Nuclear Energy Policy in the United States: Between Rocks and Hard Places

By Ben Wealer, Victoria Czempinski, Christian von Hirschhausen and Sebastian Wegel

INTRODUCTION

Nuclear energy offers some of the most daunting (and under-researched) challenges to policymakers everywhere that it has been developed and used to date, including the United States. In contrast to the policy issues that arise in other areas such as fossil fuel markets, renewables policies, and energy efficiency, where market structures are dynamic and technological progress is fast, the key issues surrounding nuclear energy have remained relatively constant over time and are long-term in nature, extending up to a million years when it comes to waste management. It is, therefore, unsurprising that the new US administration faces similar issues to the previous one, and that these are not very different from issues faced by other administrations over the past decades. Key among them are the financing of nuclear power plants, the decommissioning of obsolete plants, and the storage of nuclear waste in the medium and long run.

The authors are with the Workgroup for Infrastructure Policy at the Berlin University of Technology (corresponding Author: Ben Wealer: bw@wip.tu-berlin.de), where they are part of a long-term research program on nuclear energy, run jointly with the German Institute for Economic Research (DIW Berlin). **They thank Clemens Gerbaulet for research support; the usual disclaimer applies.**

See footnotes at end of text.

NUCLEAR ENERGY IN THE UNITED STATES

Figure 1 shows the construction and shutdowns of all reactors in the United States since 1957, as well as a forecast of future shutdowns based on corporate announcements (where available) and the latest reports by the Nuclear Regulatory Commission (NRC). We see growth in the 1960s and 1970s, with construction on not less than 25 reactors having begun in 1968 alone. Construction came to a sharp halt, however, after 1978, leading to the decline of reactor startups after 1987. The last nuclear power plant (NPP) to go online was the Watts Bar 2 plant (in Watts Bar, TN) in October 2016, where construction had begun in 1973. The 2005 Energy Policy Act (EPAct) was intended to relaunch nuclear new builds, leading to four new units that are currently under construction: Summer (SC) 2, 3, and Vogtle (GA) 3, 4. As of today, 99 reactors are still online.

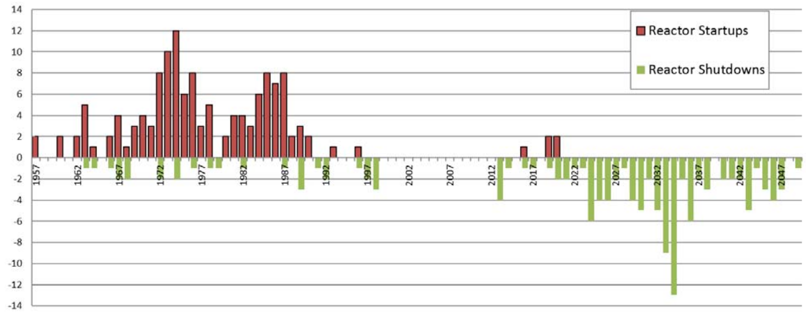

Figure 1: US nuclear power reactor grid connections and permanent shutdowns (1957 – 2050)
Sources: IAEA-PRIS, NRC, Schneider, et al. (2016), and own estimations.

Since the 1970s, nuclear power has played a significant role in overall electricity generation. Figure 2 shows the development of electricity generation from nuclear power plants since 1971 in absolute and in relative terms. Clearly, nuclear power has played an important role since the 1980s, its relative share being constant since. In 2015, nuclear generation was 797 TWh, or 19.5% of total production.

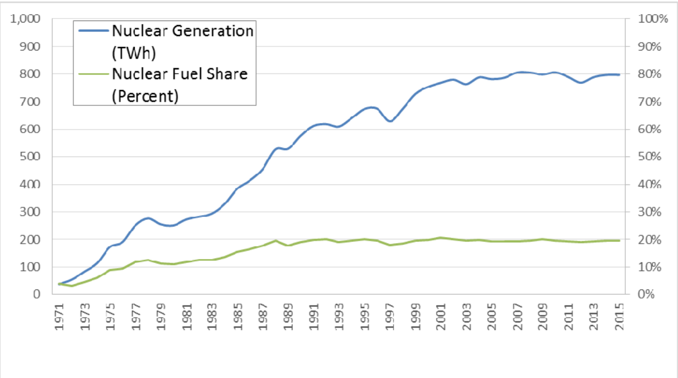

Figure 2: Electricity generation from nuclear power plants in the United States from 1972 (in TWh and relative share)
Source: NEI (2016), based on Energy Information Administration's Monthly Energy Review and Electric Power Annual

