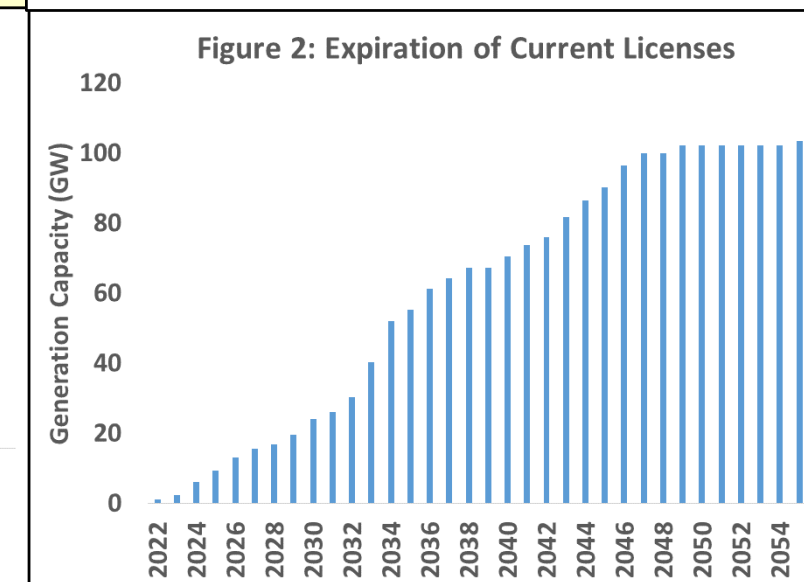
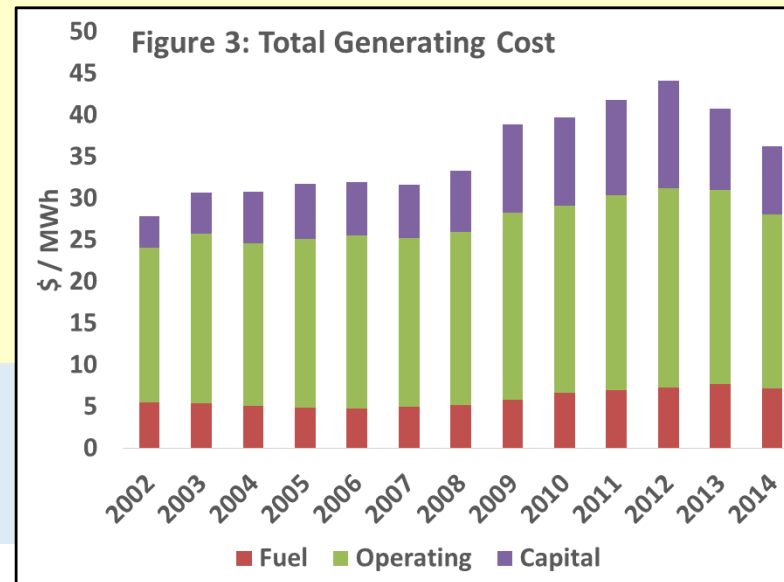
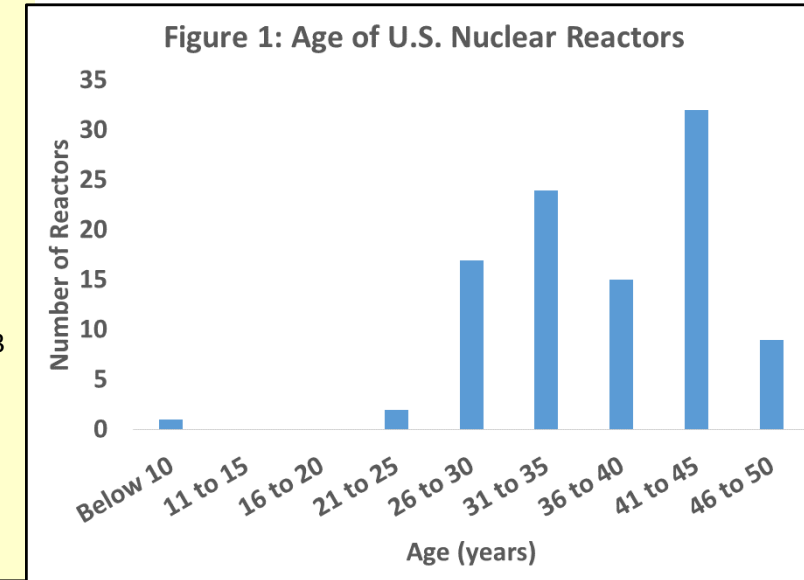


