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WHERE HAVE ALL THE NUCLEAR PLANTS GONE?

Catrina Rorke

CONTENTS

Introduction 1
Industry trends 2
Retired and retiring plants 3
At-risk plants 6
Conclusion 8
About the author 8

TABLE 1:
Kewaunee cost and pricing data, 2009-2012 3
TABLE 2:
Clinton Power Station cost and pricing data, 2009-2015 4
TABLE 3:
Quad Cities cost and pricing data, 2009-2015 4
TABLE 4:
Vermont Yankee cost and pricing data, 2009-2014 5
TABLE 5:
Pilgrim cost and pricing data, 2009-2015 5
TABLE 6:
PJM nuclear fleet cost and pricing data, 2015 6
TABLE 7:
MISO Nuclear Fleet Cost and Pricing Data, 2015 7
TABLE 8:
NYISO nuclear fleet cost and pricing data, 2015 7
TABLE 9:
ISO-NE nuclear fleet cost and pricing data, 2015 7
TABLE 10:
ERCOT nuclear fleet cost and pricing data, 2015 8

INTRODUCTION

With the recently announced planned retirements of nuclear facilities in Illinois and California, nearly 10 percent of the U.S. nuclear-energy fleet either already has closed or is scheduled to close within the next 16 years.[1] This has prompted blowback from nuclear advocates who clamor for policies to save the fleet from retirement for any number of reasons: long-term electricity costs, system reliability, fuel diversity and greenhouse-gas targets.

The nuclear industry's chief lobbyist, Nuclear Energy Institute President and CEO Marvin Fertel, has called for "a much greater sense of urgency" about nuclear closures.[2] Econometric analysis suggests that power lost from retiring nuclear facilities is made up largely by increases in natural-gas generation.[3] The think tank Third Way warns that these trends suggest continued nuclear closures will put national greenhouse gas targets out of reach.[4] Michael Shellenberger of Environmental Progress calls government interventions that favor other power sources over nuclear "policy discrimination."[5]

These cautions are not without serious substance. The nuclear fleet has been a uniquely low-cost, stable and efficient source of power. Since the first facility opened in 1958, nuclear facilities have, on average, more than doubled their efficiency. It's a more efficient fuel source than any other on the system today and 60 percent more efficient than extracting energy from coal or natural gas.[6] In 2010, President Obama asserted that "to meet our growing energy needs and prevent the worst consequences of climate change, we'll

1. The following facilities have retired or scheduled their retirement: Crystal River 3 (877 MW, retired 2013); San Onofre 2 and 3 (2150 MW, retired 2013); Kewaunee (574 MW, retired 2013); Vermont Yankee (619 MW, retired 2014); Pilgrim (684 MW, retiring 2019); Clinton (1062 MW, retiring 2026); Quad Cities (1819 MW, retiring 2032); and Diablo Canyon (2240 MW, retiring 2025).

2. Wayne Barber, "NEI's Fertel Warns More Premature Nuclear Retirements on the Way," *Power Engineering*, May 23, 2016. http://www.power-eng.com/articles/2016/05/nei-s-fertel-warns-more-premature-nuclear-retirements-on-the-way.html

3. Lucas Davis and Catherine Hausman, "Market Impacts of a Nuclear Plant Closure," Energy Institute at Haas, May 2015. https://ei.haas.berkeley.edu/research/papers/WP248.pdf

4. Samuel Brinton and Josh Freed, "When Nuclear Ends: How Nuclear Retirements Might Undermine Clean Power Plan Progress," Third Way, August 2015. http://www.thirdway.org/report/when-nuclear-ends-how-nuclear-retirements-might-undermine-clean-power-plan-progress

5. Monica Trauzzi, "Environmental Progress founder Shellenberger talks shift to nuclear energy advocacy," *E&ETV*, May 23, 2016. http://www.eenews.net/tv/videos/2134/transcript

6. Energy Information Administration, "Electric Power Monthly with Data for May 2016," U.S. Department of Energy, July 2016. https://www.eia.gov/electricity/monthly/pdf/epm.pdf

need to increase our supply of nuclear power."[7] At nearly 20 percent of the electricity supply, nuclear power accounts for three-fifths of all carbon-free energy sources.[8]

So if nuclear is so important, so efficient and so reliable, why are facilities closing at these rates? The question merits an answer, especially as nuclear advocates call for policies to keep facilities in business. If this spate of closures reflects industrywide trends that jeopardize the future of this reliable energy supply, intervention might be necessary. On the other hand, if the closures are isolated to facilities that are particularly exposed to idiosyncratic price, expense or political vulnerabilities, industrywide interventions would be inappropriate.

