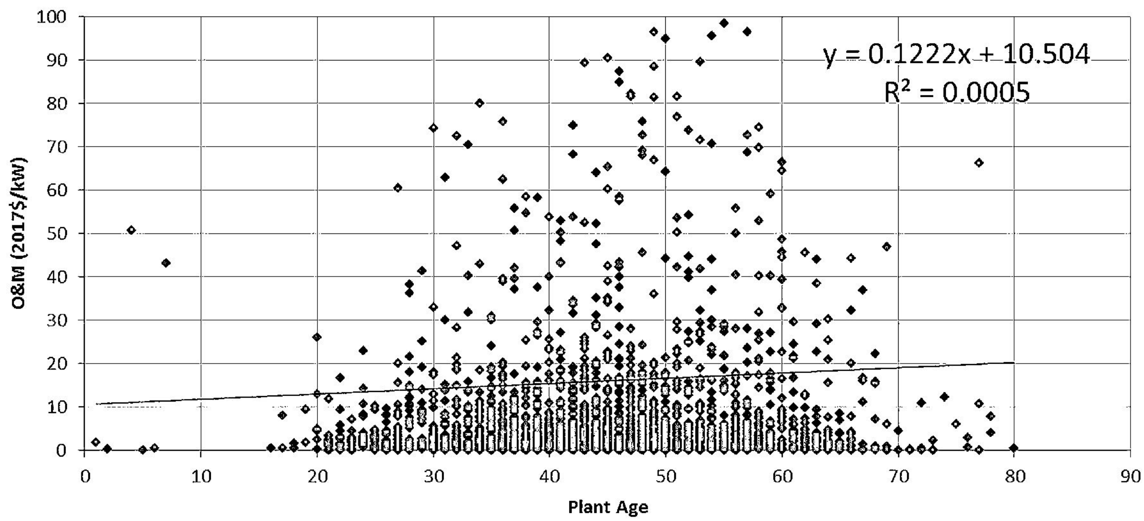
CAPITAL EXPENDITURES – ALL PLANT SIZES

The results of the regression analysis of CAPEX spending for gas/oil steam plants of all MW sizes (full dataset) are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.29, which is greater than 0.05, age is not a statistically significant predictor of CAPEX spending.

Table B-1 — Regression Statistics – Gas/Oil Steam CAPEX for All MW

		t statistic	*p-value*
Observations	2,226		
Simple Average ($/kW)	15.955		
Intercept	10.504	1.9741	4.85E-02
Slope	0.122	1.0551	2.91E-01
R^2	0.00050		

Figure B-1 — Gas/Oil Steam Dataset – CAPEX for All Plant MW Sizes



Note: Age coefficient in above regression equation is not statistically significant.

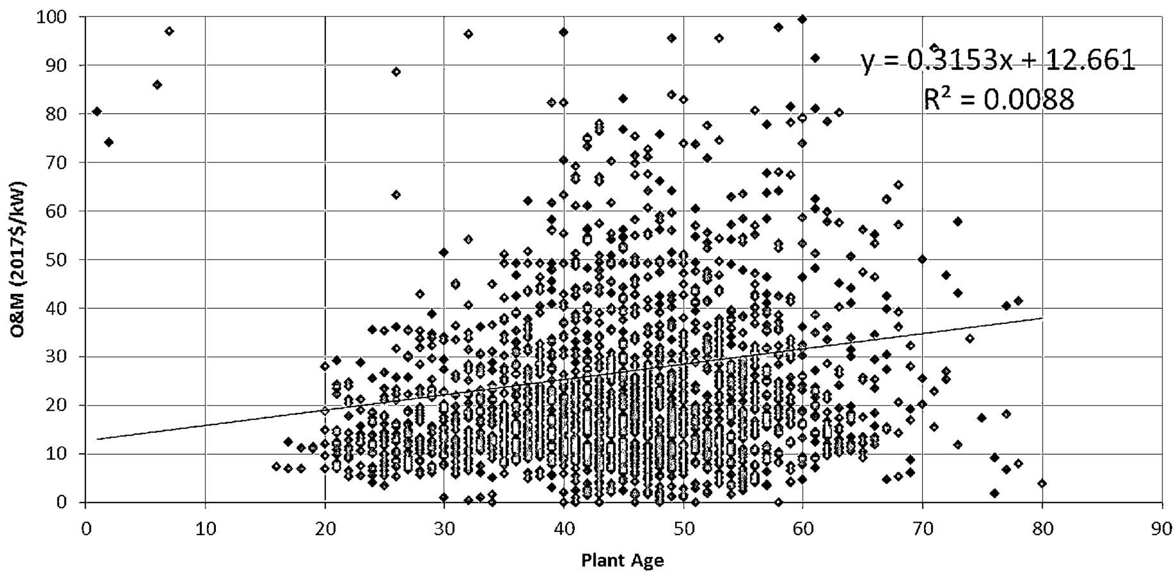
OPERATIONS & MAINTENANCE EXPENDITURES – ALL PLANT SIZES

The results of the linear regression analysis of O&M spending for gas/oil steam plants of all MW sizes (full dataset) are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of O&M spending (on a linear trend across all plant ages). However, the limited number of data points before year 20 may distort the regression analysis.

Table B-2 — Regression Statistics – Gas/Oil Steam O&M for All MW

		t statistic	*p-value*
Observations	2,224		
Simple Average ($/kW)	26.723		
Intercept	12.661	3.8863	1.05E-04
Slope	0.315	4.4455	9.20E-06
R^2	0.00882		

Figure B-2 — Gas/Oil Steam Dataset – O&M for All Plant MW Sizes



Note: Sequential data points with identical values are forecasted values for the same plant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
All MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	39.39	23.48	28.18	**26.72**	19	733	1,472	**2,224**
Net Total Capex - 2017 $/kW	8.91	14.18	16.93	**15.96**	19	733	1,474	**2,226**
Net Total O&M and Capex - 2017 $/kW	48.30	37.53	45.10	**42.63**	19	731	1,470	**2,220**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing gas/oil steam plants are described in Section 4.