U.S. Nuclear Power Reactors: At a Crossroads

- U.S. nuclear power plants supplied 20% of U.S. electricity every year since 2001, running at an average of 90% capacity factor, and constituted the majority of emission-free generation.¹
- However, U.S. reactors are aging and generating costs are increasing
 - Most plants are licensed to operate 60 years; 41 reactors are older than 40 years (Figure 1), and a **big wave of retirements is coming** (Figure 2).²
 - Avg generation costs increased from \$27.91/MWh in 2002 to \$36.27/MWh in 2014 (Figure 3).³
 - While **Fuel** plus **Operating** cost was maintained between \$25 and \$30 per MWh, **Capital** cost increased significantly since 2009.⁴
- Some plants may stay online if the owners obtain a second license renewal (to 80 years). **However, many plants may need large capital investments to qualify for this second license renewal, which is difficult to justify in current market conditions.**
 - To date, only Exelon and Dominion had notified US Nuclear Regulatory Commission of their intention to seek 2nd license renewal for one plant each.



Notes: (1) U.S. EIA [Electricity Power Annual](#); (2) U.S. Nuclear Regulatory Commission. [Information Digest \(NUREG-1350, Vol. 28\)](#); (3) Nuclear Energy Institute [Annual Briefing for the Financial Community](#), various issues. (4) Capital cost includes (i) Upgrades and license renewal, (ii) equipment replacement, (iii) regulatory requirement; and (iv) other

Plant owners are retiring aging reactors prematurely for different reasons, including unfavorable market conditions.