This paper aims to diagnose the reasons behind the announced and completed closures, as well as to identify other facilities that may be particularly at risk.

INDUSTRY TRENDS

Nuclear facilities long have been a low-cost source of power, recovering relatively high upfront construction costs by turning large profits once operational.[9] This has protected the industry from decades of competition – providing low-priced electricity to consumers all the while – and encouraged operators to reinvest and keep the fleet up and running. In the last several years, industry trends have changed for a number of reasons, forcing closures not just at nuclear facilities, but at coal facilities and older natural-gas facilities, as well.

Most notably, the growth trajectory of electricity demand has slowed dramatically. The accumulation of efficiency standards for residential and industrial appliances and equipment, changes in building codes, general improvement in the efficiency of things powered by electricity and a reorientation of the industrial sector all have put a conservative cap on electricity-demand growth. Analysts anticipate that, even without further efficiency regulations from the government, demand will grow less than 1 percent a year through 2040, a dramatic drop from the average 2.1 percent demand growth in the 15 years leading into the 2008-2009 recession.[10,11]

Moreover, policies to support renewable sources of power are depressing short-term prices in many markets. State-by-state renewable-energy mandates and both state and federal tax incentives have driven substantial increases in the amount of wind and solar electricity generated, in particular. These sources are intermittent – they only produce electricity when the wind is blowing or sun is shining – and can drive prices low or negative when they're producing all at once. While the mandates and subsidies allow these power sources to weather negative prices, other sources of power without those incentives face a substantial disadvantage.[12]

In addition, some regions are particularly beset by transmission challenges. Power is most valuable when it moves easily from a power facility to a customer base. In some areas, limitations in the transmission grid create congestion problems. Affected power facilities must pay considerable congestion penalties to get their power to market.[13]

What's more, nuclear costs are just now recovering from a decade of escalation. Operators have invested billions of dollars in facilities by applying for operating-license extensions or power uprates that increased the capacity of existing plants. Capital spending to satisfy regulatory requirements also has been substantial – increasing from 25 to 50 percent of capital spending since 2007. This is partially due to a tightening regulatory environment in the wake of 2011's Fukushima Daiichi nuclear disaster. Nuclear facilities also have increased capital expenditures to repair or replace aging equipment. Finally, uranium prices peaked in 2008. Coupled with industry practices like advanced contracts and long lifetimes for fuel that carry that high price forward, the price signal is only now abating. Total generating costs are starting to recover, falling each year since 2012.[14]

Most importantly, natural-gas prices have been low and stable. The oil-and-gas boom enabled by the innovative combination of hydraulic fracturing and horizontal drilling has had effects on prices across the energy sector. Just as lower-cost oil is making it less expensive to refuel at the gas station, lower-cost natural gas is changing the electricity fuel mix. Natural gas prices also are unusually stable, largely eliminating the historical price volatility that has made natural gas a risky fuel source for electricity. These low and stable prices are setting new standards for what electricity should cost.[15]

7. Barack Obama, "Remarks by the President on Energy in Lanham, Maryland," White House, Feb. 16, 2010. https://www.whitehouse.gov/the-press-office/remarks-president-energy-lanham-maryland

8. Energy Information Administration, "Electric Power Monthly with Data for May 2016," U.S. Department of Energy, August 2016. https://www.eia.gov/electricity/monthly/pdf/epm.pdf

9. Investopedia, "The Economic Reasons Behind Nuclear Power," *Forbes*, April 13, 2011. http://www.forbes.com/sites/investopedia/2011/04/13/the-economic-reasons-behind-nuclear-power/#3fbe96096b75

10. Laura Martin, "Implications of low electricity demand growth," Energy Information Administration, April 30, 2014. http://www.eia.gov/forecasts/archive/aeo14/elec_demand.cfm

11. R Street calculations using data from form EIA-861, comparing electricity demand in 1993 and 2007. Data available at: http://www.eia.gov/electricity/data.cfm#sales

12. Thad Huetteman, "Demand trends, prices, and policies drive recent electric generation capacity additions," Energy Information Administration, March 18, 2016. http://www.eia.gov/todayinenergy/detail.cfm?id=25432

13. Bernard Lesieutre and Joseph Eto, "Electricity Transmission Congestion Costs: A Review of Recent Reports," Ernest Orlando Lawrence Berkeley National Laboratory, October 2003. https://emp.lbl.gov/sites/all/files/lbnl-54049.pdf

14. Nuclear Energy Institute, "Nuclear Costs in Context," April 2016. http://www.nei.org/CorporateSite/media/filefolder/Policy/Papers/Nuclear-Costs-in-Context.pdf

15. Energy Information Administration, "Short-Term Energy Outlook," U.S. Department of Energy, August 2016. https://www.eia.gov/forecasts/steo/pdf/steo_full.pdf

Nuclear facilities are typically able to weather low prices, since their fuel costs and operational costs are quite low, but this trend of low-priced natural gas is dragging on.