POLICY ISSUE 1: RISING COSTS OF NEW BUILDS AND OPERATION

A major issue for the new administration is whether it should intervene to save civil nuclear power. Nuclear power has been unable to attract private capital under competitive market conditions. The recent economic literature observes the absence of an economic case for nuclear electricity, and has rejected the hypothesis of nuclear power becoming competitive as a result of, e.g., rapid diffusion, economies of scale, or positive learning. Among the major reasons for nuclear power's lack of competitiveness are high and rising capital costs, as observed early on by Joskow (1982) and shown since then by Grubler

(2010) and Rangel/Lévêque (2012), among many others. Davis (2012, p. 68) summarizes the consensus of this literature, stating that seven decades after the discovery of nuclear electricity, the industry is still unable to compete with conventional fuels such as natural gas and coal.[1] The few ongoing nuclear power plant projects provide further evidence of this: all are above previous cost estimates and several years behind schedule; see the discussion between Rothwell (Nuclear Energy Organization) and Davis (UC Berkeley), reported by Rhodes (2016).

In addition, a new phenomenon that highlights the challenges to the industry is the loss of operational competitiveness by many nuclear plants, i.e., their inability to generate an operational margin:

~ On the demand side, wholesale prices have fallen, due to weak electricity demand, low natural gas prices, and an increasing share of renewable energies with low incremental costs;

~ on the supply side, the costs of running and maintaining aging NPPs have risen in recent years. The short-run costs include fuel, operation, and maintenance, and also capital additions for these plants, safety requirements, and/or lifetime extensions (e.g., from 40 to 50 or even 60 years). Lovins (2013, p. 5) provides a detailed account of industry data, indicating a range of average U.S. nuclear generating costs between US$24-60/MWh for the period 2009 to 2011. Roughly half of the plants had higher incremental production costs than the average wholesale prices of US$36/MWh.

	Plant	State	Investor	Capacity (MWnet)	Date of closure
realized	Crystal River-3	Florida	Duke Entergy	860	20.02.2013
	Fort Calhoun	Nebraska	Omaha Public Power District	478	24.10.2016
	San Onofre-2	California	Southern California Edison	1.070	07.06.2013
	San Onofre-3	California	Southern California Edison	1.080	07.06.2013
	Kewaunee	Wisconsin	Dominion Generation	556	07.05.2013
	Vermont Yankee	Vermont	Entergy	620	29.12.2014
			SUM of closed plants:	4.664	
announced	Fitzpatrick	New York	Entergy	855	2017
	Clinton	Illinois	Exelon	1.065	2017
	Quad Cities	Illinois	Exelon	1.880	2018
	Pilgrim	Massachusetts	Entergy	685	2019
	Diablo-Canyon-1	California	PG&E	1.122	2024
	Diablo-Canyon-2	California	PG&E	1.118	2025
			SUM of announced closures:	6.725	
under discussion	Oyster Creek	New Jersey	Exelon	615	
	Prairie Island	Minnesota	Xcel Energy	1.100	
	Palisades	Michigan	Entergy	778	
	Davis Bessie	Ohio	First Entergy	894	
	Ginna	New York	Exelon	581	
	Indian Point	New York	Entergy	1.022	
			SUM of closures currently discussed:	4.990	
		SUM of plants closed, announced or discussed closures		16.379	
Sources: WNISR (2016), webpages of operators					

Table 1: Nuclear power plant closures in the United States for economic reasons

Source: Website of operators, Schneider (2016), own estimates.

Nuclear power plant operators are reacting by closing their plants. At present, over 16 GW of nuclear capacity has already been closed down prematurely or is threatened with closure in the near future. Table 1 summarizes the short-run situation of NPPs and the closure announcements made thus far.