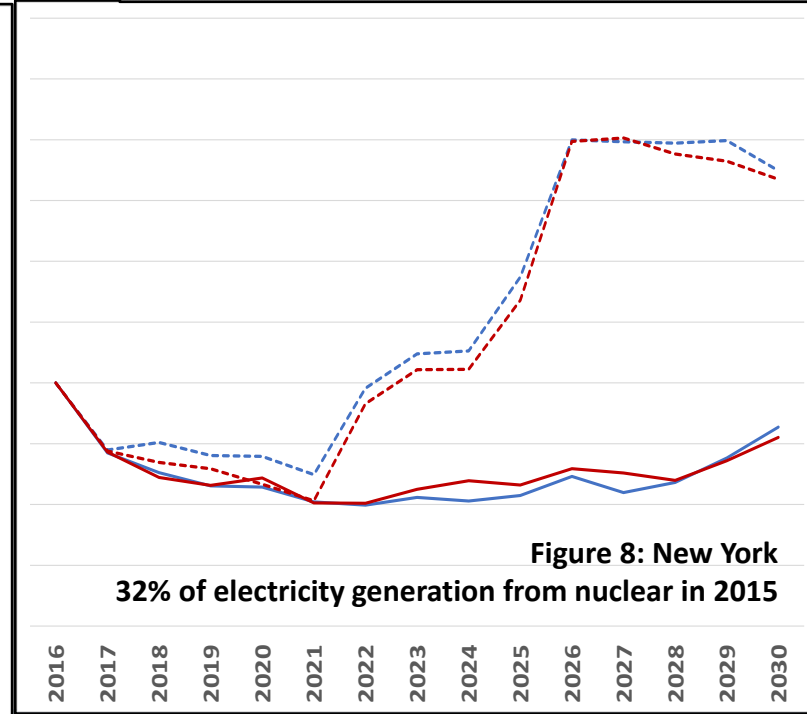
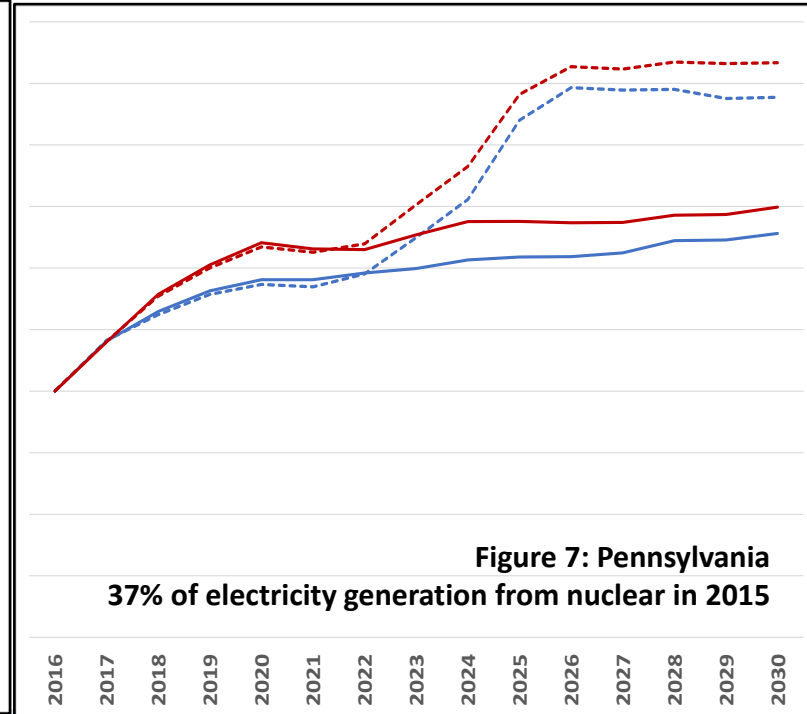
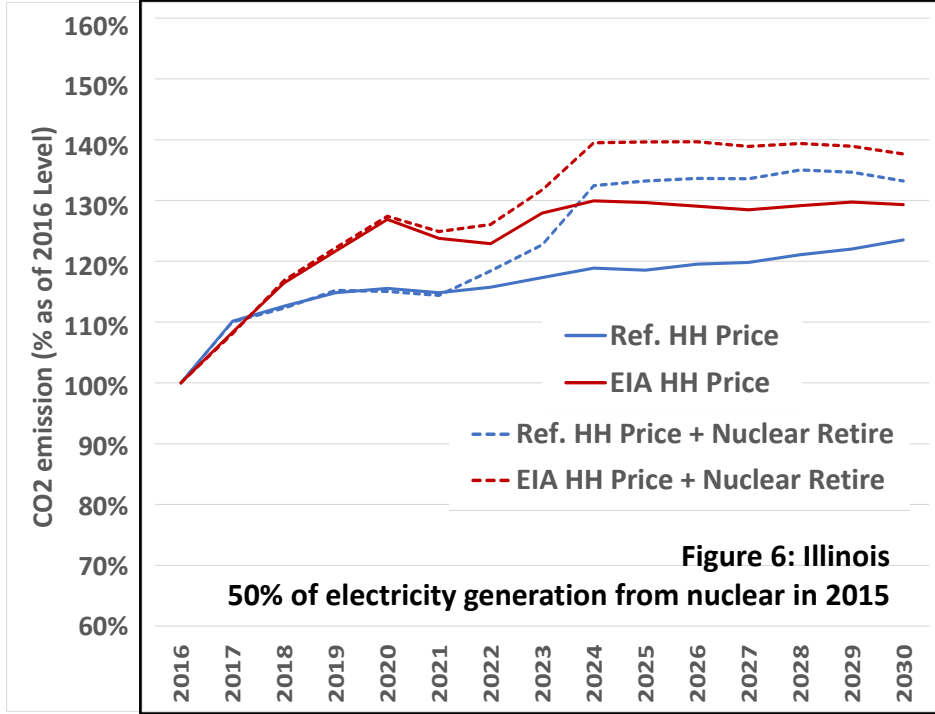
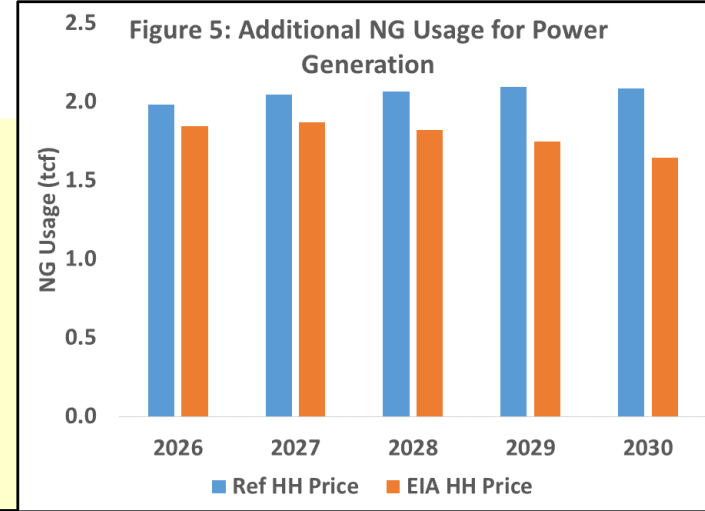
- Low natural gas price, increasing penetration of subsidized, low-operating-cost renewable energy in an environment of stagnant load growth have lowered wholesale prices and undermined nuclear economics, especially for single-unit plants (see table below).
- Recent Idaho National Lab (INL) report estimated that existing merchant plants need \$5 to \$15/MWh of additional revenue to cover costs.⁵

