NUCLEAR ENERGY INSTITUTE

NUCLEAR COSTS IN CONTEXT

October 2018

TOTAL GENERATING COSTS

In 2017, the average total generating cost for nuclear energy was $33.50 per megawatt-hour (MWh). Total generating costs include **capital, fuel and operating costs**—all the costs necessary to produce electricity from a nuclear power plant. Cost information for the U.S. nuclear fleet is collected by the Electric Utility Cost Group (EUCG) with prior years converted to 2017 dollars for accurate historical comparisons.[1]

2017 Cost Summary ($/MWh)

Category	Number of Plants / Sites	Fuel	Capital	Operating	Total Operating (Fuel + Operating)	Total Generating (Fuel + Capital + Operating)
All U.S.	60	6.44	6.64	20.43	26.86	33.50
Plant Size						
Single-Unit	24	6.42	8.92	27.32	33.74	42.67
Multi-Unit	36	6.44	5.99	18.46	24.90	30.89
Operator						
One Plant	12	6.79	7.39	21.02	27.82	35.21
Multiple Plants	48	6.33	6.43	20.26	26.59	33.02

Source: Electric Utility Cost Group

Approximately 80 percent of the electricity generated from nuclear power in the U.S. comes from plants with multiple reactors. The economies of scale allow plant operators to spread costs more, resulting in a lower total generating cost. In 2017, the average total generating cost at multi-unit plants was $30.89 per MWh compared to $42.67 per MWh for single-unit plants.[2] This separation is driven by operations and capital costs as there is not a meaningful difference in fuel costs. The average total generating costs for an operator with only one plant was $35.21 per MWh compared to $33.02 per MWh for multiple plants. Primary cost drivers were operational and capital expenditures.

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All U.S.	60	6.44	6.64	20.43	26.86	33.50
Market						
Wholesale	30	5.74	4.62	20.67	26.41	31.03
Regulated	30	7.09	8.53	20.20	27.29	35.82
Type						
BWR	23	6.22	6.63	21.58	27.81	34.44
PWR	37	6.55	6.64	19.82	26.36	33.01

Source: Electric Utility Cost Group

[1] *Data is collected by EUCG to perform benchmarking comparisons from nuclear power plant operators. The total generating cost does not include considerations for risk management or returns on investment that would be key factors in business decisions affecting a particular station.*

[2] *The data provided are based on the averages across the operating fleet. Individual plants may vary notably from the average due to factors such as geographic location, local labor costs and the timing of refueling outages.*

The 2017 total generating costs were 3.3 percent lower than in 2016 and more than 19 percent below 2012 costs. The 19 percent reduction in total generating costs since 2012 are due to a 40.8 percent reduction in capital expenditures, a 17.2 percent reduction in fuel and an 8.7 percent reduction in operations. Prior to the 2012 peak, nuclear generating costs had increased steadily over the previous decade, for various reasons. The 2017 total generating costs of $33.50 per MWh have reduced to near 2008 levels ($32.75 per MWh).

U.S. Nuclear Plant Costs ($/MWh in 2017 dollars)

Year	Fuel	Capital	Operating	Total
2002	5.93	4.06	19.25	29.24
2005	5.20	6.01	19.62	30.83
2010	7.00	9.48	21.37	37.84
2011	7.35	10.42	22.66	40.42
2012	7.77	11.21	22.37	41.35
2013	8.01	8.49	21.67	38.17
2014	7.47	8.47	21.67	37.60
2015	7.10	8.24	21.56	36.91
2016	6.90	6.89	20.87	34.65
2017	6.44	6.64	20.43	33.50
2012-2017 Change	**-17.2%**	**-40.8%**	**-8.7%**	**-19.0%**