As traditional utilities are threatened, regulators ponder market design options for the low-carbon energy transformation. Nuclear utilities are lobbying regulators at the federal and state levels to offer incentives for production, e.g., capacity payments, or instate a quota for nuclear power in the respective energy mix, an example being the New York "low-carbon electricity" scheme.[2]

POLICY ISSUE 2: DECOMMISSIONING OF NUCLEAR POWER PLANTS

A second set of policy issues relates to the need for sustainable organizational models to finance and manage the decommissioning of obsolete NPPs. According to the NRC, 35 reactors are currently in permanent shutdown. However, as Figure 1 indicates, several dozen additional reactors will be shut down in the near future, and by 2050 at the latest, the number of shut-down reactors will exceed 100. Given the long list of already shut-down reactors, and the long time span since the first shutdowns occurred in the 1960s, the operational experience with decommissioning NPPs is scarce and cannot be generalized, e.g., regarding the expected decommissioning costs. Of the 35 shut-down reactors, only 13 have been fully decommissioned thus far.[3] Six additional reactors are currently in the decommissioning process[4] and one is currently in the post-operational stage.[5]

However, a large number of reactors have been put in long-term enclosure (12), meaning that they have been "packaged" but left untouched at their initial site, and await decommissioning within the next several decades.[6] Clearly, problems of knowledge management, availability of human and financial resources in the decades to come, and safety issues during the long-term enclosure still have to be resolved.[7]

The estimated and actual costs for decommissioning a reactor vary widely and depend on many factors, including the reactor type, the location of the site, and the existing waste disposal routes. For the already decommissioned reactors, the average duration was 10 years, which is short by international comparison; one reason for these short decommissioning periods is that—in most cases—large components like the pressure vessel or the steam generators are removed in one piece (i.e., without first being dismantled) and transported to nearby disposal sites. The actual decommissioning costs range from US$280/kW (Trojan plant in Portland, OR) to US$1,500/kW (Connecticut Yankee, CT) of installed capacity.[8] It is uncertain whether future decommissioning will generate significant economies of scale and whether the high variance of costs can be reduced.

Decommissioning is not a particularly difficult operation per se, but the sheer number of NPPs to be decommissioned raises issues of capacity and appropriate organizational models, such as own-production, tendering, and public and/or private procurement. A method that was recently used for decommissioning the Zion 1 and 2 reactors was to transfer the decommissioning license to a third party (here: the waste management company "Energy Solution"); compensation schemes are difficult to define (e.g., cost-plus, fixed price, etc.). Competition between service providers may help to bring costs down; yet some centralization of knowledge is useful to bundle experience and reap economies of scale.

It is unclear whether the funds earmarked for decommissioning will be sufficient. As of December 2014, the balance in the decommissioning trust funds was about US$53 billion.[9] If this sum is put in relation to the installed net capacity, the specific cost to decommission the around 100 reactors is about US$600/kW. It is probable that the decommissioning trust funds will not be able to cover all the decommissioning costs in the foreseeable future. A recent audit by the US Office of the Inspector General concludes that the estimates should be based on the best available knowledge from research and operational experience, but the NRC formula is based on studies conducted between 1978 and 1980,[10] leading to the possibility that the actual costs might be significantly higher. The audit recommended among other things that the funding formula be reevaluated to determine whether a site-specific cost estimate would be more efficient.

Two recent cases highlight the inherent risks of insufficient financing. Exelon reported shortfalls in the decommissioning fund for three reactors ranging from US$6 million to US$83 million.[11] However, Exelon was granted a 20-year license extension (by the NRC) with the idea of allowing additional time to increase the decommissioning fund. If the difficulties of raising operational benefits continue, this strategy is at risk. A second operator stated in the audit that the NRC minimum formula estimated decommissioning costs of US$600 million, but the site-specific decommissioning cost estimate done by the operator was US$2.2 billion.[13] There seems to be a need to revise the methodology to estimate future decommissioning costs to guarantee that the necessary funds are available when decommissioning begins, and the organizational model for financing may need revision as well. The operational difficulties of current operators of nuclear power plants shed new light on the situation, which differs from those prevalent in the past.

