white paper

Nuclear Costs in Context

Prepared by the

Nuclear Energy Institute

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NUCLEAR ENERGY INSTITUTE

The Nuclear Energy Institute is the nuclear energy industry's policy organization.

This white paper and additional information about nuclear energy are available at *nei.org*.

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Total Generating Costs

In 2016, the average total generating cost for nuclear energy was $33.93 per MWh (megawatt-hour). 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 2016 dollars for accurate historical comparisons.[1]

2016 Cost Summary ($/MWh)

Category	Number of Plants / Sites	Fuel	Capital	Operating	Total Operating (Fuel + Operating)	Total Generating (Fuel + Capital + Operating)
All U.S.	60*	6.76	6.74	20.43	27.19	33.93
Plant Size						
Single-Unit	25	6.77	8.67	25.95	32.72	41.39
Multi-Unit	35	6.75	6.15	18.73	25.48	31.63
Operator						
Single	12	7.18	8.19	21.20	28.38	36.57
Fleet	48	6.63	6.32	20.21	26.84	33.16

**Costs exclude shutdown plants.*
Source: Electric Utility Cost Group (EUCG)

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 over multi-unit sites, resulting in a lower total generating cost. In 2016, the average total generating cost at multi-unit plants was $31.63 per MWh compared to $41.39 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 2016 total generating costs were 6 percent lower than in 2015 and more than 15 percent below the 2012 costs. Prior to the 2012 peak, nuclear generating costs had increased steadily over the previous decade, for various reasons. Between 2002 and 2016,

[1] EUCG data are collected to perform benchmarking comparisons by companies that operate nuclear plants. 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 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.

fuel costs increased by 16 percent, capital expenditures by nearly 70 percent, and operating costs by more than 8 percent (in 2016 dollars per megawatt-hour). Total generating costs have increased by more than 18 percent in the last 14 years.

U.S. Nuclear Plant Costs (2016 $/MWh):

Year	Fuel	Capital	Operating	Total
2002	5.80	3.97	18.85	28.62
2005	5.09	5.88	19.21	30.18
2010	6.85	9.28	20.92	37.05
2011	7.19	10.20	22.18	39.58
2012	7.57	10.91	21.77	40.25
2013	7.84	8.32	21.22	37.37
2014	7.31	8.29	21.21	36.81
2015	6.95	8.07	21.11	36.13
2016	6.76	6.74	20.43	33.93
2002-2016 Change	**16.6%**	**69.8%**	**8.4%**	**18.6%**
2012-2016 Change	**-10.7%**	**-38.2%**	**-6.2%**	**-15.7%**

Capital Costs

Industry-wide, capital spending in 2016 decreased to $5.4 billion from $6.3 billion in 2015, compared to the peak of $8.8 billion in 2012 (all in 2016 dollars).