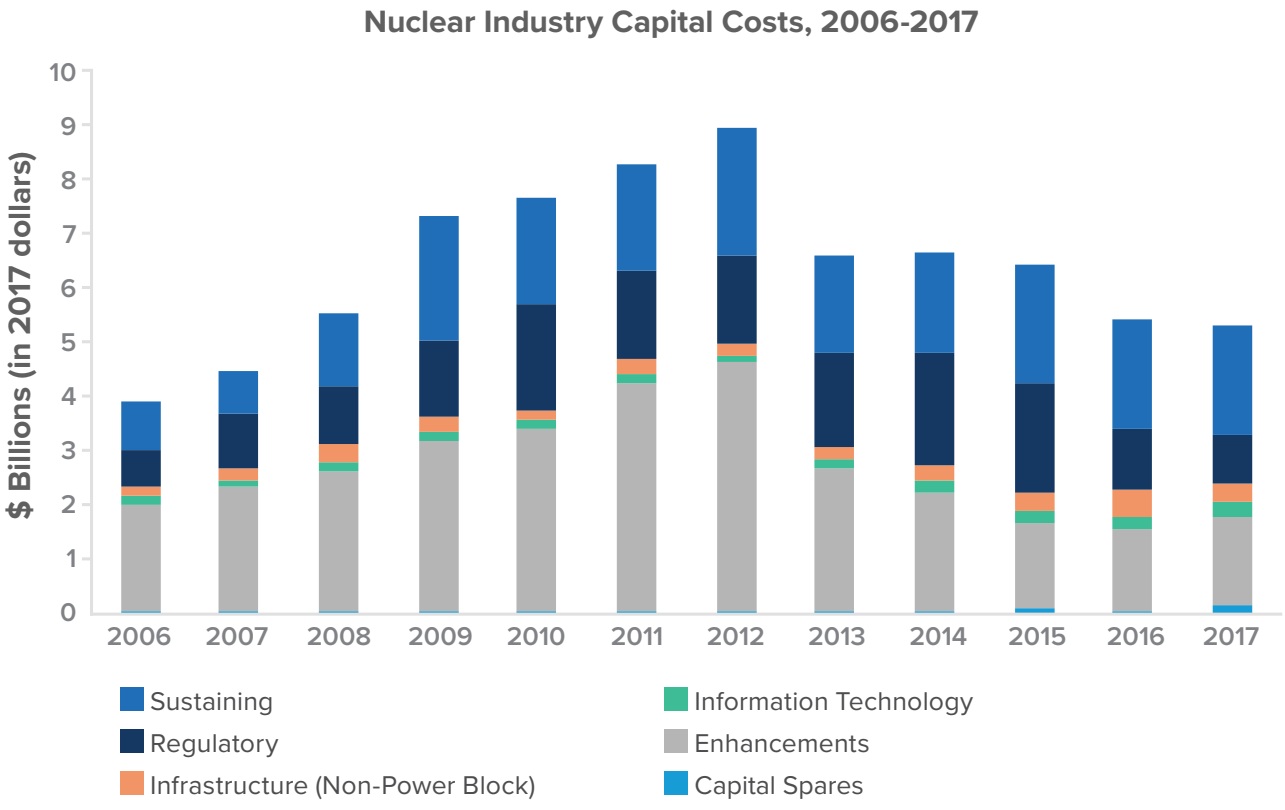
Capital Costs

Industrywide, capital spending in 2017 decreased to $5.34 billion from $5.50 billion in 2016, compared to the peak of $9.02 billion in 2012 (all in 2017 dollars).

Capital investment saw a step-change increase around 2003 followed by steady increases until another step-change increase in 2009 and finally peaking in 2012. Capital costs have declined in each of the last five years. These inflections are the result of a few major items: a series of vessel head replacements, steam generator replacements and other upgrades as companies prepared their plants for operation after the initial 40-year license, and power uprates to increase output from existing plants. As a result of these investments, 86 of the 99 operating reactors in 2017 have received 20-year license renewals[3] and 92 of the operating reactors have been approved for uprates[4] that have added over 7,900 megawatts of electricity capacity.