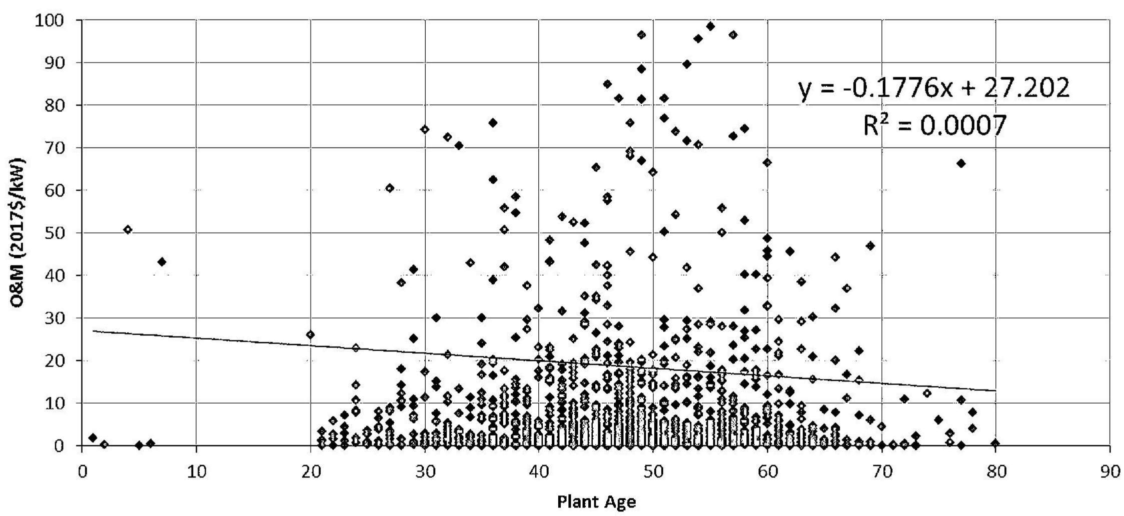
CAPITAL EXPENDITURES – LESS THAN 500 MW

The results of the regression analysis of CAPEX spending for gas/oil steam plants less than 500 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.32, which is greater than 0.05, age is not a statistically significant predictor of CAPEX spending.

Table B-3 — Regression Statistics – Gas/Oil Steam CAPEX < 500 MW

		t statistic	*p-value*
Observations	1382		
Simple Average ($/kW)	18.392		
Intercept	27.202	3.1265	1.81E-03
Slope	-0.178	-0.9867	3.24E-01
R^2	0.00071		

Figure B-3 — Gas/Oil Steam Dataset – CAPEX for Less than 500-MW Plant Size



Note: Age coefficient in above regression equation is not statistically significant.

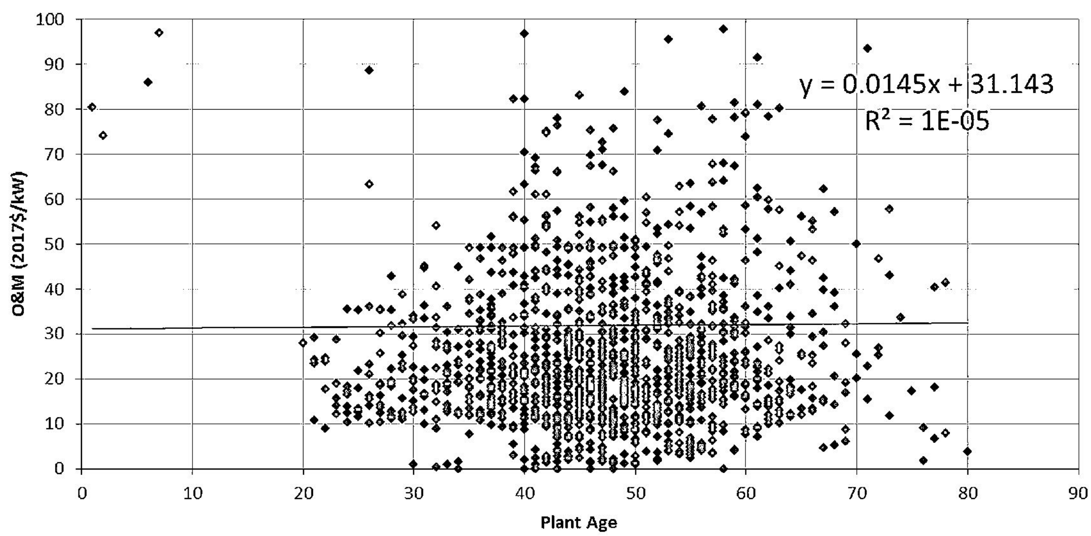
OPERATIONS & MAINTENANCE EXPENDITURES – LESS THAN 500 MW

The results of the linear regression analysis of O&M spending for gas/oil steam plants less than 500 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.90, which is greater than 0.05, age is not a statistically significant predictor of O&M spending (on a linear trend across all plant ages).

Table B-4 — Regression Statistics – Gas/Oil Steam O&M < 500 MW

		t statistic	*p-value*
Observations	1,381		
Simple Average ($/kW)	31.827		
Intercept	31.143	5.7925	8.58E-09
Slope	0.015	0.1305	8.96E-01
R^2	0.00001		

Figure B-4 — Gas/Oil Steam Dataset – O&M for Less than 500-MW Plant Size



Notes: Age coefficient in above regression equation is not statistically significant.
Sequential data points with identical values are forecasted values for the same plant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
< 500 MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	88.54	33.36	30.98	**31.83**	7	324	1,050	**1,381**
Net Total Capex - 2017 $/kW	17.44	22.13	17.82	**18.83**	7	324	1,051	**1,382**
Net Total O&M and Capex - 2017 $/kW	105.98	55.32	48.78	**50.60**	7	322	1,048	**1,377**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing gas/oil steam plants are described in Section 4.