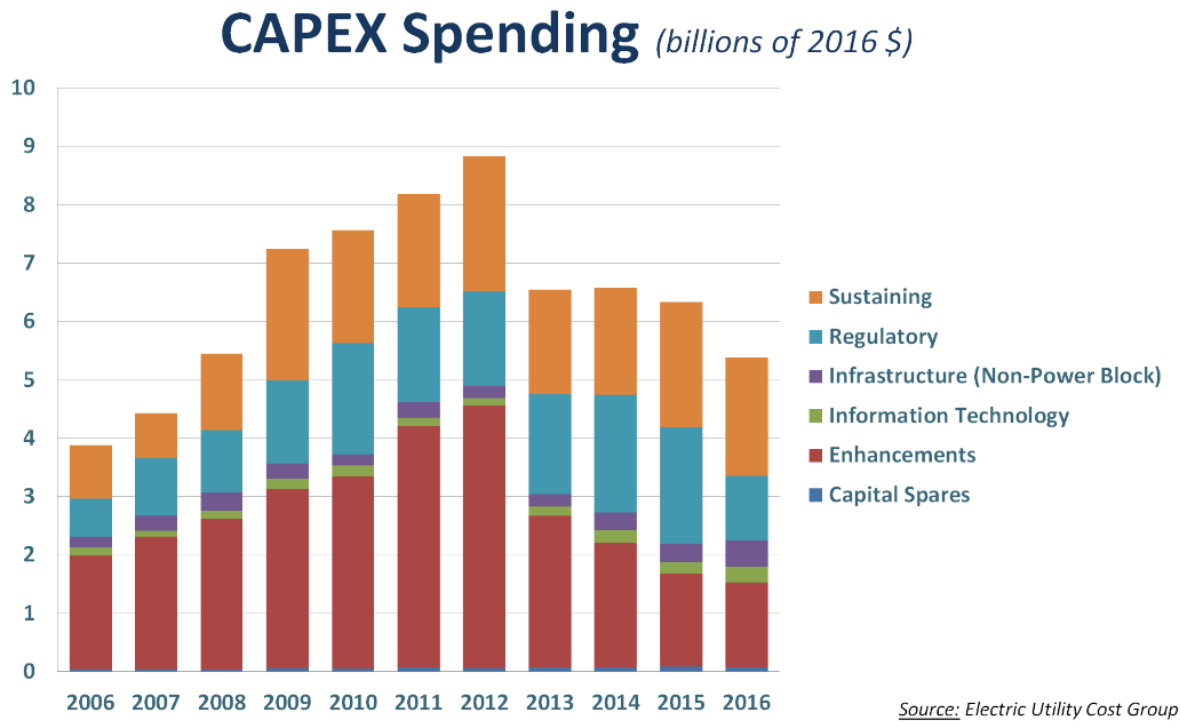
Capital investment saw a step-change increase around 2003 followed by steady increases until another step-change increase in 2009 and finally peaking in 2012. Capital costs have declined in each of the last four years. These inflections are the result of a few major items: a series of vessel head replacements, 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, 84 of the 99 operating reactors have received twenty-year license renewals[3] and 92 of the operating reactors have been approved for uprates[4] that have added over 7,300 megawatts of 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 $2.5 billion in 2012 but declined to $114 million in 2016. Some of this decline has been

[3] Nuclear Regulatory Commission: License Renewals Granted for Operating Nuclear Power Reactors. December 2016. https://www.nrc.gov/images/reading-rm/doc-collections/maps/power-reactors-license-renewals.png
[4] Nuclear Energy Institute: US Nuclear Power Uprates by Plant. June 2016. https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Power-Uprates-by-Plant

offset in other areas where spending has increased, however capital spending decreased notably in 2016 over 2015. Capital spending to meet regulatory requirements increased from approximately $1 billion in 2007 to approximately $1.9 billion in 2010 and peaked at $2 billion in 2014, before dropping to $1.1 billion in 2016 (all numbers in 2016 dollars). This increase began with significant investments post-9/11 to enhance security, followed by expenditures for post-Fukushima items, which peaked at $1.4 billion in 2015, before falling to $373 million in 2016. As the Fukushima-related safety upgrades are nearly completed, regulatory capex should also moderate, and revert toward 2007-2008 levels.

The chart below breaks down capital costs over the last decade.