Capital spending on uprates and items necessary for operation beyond 40 years has moderated as most plants are completing these efforts. Investments in uprates peaked at $2.6 billion in 2012 but declined to $158 million in 2017 (all numbers in 2017 dollars). Some of this decline has been offset in other areas where spending has increased, however capital spending decreased notably in 2017 over 2016. Capital spending to meet regulatory requirements increased from $1 billion in 2007 to over $1.93 billion in 2010 and peaked at $2.06 billion in 2014, before dropping to $869 million in 2017 (all numbers in 2017 dollars). This increase began with significant investments post-9/11 to enhance security, followed by expenditures for post-Fukushima items, which peaked at $1.2 billion in 2015, before falling to $165 million in 2017. As the Fukushima-related safety upgrades are nearly completed, regulatory capital expenditures should also moderate and revert toward 2006 levels.

The chart below breaks down capital costs over the last 11 years.



Source: Electric Utility Cost Group

[3] *U.S. Nuclear Regulatory Commission: License Renewals Granted for Operating Nuclear Power Reactors. July 2018.* https://www.nrc.gov/images/reading-rm/doc-collections/maps/power-reactors-license-renewals.png

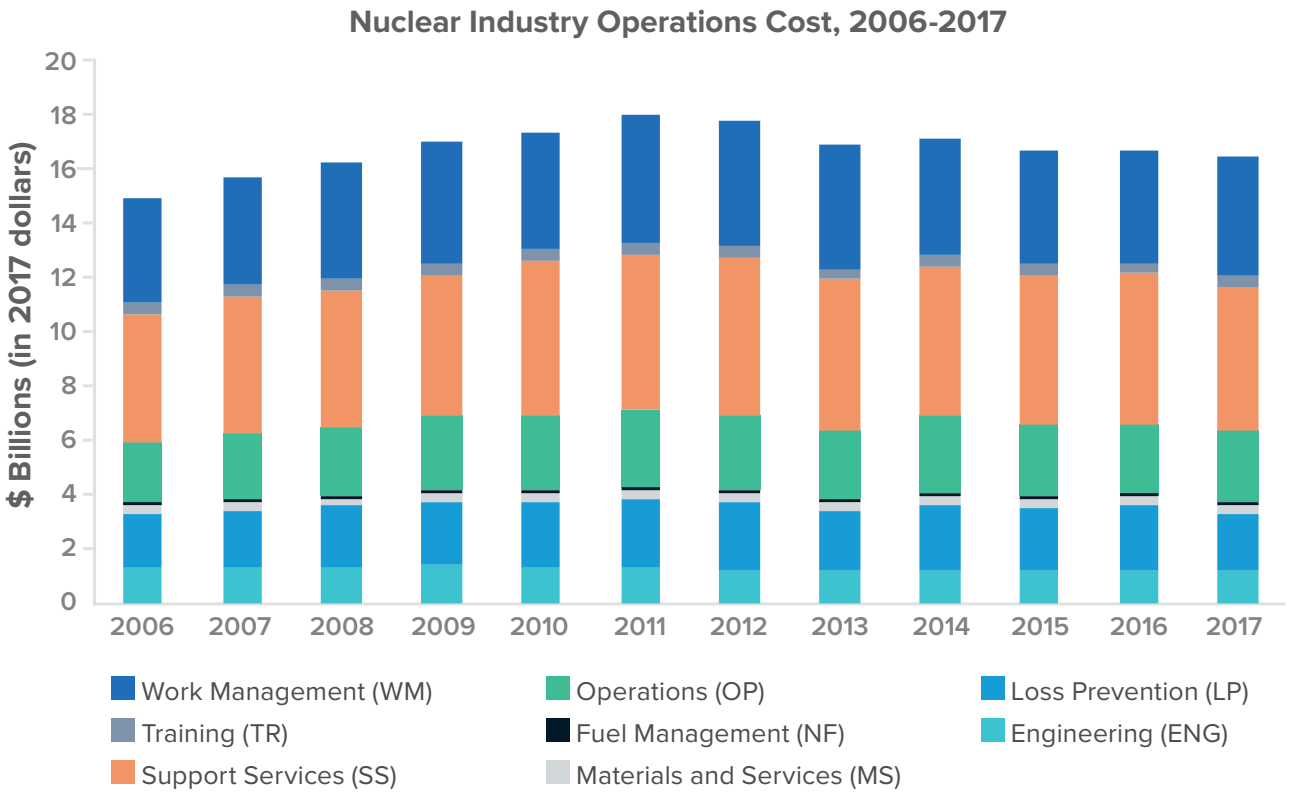
[4] *Nuclear Energy Institute: U.S. Nuclear Plant Actual and Expected Uprates by Plant. September 2018.* https://www.nei.org/resources/statistics/us-nuclear-plant-actual-and-expected-uprates

Operations

Operations costs increased over the last twelve years from $19.25 per MWh in 2002 to $20.43 per MWh in 2017. Operations costs have declined 9.8 percent from the peak in 2011.