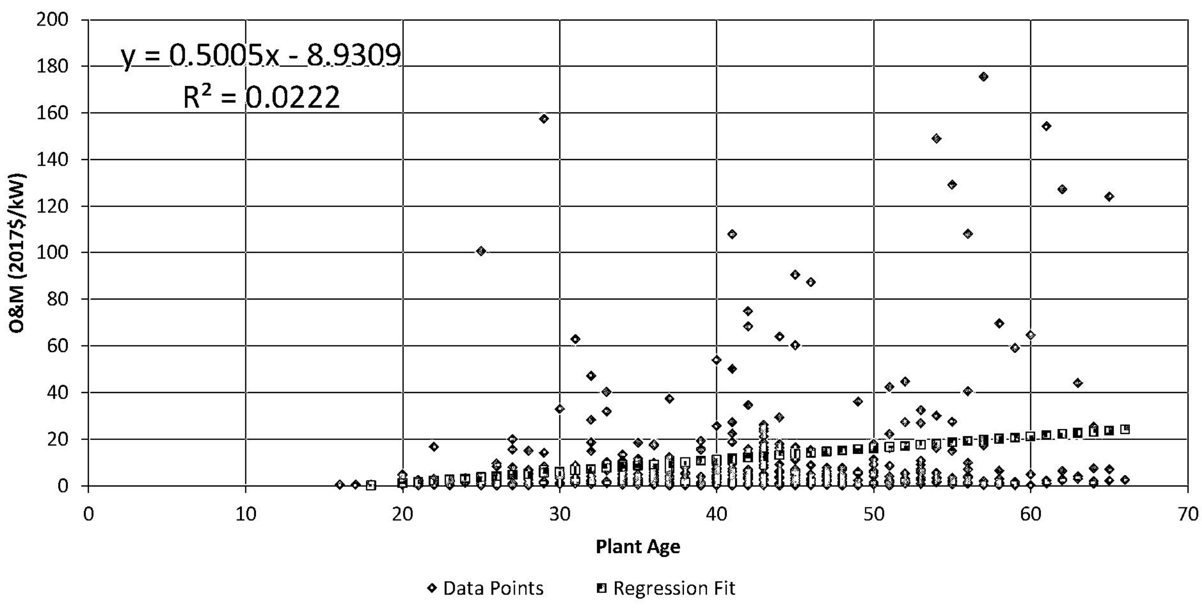
CAPITAL EXPENDITURES – BETWEEN 500 MW AND 1,000 MW

The results of the regression analysis of CAPEX spending for gas/oil steam plants between 500 MW and 1,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of CAPEX spending. However, the regression analysis shows the intercept value (i.e., the CAPEX cost during the first year) to be less than zero. This is because of the lack of data for plant ages up to 20 years—the limited amount of data causes the regression analysis to be distorted and unrealistic.

Table B-5 — Regression Statistics – Gas/Oil Steam CAPEX 500 MW to 1,000 MW

		t statistic	*p-value*
Observations	489		
Simple Average ($/kW)	11.570		
Intercept	-8.988	-1.4118	1.59E-01
Slope	0.501	3.3322	9.27E-04
R^2	0.02229		