POLICY ISSUE 3: INTERMEDIATE AND LONG-TERM STORAGE OF HIGH-LEVEL NUCLEAR WASTE

By far the most daunting issue is high-level waste management (HLW), i.e., the handling of waste from military operations and from spent nuclear fuel (SNF) in power plants. Challenges arise with respect to the siting and timing of storage as well as financial aspects of the process. HLW decay will take over a million years, and very costly technical equipment is required to separate, treat, transport, and store this waste. Total SNF amounts up to about 79,000 metric tons; around 78% of which is stored in pools, and the remaining 22% in dry casks known as Independent Spent Fuel Storage Installations (ISFSI).[13] Figure 3 shows the distribution of SNF by State; some clustering is observable

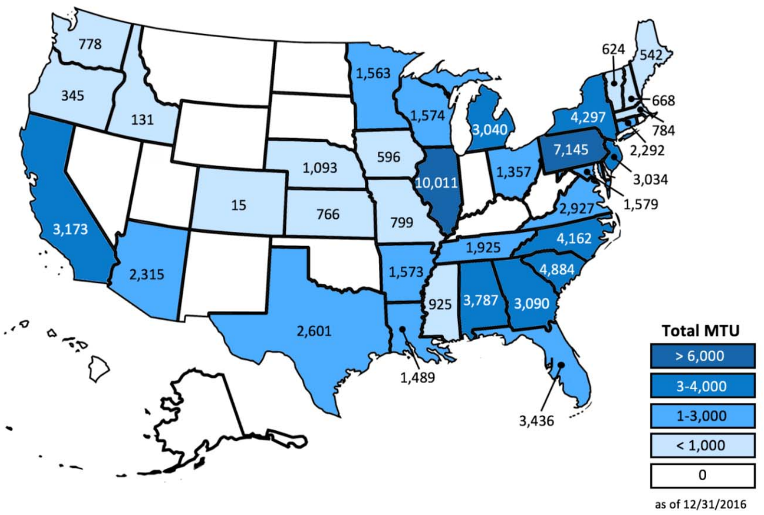

Figure 3: Regional distribution of high-level nuclear waste in the US (in metric tons)

Source: Own estimates, based on NRC (2011) in New England, in the Midwest (mainly Illinois), the Southeast, and the West (California, Arizona). [14]

At present, no long-term HLW disposal site exists in the United States. Following the 1982 Nuclear Waste Policy Act (NWPA), Yucca Mountain (NV) was identified as a potential site and the necessary research was conducted. The project was approved in 2002 by Congress, but was not pursued due to a lack of political consensus; federal funding for the site ended in 2011. Another long-term storage site is the Waste Isolation Pilot Plant (WIPP) close to Carlsbad, NM: a LLW and transuranic waste disposal facility developed by the military. For technical and legal reasons, WIPP cannot be used for SNF (Warner North, 2013, p. 2).

The absence of a HLW repository not only increases the risks of accidents and attacks on decentralized waste storage sites; it also implies a significant liability for the DOE. Since 1998, DOE has been obligated to take SNF but is unable to deliver, which forces local utilities to store SNF on their own sites, including already decommissioned sites. For this interim storage, the utilities require substantial financial compensation from the DOE.

As the search for a storage site continues, the issue of centralized interim storage sites becomes all the more urgent. In its 2013 strategy paper, the DOE plans to site, design, and operate a consent-based pilot interim storage facility by 2021. The initial focus of this facility is on accepting SNF from already shut-down reactor sites. A larger interim storage facility should then be available by 2025; here the DOE is only responsible for the siting and licensing. The plan is that this facility be able to accept enough SNF to reduce government liabilities.[15] Regional interim storage sites may offer a safer and less costly alternative to storing fuel at the power plant sites, and attempts are underway to identify and place such interim storage sites, most likely at existing large NPPs or LLW waste disposal facilities. Private service suppliers are becoming more active on the interim storage front. These include Waste Control Specialists LLC, which are applying for a license to build a storage installation in Texas (~10,000 tons capacity), and Holtec International, planning an interim SNF facility near the WIPP facility in New Mexico.