Name	State	ISO/RTO ⁶	Utility	Nameplate Capacity (MW) ⁶	Commercial Operation Year ⁷	Operation License Expiration Year ⁷	Retirement Year	Avg Capacity Factor (2008-2015) ⁷	Avg. Day-Ahead LMP \$/MWh (2011-2015) ⁸	Avg. Capacity Price \$/MW-hour (2011-2015) ⁹
Retired										
Crystal River ¹⁰	FL		Duke	890	1976	2016	2013	95% ¹¹		
Kewaunee	WI	MISO	Dominion	560	1973	2033	2013	94%	32.0	
San Onofre 2&3 ¹⁰	CA	CAISO	Southern California Edison	2,254	1982	2022	2013	83% ¹¹	41.5	
Vermont Yankee	VT	ISONE	Entergy	563	1972	2032	2014	93%	49.0	4.7
Fort Calhoun	NE	SPP	Omaha Public Power District	502	1973	2033	2016	62% ¹²		
Retirement Announced										
Clinton	IL	MISO	Exelon	1,138	1987	2026	2017	93%	29.0	3.5
James A FitzPatrick	NY	NYISO	Entergy ¹³	882	1975	2034	2017	90%	35.9	3.0
Quad Cities 1&2	IL	PJM	Exelon	2,019	1973	2032	2018	93%	24.7	4.2
Palisades ¹⁴	MI	MISO	Entergy	812	1971	2031	2018	89%	33.5	0.4
Oyster Creek ¹⁵	NJ	PJM	Exelon	550	1969	2029	2019	94%	41.0	6.9
Pilgrim	MA	ISONE	Entergy	670	1972	2032	2019	91%	49.5	4.7
Indian Point 2&3	NY	NYISO	Entergy	2,311	1974	2015	2021	92%	46.8	3.0
Diablo Canyon 1&2	CA	CAISO	PG&E	2,218	1985	2024	2024	89%	40.7	

(5) [Economic and Market Challenges Facing the U.S. Nuclear Commercial Fleet](#). INL/EXT-16-39951; (6) US EIA [Form 860](#) Annual Electric generator data; (7) US NRC Information Digest ([NUREG-1350, Volume 28](#)) Appendix A and Appendix C. By comparison, five-year national average CFs (2011-2015) for coal 59%; natural gas combined cycle 49%; and wind 32%; (8) Locational Marginal Price at generation node for MISO, NYISO and PJM; average zonal price for CAISO and ISONE. Data gathered from relevant ISO/RTOs. (9) Zonal Capacity Price reported either as \$/MW-day or \$/kW-month by relevant ISO/RTOs. Converted to \$/MW-hour by CEE. (10) The retirement decision for Crystal River and San Onofre was based on technical issues. Utilities could not justify high cost of repairs under current market conditions; (11) Average capacity factor before plant was shut down due to technical issues. (12) Fort Calhoun had extended outage between 2011 and 2013 for operating and safety system upgrades, after Missouri River flooded the plant in June 2011. (13) After Entergy announced retirement, Exelon purchased FitzPatrick from Entergy in 2016 Q4. (14) After Entergy terminated an existing PPA with Consumer Energy (through April 2022). (15) The plan to shut down Oyster Creek was announced in 2010. The most obvious reason was a requirement by NJ Department of Environmental Protection to install a cooling tower, a more expensive capital investment in the foreseeable power market that Exelon could not justify.