Figure B-5 — Gas/Oil Steam Dataset – CAPEX for 500-MW to 1,000-MW Plant Size



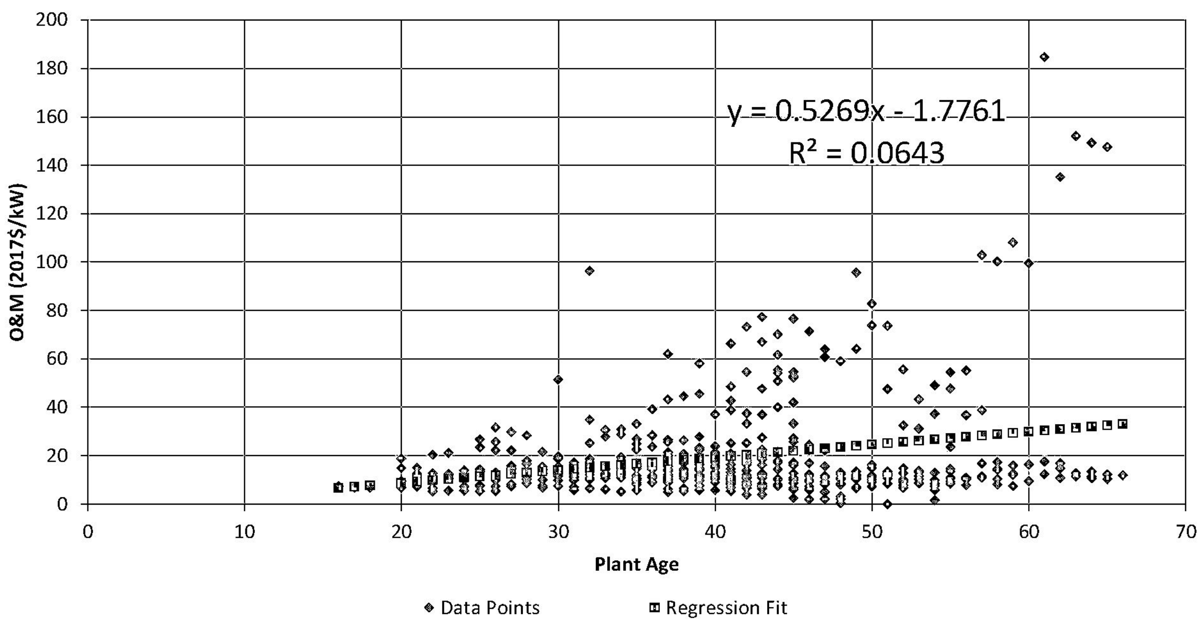
OPERATIONS & MAINTENANCE EXPENDITURES – BETWEEN 500 MW AND 1,000 MW

The results of the regression analysis of O&M spending for gas/oil steam plants between 500 MW and 1,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of O&M spending. However, the regression analysis shows the intercept value (i.e., the O&M cost during the first year) to be less than zero. This is because of the lack of data for plant ages up to 20 years—the limited data causes the regression analysis to be distorted.

Table B-6 — Regression Statistics – Gas/Oil Steam O&M 500 MW to 1,000 MW

		t statistic	*p-value*
Observations	488		
Simple Average ($/kW)	19.823		
Intercept	-1.776	-0.4606	6.45E-01
Slope	0.527	5.7810	1.33E-08
R^2	0.06434		

Figure B-6 — Gas/Oil Steam Dataset – O&M for 500-MW to 1,000-MW Plant Size



The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
500 MW - 1000 MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	10.10	15.82	23.61	**19.82**	7	225	256	**488**
Net Total Capex - 2017 $/kW	1.94	6.32	16.43	**11.57**	7	225	257	**489**
Net Total O&M and Capex - 2017 $/kW	12.04	22.14	40.07	**31.40**	7	225	256	**488**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing gas/oil steam plants are described in Section 4.

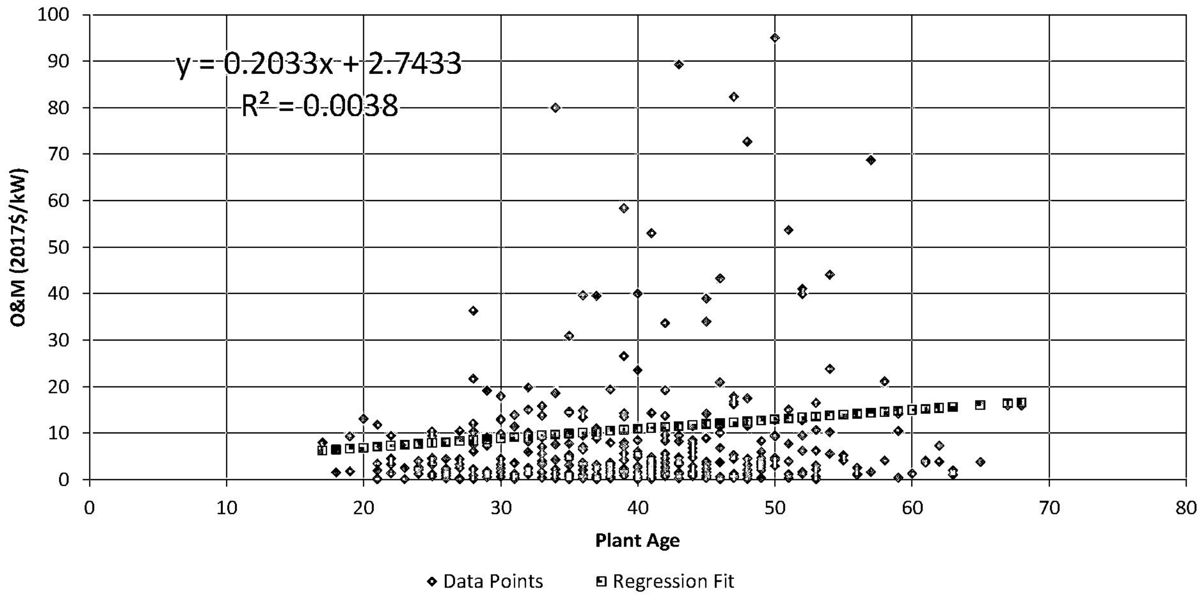
CAPITAL EXPENDITURES – GREATER THAN 1,000 MW

The results of the regression analysis of CAPEX spending for gas/oil steam plants greater than 1,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.24, which is greater than 0.05, age is not a statistically significant predictor of CAPEX spending.

Table B-7 — Regression Statistics – Gas/Oil Steam CAPEX > 1,000 MW

		t statistic	*p-value*
Observations	355		
Simple Average ($/kW)	10.815		
Intercept	2.743	0.3846	7.01E-01
Slope	0.203	1.1660	2.44E-01
R^2	0.00384		

Figure B-7 — Gas/Oil Steam Dataset – CAPEX for Greater than 1,000-MW Plant Size



Note: Age coefficient in above regression equation is not statistically significant.