Together, these trends are challenging nuclear as a low-cost fuel supply.

One notable caveat to these observation is that, even as some facilities are closing, others are coming online. In regulated marketplaces that hold on to the integrated monopoly-utility model, investment and operation decisions are left to the determinations of regulators, not to market signals. While regulators in some regions have allowed closures – notably the entire nuclear fleet of California – in others, they allow power companies to pass the relatively high costs of nuclear construction on to their customers and fully compensate power facilities for their costs under cost-of-service policy. The subjective determination of whether the costs of continued operation or construction are too high to be prudent investment makes analyzing these facilities difficult.

It's only in restructured markets that merchant operators have seen these prevailing market signals put pressure on existing nuclear facilities. This is the locus of concern: the future of the nuclear fleet in competitive marketplaces. It is these closures that this paper targets for analysis.

RETIRED AND RETIRING PLANTS

Five of the eight facilities that have announced or completed their retirement fall into the category of "merchant unregulated" facilities that sell electricity into the competitive marketplace.[16] This paper examines modeled operations and maintenance (O&M) cost data for each facility and day-ahead pricing data from the major Independent System Operators that manage the marketplaces into which these facilities trade.[17] The results suggest that, while natural gas certainly has affected the industry by putting a ceiling on prices, the facilities that are closing are ones located in areas with considerable transmission constraints, that have required significant and unexpected capital investments to extend their operational life or where closure has been a response to heightened regulatory oversight. In other words, they face substantial additional financial challenges beyond natural-gas prices.

Transmission congestion effects

These facilities were driven to closure or announced their closure because of pricing trends particular to their geographies. Power from these facilities was rendered less valuable because of transmission constraints and congestion that makes it more difficult to move power to market.

Kewaunee Power Station

The Kewaunee Power Station in Carlton, Wisconsin, ceased operations in May 2013 after 39 years of operation. Its closure, the first based on economics, came as a surprise. Purchased by merchant operator Dominion in 2005, Kewaunee was supposed to serve as a seed from which to grow the Dominion nuclear fleet in the Midwest and achieve economies of scale in operation. That plan was ill-fated, and Dominion could not lower operating costs enough to keep Kewaunee open.[18]

One of the reasons Dominion had to cut costs is that Kewaunee was located in an area that was too congested. Table 1 provides SNL cost data for Kewaunee for its last four years of operations and prices in the Minnesota hub of the Midcontinent Independent System Operator (MISO), the closest hub to Kewaunee and the best representation of the market prices the facility faced. As an alternative data point, it provides the prices within MISO's Michigan hub, which regularly were priced significantly higher than in Minnesota.

TABLE 1: KEWAUNEE COST AND PRICING DATA, 2009-2012

	Plant O&M Costs ($/MWh)		MISO Pricing Data ($/MWh)	
Year	Kewaunee	U.S. Average	Minnesota Hub	Michigan Hub
2012	26.88	28.97	25.44	30.87
2011	25.95	29.01	26.66	36.07
2010	23.96	27.43	28.96	37.10
2009	28.54	26.46	24.55	30.74

SOURCES: SNL data, Nuclear Energy Institute

The Kewaunee facility operated at a lower operating and fuel cost than the average nuclear reactor, suggesting the facility was more likely than others in the nuclear fleet to weather the lower prices of natural gas. Unfortunately, it was located in an area plagued by transmission congestion, so the power from Kewaunee fetched a significantly lower price than if it were located elsewhere. Even within MISO, Kewaunee would have fared better if it were located and able to trade within the Michigan hub instead.

16. One additional facility, the James A. FitzPatrick facility in Oswego County, New York, announced its retirement under current owner Entergy Corp., due to cost concerns. The governor's office made considerable efforts to keep the facility open, culminating in changes to state policy that would begin compensating nuclear facilities at above-market rates under a new "clean energy standard." As a result of this move, Exelon Corp. announced it would purchase the facility and maintain operations. This intervention, along with other market changes and proposals, will be examined in a future paper.