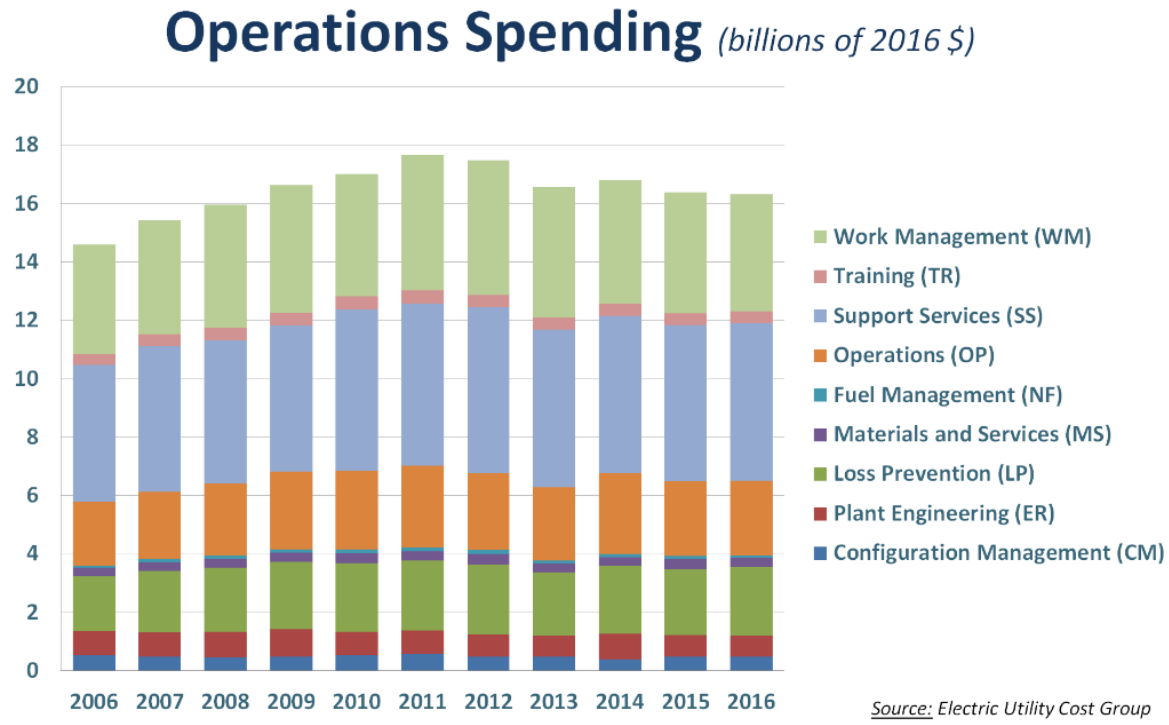


Operations

Operations costs increased over the last twelve years from $18.85 per megawatt-hour in 2002 to $20.43 per megawatt-hour in 2016. Operations costs have declined 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 2009-2016 period. However, operations costs have remained flat compared to the past decade. Between 2002 and 2010, operations costs increased 11 percent while, over the past five years, operations costs have decreased by 6 percent.

The chart below breaks down operations spending over the last decade.



Fuel

Fuel costs represent 15-20 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.

Economic Pressures Facing Nuclear Plants

Since 2013, six nuclear reactors (Crystal River 3 in Florida, San Onofre 2 and 3 in California, Kewaunee in Wisconsin, Vermont Yankee, and Fort Calhoun in Nebraska) have shut down permanently. Entergy announced in October 2015 that it would close its Pilgrim plant in Massachusetts by June 2019. In June 2016, Pacific Gas & Electric announced it would close both Diablo Canyon units by August 2025. In December 2016, Entergy announced it would close its Palisades plant in 2018. A month later, Entergy announced it would close Indian Point 2 and 3 by April 2021. In May 2017, Exelon announced that Three Mile Island would cease operations in 2019.

Crystal River and San Onofre shut down due to failed steam generator replacements – unique situations that are unlikely to be repeated. Since the Surry nuclear power plant in Virginia replaced its steam generators in the early 1980s, it has become a routine practice.

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 and Indian Point, Three Mile Island – 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, 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, and market policies and practices – e.g., reliance on out-of-market revenues – that tend to suppress prices.

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 and Illinois have enacted policies that will compensate nuclear plants for their environmental attributes, ensuring that a total of seven reactors in those two states will not be forced to shut down prematurely.

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 2016, on average, U.S. nuclear power plants produced electricity for less than $34 per megawatt-hour. The smaller single-unit plants like Kewaunee, Vermont Yankee and Fort Calhoun were a little more costly – about $41 per megawatt-hour. The larger, multi-unit sites were less costly – less than $32 per megawatt-hour range. The electricity these plants produce will likely be replaced with combined cycle gas-fired capacity at a levelized cost of $49 per megawatt-hour[5] according to the U.S. Energy Information Administration

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[5] U.S. Energy Information Administration: Annual Energy Outlook 2017 Levelized Costs – Appendix A. April 2017. https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf