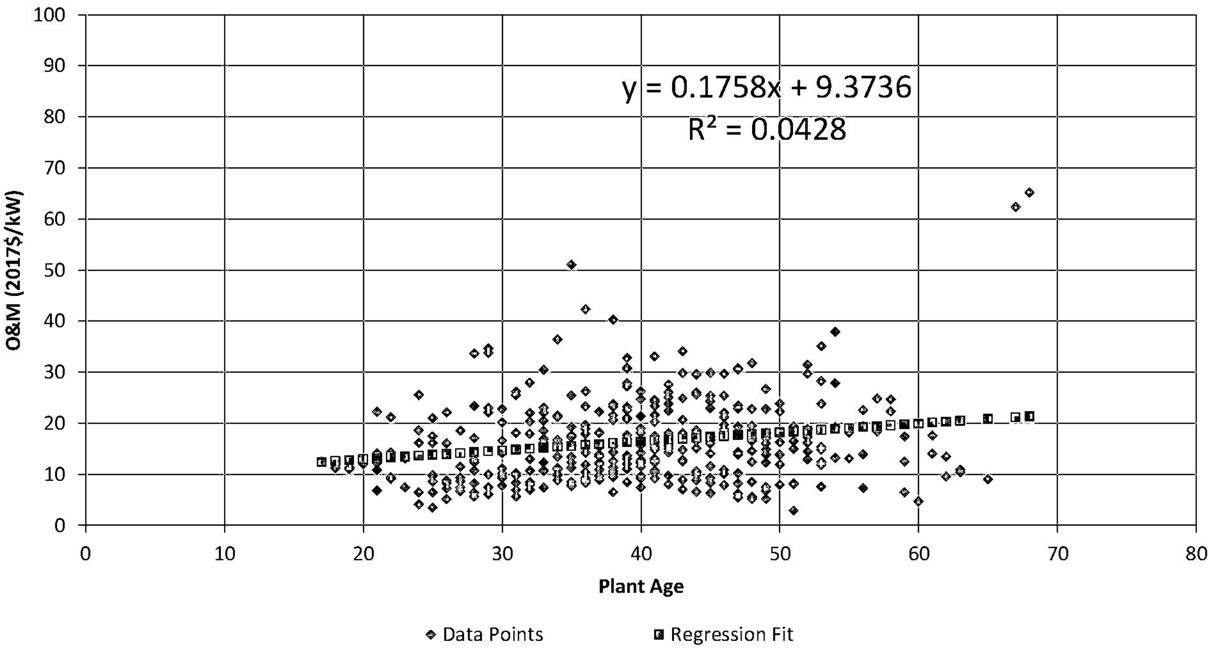
OPERATIONS & MAINTENANCE EXPENDITURES – GREATER THAN 1,000 MW

The results of the regression analysis of O&M spending for gas/oil steam plants greater than 1,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of O&M spending (on a linear trend across all plant ages). However, the limited number of data points before year 20 may distort the regression analysis.

Table B-8 — Regression Statistics – Gas/Oil Steam O&M > 1,000 MW

		t statistic	*p-value*
Observations	355		
Simple Average ($/kW)	16.353		
Intercept	9.374	5.1812	3.71E-07
Slope	0.176	3.9752	8.53E-05
R^2	0.04285		

Figure B-8 — Gas/Oil Steam Dataset – O&M for Greater than 1,000-MW Plant Size



The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
> 1000 MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	11.59	15.44	17.50	**16.35**	5	184	166	**355**
Net Total Capex - 2017 $/kW	6.70	9.78	12.09	**10.82**	5	184	166	**355**
Net Total O&M and Capex - 2017 $/kW	18.29	25.22	29.60	**27.17**	5	184	166	**355**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing gas/oil steam plants are described in Section 4.

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Appendix C. Regression Analysis – Gas/Oil Combined Cycle

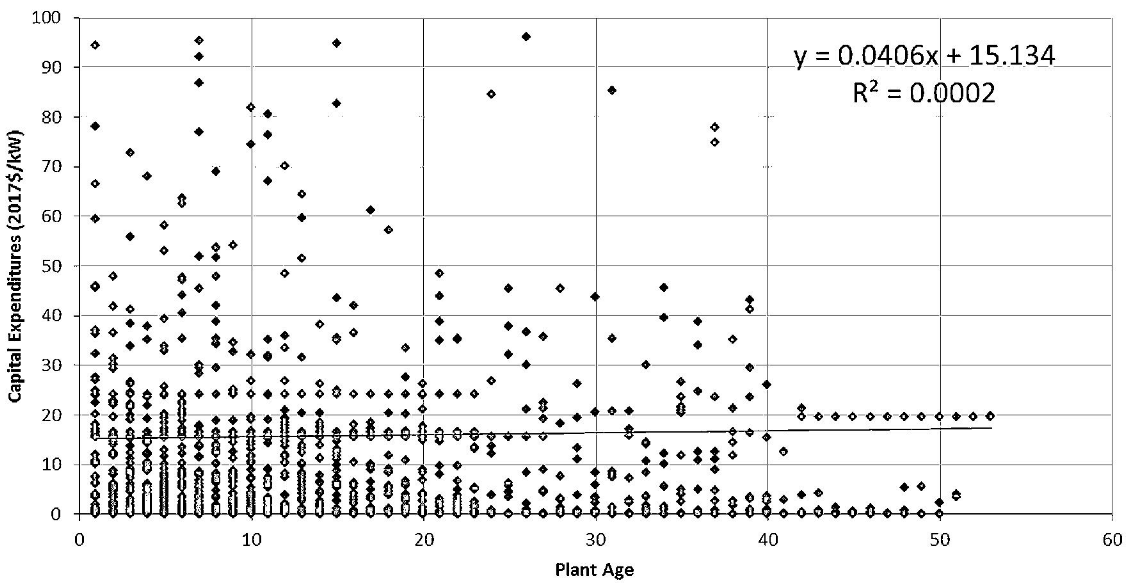
CAPITAL EXPENDITURES – ALL PLANT SIZES

The results of the regression analysis of CAPEX spending for gas/oil CC plants of all MW sizes (full dataset) are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.63, which is greater than 0.05, age is not a statistically significant predictor of CAPEX spending.

Table C-1 — Regression Statistics – CC CAPEX for All MW

		t statistic	*p-value*
Observations	1,368		
Simple Average ($/kW)	15.765		
Intercept	15.134	9.2176	1.11E-19
Slope	0.041	0.4853	6.28E-01
R^2	0.00017		

Figure C-1 — Gas/Oil CC Dataset – CAPEX for All Plant MW Sizes



Notes: Age coefficient in above regression equation is not statistically significant.
Sequential data points with identical values are forecasted values for the same plant.