This increase in operations costs was not driven by any single category. Operations costs in the 2002-2008 period are similar to where money was being spent in the 2009-2017 period. However, operations costs have remained flat compared to the past decade.

The chart below breaks down operations spending over the last 11 years.



Source: Electric Utility Cost Group

Fuel

Fuel costs represent approximately 20 percent of the total generating cost. Fuel costs experienced a relatively rapid increase from 2009 to 2013. This was largely the result of an escalation in uranium prices, which peaked in 2008. Since uranium is purchased far in advance of refueling and resides in the reactor for four to six years, the effect of this commodity price spike persisted for a long time after the price increase actually occurred. Recent drop in uranium spot prices have caused utilities to move toward shorter fuel purchase cycles.

ECONOMIC PRESSURES FACING NUCLEAR PLANTS

Since 2013, seven nuclear reactors (Crystal River 3 in Florida, San Onofre 2 and 3 in California, Kewaunee in Wisconsin, Vermont Yankee, Fort Calhoun in Nebraska, and Oyster Creek in New Jersey) have shut down permanently. Entergy Corp. announced in October 2015 that it would close Pilgrim Nuclear Power Station in Massachusetts by June 2019. In June 2016, Pacific Gas and Electric Co. announced it would close both Diablo Canyon units by August 2025. In December 2016, Entergy announced it would close Palisades Nuclear Plant in 2018. A month later, Entergy announced it would close Indian Point 2 and 3 by April 2021. In May 2017, Exelon Corp. announced that Three Mile Island Generating Station would cease operations in 2019. In March 2018, FirstEnergy Corp. announced that it would prematurely retire its Davis-Besse and Perry plants in Ohio and Beaver Valley 1 and 2 in Pennsylvania by 2021. In July 2018, NextEra Energy Inc. announced that Duane Arnold Energy Center in Iowa would prematurely cease operations by 2020.

Crystal River and San Onofre shut down due to failed steam generator replacements—unique situations that are unlikely to be repeated. It is a routine practice to replace steam generators over the life of the plant. Exelon decided to retire Oyster Creek in 2010 after New Jersey's revisions to the water rule would have required two new cooling towers.

Diablo Canyon is retiring due to a combination policy and market pressures that created a situation where the plant could not optimally operate. Kewaunee, Vermont Yankee, Fort Calhoun, Palisades, Pilgrim, Indian Point, Three Mile Island, Devis-Besse, Perry, Beaver Valley and Duane Arnold—all in competitive markets—succumbed to a combination of market-related factors (and, in some cases, a combination of several factors) including:

- sustained low natural gas prices, which are suppressing prices in wholesale power markets and will continue to do so.
- relatively low growth (in some markets, no growth) in electricity demand, due partly to subpar U.S. economic performance since the 2008 recession and partly to greater efficiency.
- federal and state mandates for renewable generation, which suppress prices, particularly during off-peak hours (when wind generation is highest and the electricity is needed the least). For example, the federal production tax credit allows wind producers to bid negative prices, which places baseload plants at a disadvantage. Some nuclear plants in Illinois see negative prices as much as 10-11 percent of the off-peak hours and 5-6 percent of all hours.
- transmission constraints, which require a power plant to pay a congestion charge or penalty to move its power on to the grid Certain nuclear plants at particularly congested points on the grid pay a penalty of $6-9 per megawatt-hour to move their power out.
- market designs that do not compensate the baseload nuclear plants for the value they provide to the grid (e.g. emissions-free electricity, providing resilience to the grid) and market policies and practices that tend to suppress prices.

Prematurely Retired Nuclear Power Plants Since 2013

Plant	MWe	Closure Year	Reason	Last Operational Year Generation (billion kWh per year)	Last Operational Year CO_2 Avoided (million metric tons/year)
Crystal River 3	860	2013	Mechanical	7.0	4.8
San Onofre 2 & 3	2,150	2013	Mechanical	18.1	8.0
Kewaunee	566	2013	Market	4.5	4.4
Vermont Yankee	620	2014	Market	4.8	2.4
Fort Calhoun	478	2016	Market	3.5	3.4
Oyster Creek	625	2018	Policy	5.4	4.0
TOTAL	**5,299**			**43.4**	**26.9**

Sources: U.S. Environmental Protection Agency; U.S. Energy Information Administration; Nuclear Energy Institute

Announced Retirements of Nuclear Power Plants

Plant	MWe	Closure Year	Reason	Generation in 2017 (billion kWh per year)	CO2 Emissions Avoided in 2017 (million metric tons/year)
Three Mile Island 1	803	2019	Market	6.9	5.0
Pilgrim	678	2019	Market	5.1	2.3
Davis-Besse	908	2020	Market	7.9	5.7
Duane Arnold	619	2020	Market	5.2	5.0
Indian Point 2 & 3	2,061	2020-2021	Market & Policy	15.3	7.1
Beaver Valley 1 & 2	1,872	2021	Market	15.3	11.1
Perry	1,268	2021	Market	9.8	7.1
Palisades	789	2022	Market	6.1	5.3
Diablo Canyon 1 & 2	2,240	2024-2025	Policy	17.9	6.9
TOTAL	**11,238**			**89.5**	**55.5**

Sources: U.S. Environmental Protection Agency; U.S. Energy Information Administration; Nuclear Energy Institute

In the face of these pressures, additional plants will face the prospect of early closure unless policies are put in place to better reflect the value of the benefits provided by nuclear energy. New York, Illinois, New Jersey, and Connecticut have enacted policies that will compensate nuclear plants for their environmental attributes, ensuring that a total of 12 reactors in these states will not be forced to shut down prematurely.

Plant	MWe	Projected Closure Year	Reason for Potential Shutdown	Generation in 2017 (billion kWh per year)	CO2 Emissions Avoided in 2017 (million metric tons/year)
Clinton	1,065	2017	Market	8.3	8.1
Fitzpatrick	852	2017	Market	6.2	2.9
Ginna	582	2017	Market	4.7	2.2
Hope Creek	1,172	~2020	Market	10.6	7.7
Millstone 2 & 3	2,096	~2020	Market	16.5	7.4
Nine Mile Point 1 & 2	1,770	2017-2018	Market	16.0	7.4
Quad Cities 1 & 2	1,819	2018	Market	15.4	11.2
Salem 1 & 2	2,328	~2020-2021	Market	18.0	13.1
TOTAL	**11,683**			**95.7**	**60.0**

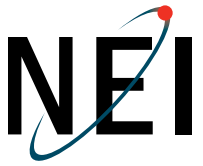
Sources: U.S. Environmental Protection Agency; U.S. Energy Information Administration; Nuclear Energy Institute

Economic Impact of Nuclear Plant Closures

The plants that have closed or announced closure were all highly reliable plants with high capacity factors and relatively low generating costs. Allowing these facilities to close will have long-term economic consequences: replacement generating capacity, when needed, will produce more costly electricity, fewer jobs that will pay less, and more pollution.

In 2017, on average, U.S. nuclear power plants produced electricity for less than $34 per MWh. The smaller single-unit plants like Kewaunee, Vermont Yankee Fort Calhoun, Oyster Creek, were a little more costly—about $43 per MWh. The larger, multi-unit sites were less costly—less than $31 per MWh range. The electricity these plants produce will likely be replaced with combined cycle gas-fired capacity at a levelized cost of $48 per MWh[5] according to the U.S. Energy Information Administration.

[5] *U.S. Energy Information Administration: Annual Energy Outlook 2018 Levelized Costs—Appendix A. March 2018.* https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf



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