17. Costs and pricing data are pulled from S&P Global Market Intelligence's SNL Energy service, which provides financial data for energy facilities and collects pricing information from all major RTO/ISOs and their regional hubs. The service models O&M costs for facilities on a per-Megawatt-hour (MWh) basis as far back as 2009. While electricity prices are determined at geographically granular "nodes," SNL provides information at the less granular "hub" level, which aggregates locational prices. Hub-level data may obscure some congestion trends, but is the most granular level of data available to the author. The majority of facilities draw most of their revenue from the day-ahead market, so this is what is used for our analysis.

18. Sharryn Dotson, "Lessons Learned from Kewaunee's Closing," *Power Engineering*, June 25, 2014. http://www.power-eng.com/articles/npi/print/volume-7/issue-3/nucleus/lessons-learned-from-kewaunee-s-closing.html

Clinton and Quad Cities

Earlier this year, Exelon announced it would take steps to close the Clinton Nuclear Generating Station near Clinton, Illinois, by 2026 and the Quad Cities Nuclear Generating Station in Cordova, Illinois, by 2032 because the facilities had lost a combined $800 million over the past seven years.[19] Much like Kewaunee, these facilities are notable for being generally well-run and escaping large capital expenses. Also like Kewaunee, both facilities suffered significantly from transmission congestion that made their power less valuable.

The facilities are located near one another, outside of Chicago, but trade across two different ISOs. Clinton trades within the PJM Interconnection (PJM), while Quad Cities trades within MISO. However, as the data suggest, both of these RTO/ISOs exhibit considerably congested pricing signals within the region.[20]

TABLE 2: CLINTON POWER STATION COST AND PRICING DATA, 2009-2015

	Plant O&M Costs ($/MWh)		MISO Pricing Data ($/MWh)	
Year	Clinton	U.S. Average	Illinois Hub	Michigan Hub
2015	24.87	27.93	26.67	28.59
2014	23.13	39.93	37.03	44.93
2013	25.12	32.20	30.58	33.03
2012	23.04	28.57	27.07	30.87
2011	24.77	33.24	31.67	36.07
2010	25.12	33.13	31.39	37.10
2009	20.87	28.69	26.05	30.74

SOURCES: SNL data, Nuclear Energy Institute

Table 2 again shows that the Michigan hub exhibits higher prices for power than other MISO hubs in the Midwest. In the case of the Clinton facility, the prices it fetches in the Illinois hub are well below prices it would face if located within the Michigan region.

TABLE 3: QUAD CITIES COST AND PRICING DATA, 2009-2015

	Plant O&M Costs ($/MWh)		PJM Pricing Data ($/MWh)	
Year	Quad Cities	U.S. Average	Northern Illinois Hub	Western Hub
2015	24.08	27.53	27.93	35.82
2014	23.66	28.17	39.93	51.01
2013	25.21	28.69	32.20	38.42
2012	23.85	28.97	28.57	33.89
2011	23.28	29.01	33.24	43.59
2010	23.28	27.43	33.13	46.59
2009	21.73	26.46	28.69	38.75

SOURCES: SNL data, Nuclear Energy Institute

Quad Cities faces significantly lower prices in PJM's Northern Illinois hub, rather than the higher prices of PJM's western hub. Both Clinton and Quad Cities also had very low O&M costs compared to the industry average. The facilities are able to produce a low-cost stable source of electrons, but fail to remain competitive because of unfortunate geography.

Escalating capital expense effects

The two remaining facilities that have retired or announced their retirement in competitive marketplaces – Vermont Yankee Nuclear Power Plant in Vernon, Vermont, and Pilgrim Nuclear Power Station, in Mahomet, Massachusetts – are facilities that faced escalating capital costs. These facilities both trade in ISO New England (ISO-NE) and are owned by Entergy Corp., which operates 12 reactors at 10 nuclear sites across the country.[21] The facilities are located in regions where day-ahead prices were above operating costs.

Unlike the facilities suffering from significant congestion problems in the region, these facilities had O&M costs well below market prices and could use that cushion to recover capital costs on a continuous basis. But significant problems with the facilities began demanding large capital investments. Compounded by negative public sentiment, these capital costs eventually did these facilities in.

Vermont Yankee

Despite smooth operations and a huge economic lift to its rural Vermont neighbors, the Yankee facility faced a long history of public opposition.[22] That opposition reached a nadir when the plant began to experience infrastructure problems, ultimately culminating in a 2010 state Senate vote to deny the facility an anticipated license extension.[23] While that vote

19. Press release, "Exelon Announces Early Retirement of Clinton and Quad Cities Nuclear Plants," Exelon Corp., June 2, 2016. http://www.exeloncorp.com/newsroom/clinton-and-quad-cities-retirement

20. The Quad Cities facility trades roughly 75 percent of its electricity within PJM and 25 percent within MISO. We use PJM data to reflect the more significant price signal facing the facility.

21. One of these facilities, Vermont Yankee, is currently undergoing the decommissioning process.

22. Anne Galloway, "Vermont Yankee: Where Activists, Lawyers and Politicians Failed, the Market Succeeded," VTDigger.org, Aug. 28, 2013. http://vtdigger.org/2013/08/28/vermont-yankee-where-activists-lawyers-and-politicians-failed-the-market-succeeded/

23. Matthew Wald, "Vermont Senate Votes to Close Nuclear Plant," *The New York Times*, Feb. 24, 2010. http://www.nytimes.com/2010/02/25/us/25nuke.html

was ultimately fruitless – the state House never considered the question – it certainly reflected a state environment hostile to continuing operations.

This opposition abounded despite the reliable, low-cost power Vermont Yankee provided to the state and the New England region. The Independent Systems Operators of New England (ISO-NE) market has prices well above the national average, making the low-cost electrons from Vermont Yankee particularly valuable.

TABLE 4: VERMONT YANKEE COST AND PRICING DATA, 2009-2014

	Plant O&M Costs ($/MWh)		ISO-NE Pricing Data ($/MWh)
Year	Vermont Yankee	U.S. Average	Vermont Hub
2014	32.36	28.17	63.81
2013	24.69	28.69	55.36
2012	25.80	28.97	36.25
2011	26.34	29.01	46.67
2010	26.51	27.43	49.57
2009	26.56	26.46	41.59

SOURCES: SNL data, Nuclear Energy Institute

But these data hide mounting capital costs. Immediately following its 2006 application for a license extension, Yankee began to face unexpected expenses. They included recovering from a partial cooling-tower collapse, installing an emergency backup generator and a the cost of reclamation efforts following both a tritium leak from faulty steam pipes and the discovery of contaminated soil from an old leak.[24,25,26,27] This series of expenses came just as lower natural-gas prices were making operations more difficult for parent company Entergy and as regulatory requirements were growing more strict post-Fukushima. It became difficult to justify continued investment at this relatively old, relatively small facility. Entergy shut down Yankee in December 2014.[28]

Pilgrim Nuclear Power Station

In its press release announcing the planned closure of the Pilgrim Nuclear Power Station, Entergy suggested that low-priced natural gas had caused revenue at the facility to drop $40 million per year.[29] Declaring the plant unprofitable, Entergy announced its plans to stop running the facility at the end of its next fuel cycle in May 2019.

Much as with Vermont Yankee, Pilgrim ultimately required a number of expensive investments caused by equipment failures and tightening Nuclear Regulatory Commission regulation. In the second half of 2015, the NRC placed Pilgrim in the "Multiple/Repetitive Degraded Cornerstone Column" category of its Reactor Oversight Process Action Matrix – a designation shared by just two other U.S. nuclear facilities. This came after a series of unplanned shutdowns in 2013 and 2015 that were possibly related to safety-relief-valve problems associated with first-line safety features. While the NRC described the plant's safety problems as "low to moderate," the designation brought with it more frequent and exacting NRC scrutiny and significant investments in the facility.[30]

TABLE 5: PILGRIM COST AND PRICING DATA, 2009-2015

	Plant O&M Costs ($/MWh)		ISO-NE Pricing Data ($/MWh)
Year	Pilgrim	U.S. Average	SE Massachusetts Hub
2015	30.55	27.53	42.23
2014	30.59	28.17	64.71
2013	30.55	28.69	57.02
2012	24.69	28.97	36.09
2011	27.17	29.01	46.18
2010	24.00	27.43	48.33
2009	27.30	26.46	41.71

SOURCES: SNL data, Nuclear Energy Institute

In the years since its first unplanned shutdown, costs to run Pilgrim started to inch higher. While the plant was trading in the higher price environment of ISO-NE, this squeeze nonetheless made it more difficult to justify the considerable investments needed to return to normal oversight.

Capital investments ultimately set these two plants apart as particularly vulnerable to closure. Nonetheless, owner Entergy bemoaned structural market problems and what they viewed as insufficient compensation for the facilities' reliable, clean electricity. These market structures will be discussed in a later paper.