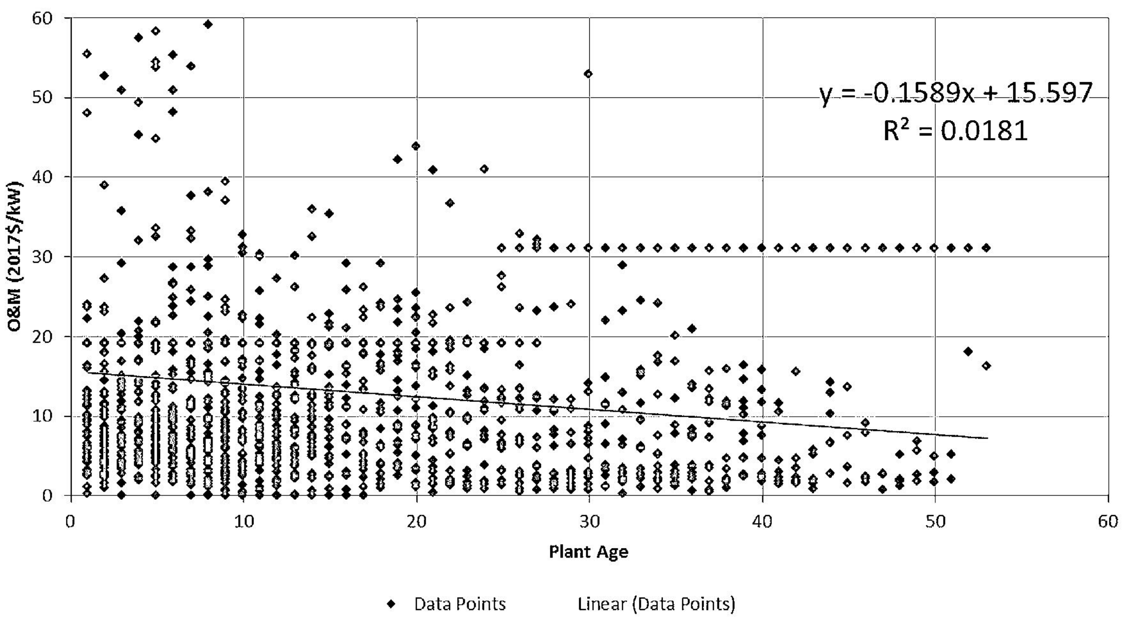
OPERATIONS & MAINTENANCE EXPENDITURES – ALL PLANT SIZES

The results of the linear regression analysis of O&M spending for gas/oil CC plants of all MW sizes (full dataset) are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is much lower than 0.05, the dataset appears to support age as a statistically significant predictor of O&M spending (on a linear trend across all plant ages).

Table C-2 — Regression Statistics – CC O&M for All MW

		t statistic	*p-value*
Observations	1,388		
Simple Average ($/kW)	13.080		
Intercept	15.597	24.8961	2.19E-113
Slope	-0.159	-5.0573	4.82E-07
R^2	0.01812		

Figure C-2 — Gas/Oil CC Dataset – O&M for All Plant MW Sizes



Note: Sequential data points with identical values are forecasted values for the same plant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
All MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	14.16	10.56	10.26	**13.08**	978	344	66	**1,388**
Net Total Capex - 2017 $/kW	15.45	16.37	17.56	**15.76**	979	326	63	**1,368**
Net Total O&M and Capex - 2017 $/kW	29.64	27.24	28.19	**29.00**	976	326	63	**1,365**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing gas/oil CC plants are described in Section 5.

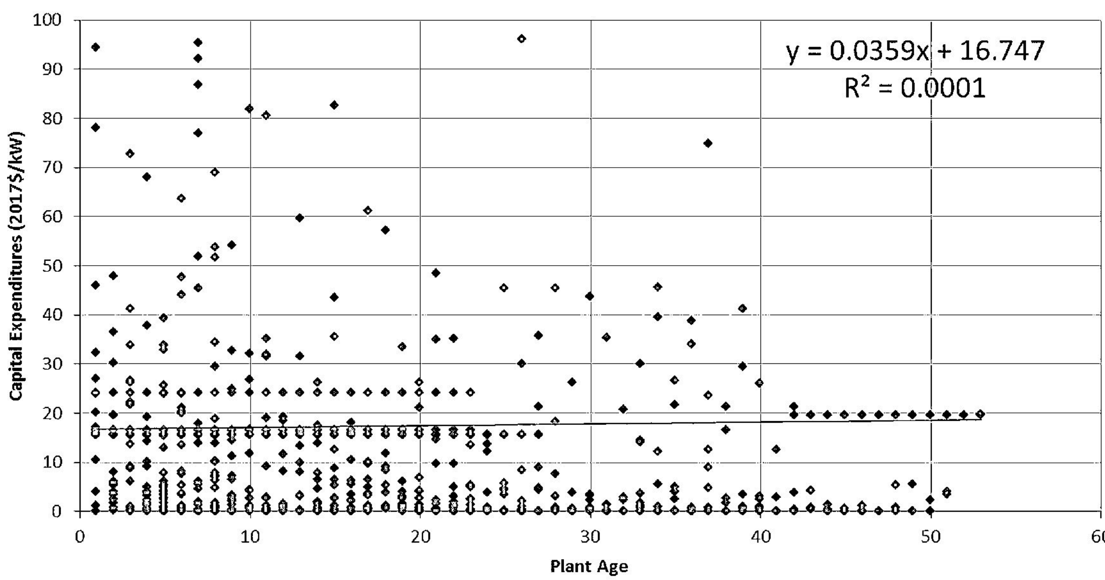
CAPITAL EXPENDITURES – LESS THAN 500 MW

The results of the regression analysis of CAPEX spending for gas/oil CC plants under 500 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is 0.76, which is greater than 0.05, age is not a statistically significant predictor of CAPEX spending.