Implications of retiring nuclear units

- We model the retirement of 43 GW nuclear capacity by 2025 under two Henry Hub NG price scenarios (see Fig. 2 in our Aug 2016 [Snapshot](#) for HH prices).
- **Gas-fired generation increases**, resulting in 8.9 to 10.2 tcf additional gas burn between 2026 and 2030. (Figure 5)*
- **Total system costs (Fuel + O&M + Capital) increase** by \$46 to \$65 billion between 2026 and 2030.
- **CO₂ emissions increase significantly in some states** (Figures 6 to 8).



In IL and PA, coal is the second largest source of power generation. Nuclear retirements would delay coal retirements, increase coal generation, and raise CO₂ emissions. In NY, natural gas is the largest source of power generation; nuclear retirements would reverse the decline in CO₂ emissions.

State interventions to save nuclear plants: Moral Hazard?

- States have been intervening to save some nuclear plants to preserve zero emission generation, to save direct and indirect jobs, and to sustain local economic benefits, and/or to maintain resource adequacy.
 - NY is pursuing a Clean Energy Standard and IL passed Future Energy Jobs Bill (Table 2).¹⁶
 - Exelon is actively engaged with many policy leaders in Pennsylvania to save Three Mile Island.¹⁷
 - FirstEnergy is talking to Ohio regulators to seek ways of saving their nuclear plants in the state.¹⁸
- **What could happen?**
 - Federal intervention?
 - State actions similar to those by NY and IL?
 - Changes in Federal and/or state regulatory review?
 - Continued cost reduction by the nuclear industry?
 - Higher revenues (\$5-\$15/MWh per the INL study)? Higher natural gas prices could help but **changes to energy, ancillary and/or capacity markets to reflect all costs and to value all attributes (e.g., reliability, on-site storage of fuel) are needed not only to maintain nuclear but to improve and sustain competitive electricity markets.** Otherwise, we face the **moral hazard** created by out-of-market interventions.

New York	Illinois
Clean Energy Standard (Aug. 1, 2016)	Future Energy Jobs Bill (SB 2814; Dec 1, 2016)
Zero emission credit (ZEC) with an initial value of \$17.48/MWh for 12 years ¹⁹	Zero emission credit (ZEC) of roughly \$235 million per year (or about \$10/MWh) for 10 years
Cost impact to residential customer: less than \$2 per month	Cost impact to residential customer: Capped at 25 cents per month
Plants to be saved: FitzPatrick (852 MW) R.E. Ginna (582 MW) Nine Mile Point (1,937 MW)	Plants to be saved: Clinton (1,078 MW) Quad Cities (1,819 MW)

- **CEE research on price formation in day-ahead and real-time markets indicates that proposed fixes, albeit necessary, are not sufficient to induce substantial capital investment for either 2nd license renewal or deployment of new next generation nuclear reactors.**
- **We model electricity markets and test various scenarios to evaluate the “health” of nuclear plants and competitive markets as part of our Electric Power Research Forum. [Contact CEE](#) if you want to engage.**

(16) Exelon had previously expressed their intention to retire Ginna and Nine Mile Point plants, if NY subsidies were not passed. (17) See Bloomberg [States Are the Nuclear Industry’s Best Hope](#)
 (18) See Utility Dive, [Predictions 2017: 8 sector insiders on what's next for power markets and regulation.](#)
 (19) https://www.iso-ne.com/static-assets/documents/2016/08/a3_update_on_new_york_environmental_issues.pdf