It's clear that the low price for natural gas is creating a challenging environment for the nuclear fleet, along with all other forms of baseload electricity generation in the competitive

24. Susan Smallheer, "Vermont Yankee officials are baffled by cooling tower collapse," *Times Argus*, Aug. 25, 2007. http://www.timesargus.com/apps/pbcs.dll/article?AID=/20070825/NEWS01/708250359/1002/NEWS01

25. Andrew Stein, "PSB grants Vermont Yankee permit for backup generator," *Vermont Business Magazine*, June 6, 2013. http://www.vermontbiz.com/news/june/psb-grants-vermont-yankee-permit-backup-generator

26. Susan Smallheer, "Radiation levels in test well soar at Yankee," *Times Argus*, Feb. 5, 2010. http://www.vermonttoday.com/apps/pbcs.dll/article?AID=/BT/20100205/NEWS01/2050323

27. Susan Smallheer, "Trace amounts of cesium-137 found underground at Yankee," *Times Argus*, Feb. 26, 2010. http://www.vermonttoday.com/apps/pbcs.dll/article?AID=/BT/20100226/NEWS01/2260342

28. Press release, "Entergy to Close, Decommission Vermont Yankee," Entergy Corp., Aug. 27, 2013. http://www.entergy.com/news_room/newsrelease.aspx?NR_ID=2769

29. Press release, "Entergy to Close Pilgrim Nuclear Power Station in Massachusetts No Later than June 1, 2019," Entergy Corp., Oct. 13, 2015. http://www.entergynewsroom.com/latest-news/entergy-close-pilgrim-nuclear-power-station-massachusetts-no-later-than-june2019/

30. U.S. Nuclear Regulatory Commission, "Additional NRC Oversight at Pilgrim Nuclear Power Plant," accessed Aug. 16, 2016.http://www.nrc.gov/info-finder/reactors/pilg/special-oversight.html

marketplace. But these particular plants struggled to weather the price signals from natural gas because of other fundamental factors.

A note should be offered on some important limitations of this paper's analysis. Notably, the data source may not accurately reflect individual facility O&M costs, which can distort the results. This paper relies on hub data within the RTOs/ISOs for day-ahead pricing. More localized price points (node data) may reveal very different congestion information at a higher geographical resolution. For that reason, further analysis with more granular data is warranted.

AT-RISK PLANTS

Accepting that lower prices for natural gas are making things more difficult for all nuclear facilities, this paper examines which facilities may be similarly exposed thanks to unfavorable localized electricity pricing or significant capital investments. Again, this paper look only at facilities participating in competitive markets, as nuclear power plants in regulated states are insulated from market dynamics. Analysis was completed for 29 merchant nuclear facilities across PJM, MISO, ISO-NE, New York Independent System Operator (NYISO) and the Electric Reliability Council of Texas (ERCOT) that have not announced or completed their retirement and remain at risk from market signals.

The facilities in this analysis are distributed across five competitive marketplaces. These markets have very different rules, particularly in regard to capacity payments. By limiting the analysis to day-ahead prices from energy markets, this paper excludes what can be substantial payments to facilities from capacity markets.[31] The analysis again relies on hub-level pricing data within the ISOs. Pricing at a more granular geographic level (node pricing) might reveal very different results with regards to congestion pricing. As a result, the analysis is not intended as a predictive model, but one indicative of larger trends.

PJM Interconnection

All 16 nuclear facilities within the PJM Interconnection that have not announced retirements continue to see market prices above their operating costs, reflecting that regional congestion may not be causing trouble for the nuclear fleet. For PJM, this paper uses "transmission zones" rather than hubs, as these give a slightly more refined view of regional pricing patterns.

TABLE 6: PJM NUCLEAR FLEET COST AND PRICING DATA, 2015

	Plant O&M Costs ($/MWh)	Transmission Zone	Pricing Data ($/MWh)	Hub Price less O&M Costs ($/MWh)
Beaver Valley	25.16	ATSI	32.63	7.47
Braidwood Generating System	23.31	ComEd	28.01	4.70
Byron	23.38	ComEd	28.01	4.63
Calvert Cliffs	23.59	Delmarva	37.48	13.89
Donald C. Cook	25.82	Dayton	32.45	6.63
Davis-Besse	24.52	ATSI	32.63	8.11
Dresden	23.63	ComEd	28.01	4.38
Hope Creek	24.79	Atlantic Electric	33.98	9.19
LaSalle County Generating Station	23.67	ComEd	28.01	4.34
Limerick	23.96	PECO	33.13	9.17
Oyster Creek	28.21	Atlantic Electric	33.98	5.77
Peach Bottom	23.79	PECO	33.13	9.34
Perry	26.11	ATSI	32.63	6.52
Salem	24.17	Atlantic Electric	33.98	9.81
Susquehanna Nuclear	24.13	PPL	33.01	8.88
Three Mile Island	27.14	Metropolitan Edison Co.	32.94	5.80

SOURCE: SNL data

Both the Davis–Besse Nuclear Power Station in Oak Harbor, Ohio, and the Oyster Creek Nuclear Generating Station in Forked River, New Jersey, are under heightened regulatory scrutiny from the NRC, which may compel significant additional capital investments. Unless these investments are significant, one would not anticipate widespread closure risk among the PJM fleet.

MISO

Of the five nuclear facilities within MISO that have not announced their retirements, just one has operating costs below the price signal it sees in the day-ahead market. These facilities and their O&M cost and hub pricing data for 2015 are detailed in Table 7. It is evident that the MISO nuclear fleet faces significant market pressure.

31. Capacity market revenues can be particularly high within PJM, ISO-NE and NYISO.

TABLE 7: MISO NUCLEAR FLEET COST AND PRICING DATA, 2015

	Plant O&M Costs ($/MWh)	MISO Hub	Pricing Data ($/MWh)	Hub Price less O&M Costs ($/MWh)
Duane-Arnold Energy Center	27.05	Illinois	26.67	-0.38
Fermi	31.83	Michigan	28.59	-3.24
Grand Gulf	21.33	Louisiana	28.80	7.47
Palisades	28.28	Michigan	28.59	0.31
Point Beach	25.10	Minnesota	22.18	-2.92

SOURCE: SNL data

The Enrico Fermi Nuclear Generating Station in Newport, Michigan, has substantial cost exposure, with O&M costs more than $4 above the 2015 U.S. average of $27.53/MWh. This is compounded by market pressures within the MISO region that leave four of five facilities struggling to recover costs.

While there are no significant anticipated capital expenditures or opportunities for increased regulatory oversight, the analysis would conclude that, due to natural gas and congestion pricing, all MISO facilities except for the Grand Gulf Nuclear Generating Station near Port Gibson, Mississippi, are at risk for retirement. This amounts to nearly 4 GW of nuclear capacity.[32]

NYISO

There are five operational reactors at four nuclear facilities in the NYISO region. Three of these facilities maintain O&M costs below hub prices. Though some of the facilities have noted struggles to remain profitable in the NYISO price environment – notably the James A. FitzPatrick Nuclear Power Plant in Oswego County, New York, which will change ownership in order to stay operational – they do not yet face losses.

TABLE 8: NYISO NUCLEAR FLEET COST AND PRICING DATA, 2015

	Plant O&M Costs ($/MWh)	NYISO Hub	Pricing Data ($/MWh)	Hub Price less O&M Costs ($/MWh)
James A. FitzPatrick	25.00	Central-C	28.78	3.78
Robert E. Ginna	28.66	Genesee-B	27.42	-1.24
Indian Point 2	24.71	Millwood-H	38.09	13.38
Indian Point 3	28.23	Millwood-H	38.09	9.86
Nine Mile Point	24.10	Central-C	28.78	4.68

SOURCE: SNL data

32. Recent changes to MISO's capacity market design and a reduction in MISO's capacity may make a substantial difference to the future of these facilities. Capacity payments historically have been low in this market, but future prices may be substantially higher. See, e.g., Jeffrey Tomich, "MISO capacity auction sees higher prices across many states," *EnergyWire*, April 15, 2016. http://www.eenews.net/stories/1060035686.

TABLE 9: ISO-NE NUCLEAR FLEET COST AND PRICING DATA, 2015

	Plant O&M Costs ($/MWh)	ISO-NE Hub	Pricing Data ($/MWh)	Hub Price less O&M Costs ($/MWh)
Millstone	24.08	Connecticut	41.23	17.15
Seabrook	25.54	New Hampshire	42.11	16.57

SOURCE: SNL data

The exception is the Robert E. Ginna facility in Ontario, New York, which absorbs a loss for every MWh produced. The poor financials at this facility led NYISO to create a "reliability must run" order for the plant, which directs Exelon to keep the facility open in order to maintain a reliable electric supply in the region.[33]

The New York nuclear fleet has operated largely without problems, though the Indian Point Energy Center in Buchanan, New York, has documented some small leak events recently that may trigger some remediation efforts.[34] It has also triggered increased oversight from the NRC. Nonetheless, with this exception, all other facilities in NYISO show no signs of major capital costs on the horizon and this paper's analysis does not expect this to be a risk factor for closure.

New York Gov. Andrew Cuomo's office has advanced a "clean energy standard" that offers above-market payments to these facilities in order to guarantee operations.[35] This intervention will be discussed in a subsequent paper.

ISO-NE

With the retirement of Vermont Yankee and the announced retirement of Pilgrim, two nuclear facilities remain within ISO-NE. Because of the relatively high prices in New England, these plants maintain a cushion between O&M costs and day-ahead prices within their regional hubs.

The Seabrook Nuclear Power Plant in Seabrook, New Hampshire, recently completed a period of heightened oversight and increased maintenance costs to restore degraded concrete at the facility.[36] Neither facility within ISO-NE currently faces predictable increases in capital expenditures or

33. Federal Energy Regulatory Commission, "Order Rejecting in Part, and Accepting in Part and Suspending Proposed Rate Schedule, Subject to Refund, and Establishing Hearing and Settlement Procedures," April 14, 2015. http://www.ferc.gov/CalendarFiles/20150414172357-ER15-1047-000.pdf

34. U.S. Nuclear Regulatory Commission, "Indian Point Groundwater Contamination," accessed Aug. 16, 2016. http://www.nrc.gov/info-finder/reactors/ip/ip-groundwater-leakage.html

35. Press release, "Governor Cuomo Announces Establishment of Clean Energy Standard that Mandates 50 Percent Renewables by 2030," Office of Gov. Andrew Cuomo, Aug. 1, 2016. https://www.governor.ny.gov/news/governor-cuomo-announces-establishment-clean-energy-standard-mandates-50-percent-renewables

36. U.S. Nuclear Regulatory Commission, "Special NRC Oversight at Seabrook Nuclear Power Plant: Concrete Degradation," accessed Aug. 31, 2016. http://www.nrc.gov/reactors/operating/ops-experience/concrete-degradation.html

increased regulatory oversight and are not anticipated to be at significant risk for closure.

ERCOT

There are currently two operating nuclear facilities in Texas that fall within the ERCOT region. Both facilities have very tight margins between O&M costs and the hub price.

TABLE 10: ERCOT NUCLEAR FLEET COST AND PRICING DATA, 2015

	Plant O&M Costs ($/MWh)	ERCOT Hub	Pricing Data ($/MWh)	Hub Price less O&M Costs ($/MWh)
Comanche Peak	23.31	North	25.34	2.03
South Texas Project	24.75	South	25.80	1.05

SOURCE: SNL data

NRG Energy, the operator of the South Texas Nuclear Project Electric Generating Station in Wadsworth, Texas, had filed an application to construct additional reactors at its facility, but abandoned that effort once the price signal for natural gas started pushing down energy prices in the state. Further, neither the South Texas Project nor the Comanche Peak Nuclear Power Plant in Glen Rose, Texas, currently is experiences increased oversight from the NRC or faces significant capital expenditures on the horizon.

Because of the narrow margin between O&M costs and electricity pricing, the Texas nuclear facilities are at risk for closure due to market signals. However, ERCOT uses scarcity pricing, which increases energy market prices during supply shortages. These payments may be sufficient to make up for the narrow margin experienced by the Texas nuclear facilities, which makes it much more difficult to predict the likelihood of closure.

CONCLUSION

Low and stable natural gas prices are creating significant risk for all sources of baseload power, including nuclear. But the resulting appeals for a policy response to save the fleet demand a sober assessment of the data: is the full fleet at risk? Are systemwide interventions necessary?

This analysis demonstrates that some portions of the nuclear fleet are more vulnerable than others. Transmission congestion and large capital expenditures have been the two factors that tip the scales in favor of retirements. With better geography or lower costs, the facilities that have announced or completed their retirements may still be operational.

When we consider the national fleet, market changes induced by falling natural-gas prices are evident. The nuclear fleet within MISO and ERCOT are particularly exposed to lower electricity prices. In other regions, O&M costs still fall below market prices for power.

The nuclear fleet seems broadly vulnerable in this limited analysis, but more analysis is needed. Already, individual states and RTO/ISOs are advancing changes to markets and out-of-market payments that may impact whether or not nuclear facilities will weather the low-price environment. A future paper will look at proposed changes, like New York's clean energy standard, capacity payments and other features of existing markets that offer nuclear facilities more protection. This will help identify whether markets are exhibiting structural problems that compound the problems faced by the nuclear fleet.

ABOUT THE AUTHOR

Catrina Rorke is director of energy policy and a senior fellow at the R Street Institute, founding and leading the institute's energy program that seeks to help lawmakers, stakeholders, coalition partners and the policy community make informed decisions about such issues as infrastructure, wholesale and retail electricity, fuel diversity, energy choice and climate adaptation and mitigation.

Before joining R Street, Catrina founded the energy program at the American Action Forum, a center-right policy institute that specializes in actionable research and analysis. While at AAF, she emphasized free-market policies and critiqued administration regulatory efforts.