Table C-3 — Regression Statistics – CC CAPEX < 500 MW

		t statistic	*p-value*
Observations	765		
Simple Average ($/kW)	17.378		
Intercept	16.747	6.4870	1.57E-10
Slope	0.036	0.3007	7.64E-01
R^2	0.00012		

Figure C-3 — Gas/Oil CC Dataset – CAPEX for Less than 500-MW Plant Size



Notes: Age coefficient in above regression equation is not statistically significant.
Sequential data points with identical values are forecasted values for the same plant.

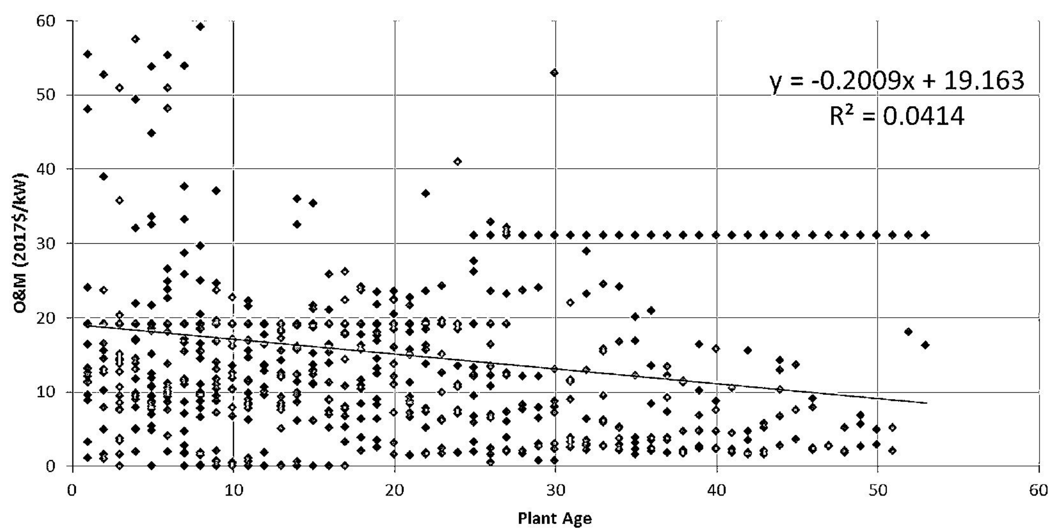
OPERATIONS & MAINTENANCE EXPENDITURES – LESS THAN 500 MW

The results of the regression analysis of O&M spending for gas/oil CC plants less than 500 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient (“slope”) is less than 0.05, age is a statistically significant predictor of O&M spending (on a linear trend across all plant ages). However, the outliers before year 20 and relatively low number of data points after year 40 may distort the regression analysis.

Table C-4 — Regression Statistics – CC O&M < 500 MW

		t statistic	*p-value*
Observations	766		
Simple Average ($/kW)	15.619		
Intercept	19.163	25.2973	4.82E-103
Slope	-0.201	-5.7467	1.31E-08
R^2	0.04143		

Figure C-4 — Gas/Oil CC Dataset – O&M for Less than 500-MW Plant Size



Note: Sequential data points with identical values are forecasted values for the same plant.

The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

	Average \$/kW (years 1 - 20) =	Average \$/kW (years 21 - 40) =	Average \$/kW (years 41 - 80) =	**Average \$/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
< 500 MW, All Capacity Factors								
Net Total O&M- 2017 \$/kW	17.10	13.01	12.27	**15.62**	498	216	52	**766**
Net Total Capex - 2017 \$/kW	16.83	17.78	21.01	**17.38**	499	214	52	**765**
Net Total O&M and Capex - 2017 \$/kW	34.00	30.72	33.28	**33.03**	497	214	52	**763**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing gas/oil CC plants are described in Section 5.

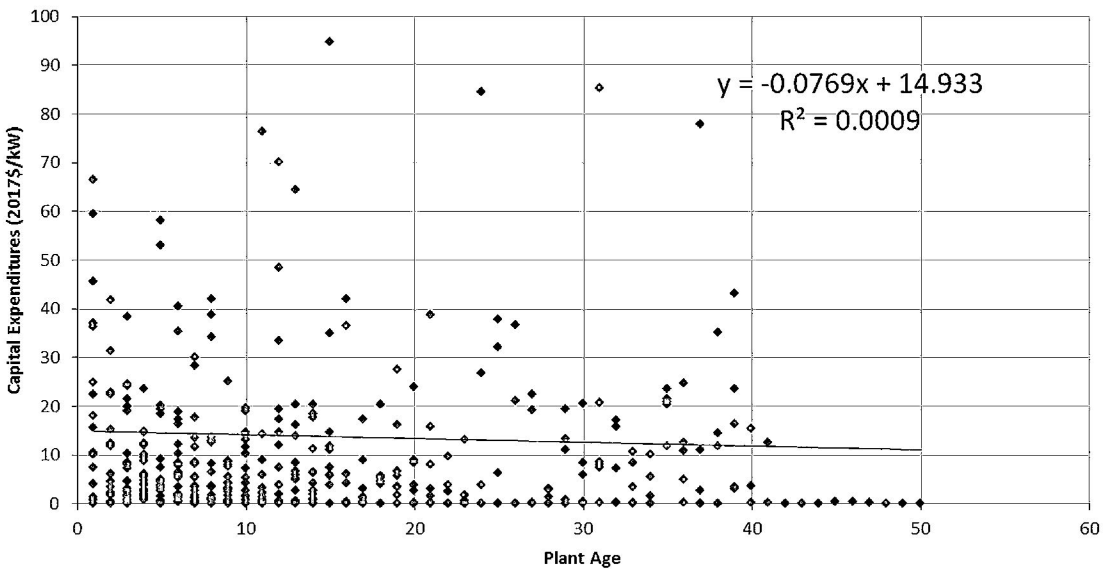
CAPITAL EXPENDITURES – BETWEEN 500 MW AND 1,000 MW

The results of the regression analysis of CAPEX spending for gas/oil CC plants between 500 MW and 1,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient (“slope”) is 0.52, which is greater than 0.05, age is not a statistically significant predictor of CAPEX spending.

Table C-5 — Regression Statistics – CC CAPEX 500 MW to 1,000 MW

		t statistic	***p-value***
Observations	426		
Simple Average (\$/kW)	13.780		
Intercept	14.933	6.3972	4.19E-10
Slope	-0.077	-0.6252	5.32E-01
R^2	0.00092		

Figure C-5 — Gas/Oil CC Dataset – CAPEX for 500-MW to 1,000-MW Plant Size



Note: Age coefficient in above regression equation is not statistically significant.

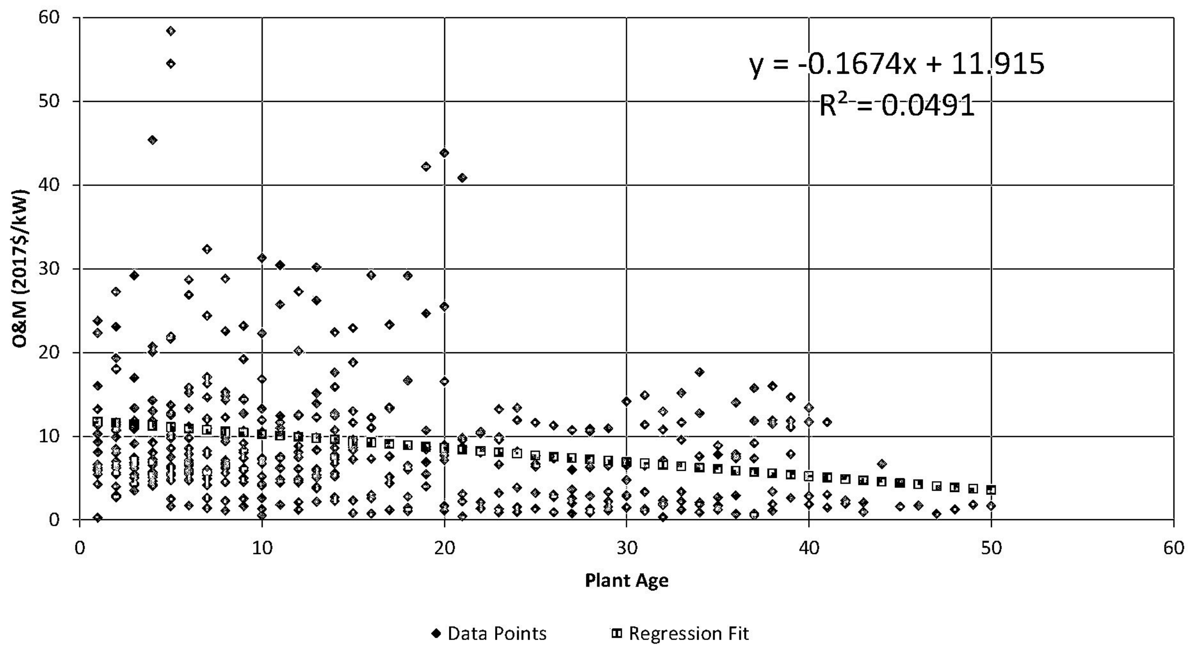
OPERATIONS & MAINTENANCE EXPENDITURES – BETWEEN 500 MW AND 1,000 MW

The results of the regression analysis of O&M spending for gas/oil CC plants between 500 MW and 1,000 MW are summarized in the table below and plotted in the figure below. Since the p-value for the age coefficient ("slope") is less than 0.05, age is a statistically significant predictor of O&M spending (on a linear trend across all plant ages). However, the outliers before year 20 and relatively low number of data points after year 40 may distort the regression analysis.

Table C-6 — Regression Statistics – CC O&M 500 MW to 1,000 MW

		t statistic	*p-value*
Observations	445		
Simple Average ($/kW)	9.269		
Intercept	11.915	17.1008	1.04E-50
Slope	-0.167	-4.7810	2.38E-06
R^2	0.04907		

Figure C-6 — Gas/Oil CC Dataset – O&M for 500-MW to 1,000-MW Plant Size



The simple average O&M and CAPEX values for each 20-year age band, expressed in constant 2017 $/kW-year, are summarized in the table below.

	Average $/kW (years 1 - 20) =	Average $/kW (years 21 - 40) =	Average $/kW (years 41 - 80) =	**Average $/kW (all years) =**	Data Points (years 1 - 20) =	Data Points (years 21 - 40) =	Data Points (years 41 - 80) =	**Data Points (all years) =**
500 MW - 1000 MW, All Capacity Factors								
Net Total O&M- 2017 $/kW	10.68	6.50	2.78	**9.27**	307	124	14	**445**
Net Total Capex - 2017 $/kW	14.38	13.36	1.28	**13.78**	307	108	11	**426**
Net Total O&M and Capex - 2017 $/kW	25.06	20.38	4.15	**23.33**	306	108	11	**425**

Starting with the initial analysis of CAPEX and O&M raw data, as presented above, Sargent & Lundy developed recommended changes to the existing values used in the EMM. The recommended changes for existing gas/oil CC plants are described in Section 5.