Financial flows to manage the future storage of HLW are irregular at present. Following the 1982 NWPA, electricity ratepayers were required to pay a tenth of a cent per kilowatt-hour into the nuclear waste fund held by the DOE in exchange for the administration accepting SNF for disposal. As the DOE failed to deliver, the fee was abandoned in 2014. Already, DOE has spent over US$10 billion in legal penalties, and the administration currently estimates that total damages could amount to $20.8 billion—if the government begins accepting fuel in 2020. If the administration fails again to deliver, the liabilities could increase by hundreds of millions of dollars annually (BRC, 2012, p. 79).[16]

The Blue Ribbon Commission “On America’s Nuclear Future”, set up in 2012 by the Secretary of Energy at the request of the former President, conducted a comprehensive review of policies, including a suggestion to fund the waste management program (BRC, 2012, pp. 70–80). According to the final report, the annual fee revenues and the unspent balance in the waste fund have become inaccessible to federal budgeters and appropriators after a series of actions by successive administrations and Congress, and have forced them to take money away from other federal priorities to fund waste management activities. The commission, therefore, recommended a two-stage transition: first, non-legislative actions that would allow full access to future waste fee revenues, and second, legislative action as part of an independent waste management organization that would allow it to function as an autonomous self-financed entity.

A reform of the financing scheme is urgent to restore stability in the sector. DOE is currently the main actor but might need institutional support to become more flexible and to accumulate and maintain knowledge. Preparing a physical scheme for storage must go hand in hand with financing, and both require immediate attention. The proposal to found a new organization with the central task of licensing, building, and operating the facility with assured access to funds and overseen by Congress and the appropriate government agencies, as proposed by the Blue Ribbon Commission, might be the right starting point to tackle the serious problem of nuclear waste.

CONCLUSIONS

Nuclear policy has been a dilemma for previous U.S. administrations, and there is no reason to believe that this will change with the new administration. To the contrary: the recent loss of short-term competitiveness of nuclear power plants increases the need to take effective action soon. The decommissioning of plants has not been a major policy issue to date, but this may change as the number of reactors awaiting decommissioning continues to rise rapidly, as cost estimates continue to vary, and financing is not fully assured. New governance structures might yield the benefits of scale economies while maintaining the information advantage of incumbent NPP operators. Long-term storage of waste requires special action with respect to siting interim sites as well as one or two long-term sites in a consensual process, while cleaning up the financial flows to make the process sustainable.

Footnotes

[1] For a recent methodological reference on the economics of nuclear power plants, see Rothwell (2015).

[2] New York Department of Public Service (2016, pp. 27-33): Staff White Paper on Clean Energy Standard. New York.

[3] Successfully decommissioned: Big Rock Point (MI), Connecticut Yankee (CT), CVTR (SC), Elk River (MN), Fort St. Vrain (CO), Maine Yankee (ME), Pathfinder (SD), Rancho Seco Unit 1 (CA), Saxton (PA), Shippingport (PA), Shoreham (NY), Trojan (OR), and Yankee Rowe (MA).

[4] Slighted for decommissioning: Humboldt Bay (CA), San Onofre-2 and -3 (CA): Three Mile Island 2 (PA), Zion 1 and 2 (IL).

[5] The latest shutdown reactor is Fort Calhoun 1 (NE) and was shut down in October 2016.

[6] The following plants are in a stage of long-term enclosure: Crystal River 3 (FL), Dresden 1 (IL), Fermi 1 (MI), GE EVESR (CA), GE Vallecitos (CA), Indian Point 1 (NY), Kewaunee (WI), Lacrosse (WI), Millstone 1 (CT), Peach Bottom 1 (PA), San Onofre 1 (CA), and Vermont Yankee (VT).

[7] Additionally, three reactors are in entombment; here, radioactive contaminants are permanently encased on-site in materials such as concrete: Bonus (Puerto Rico), Piqua (OH), and Hallam (NE).

[8] The total costs including site restoration amounted to US$836 million for Connecticut Yankee (also named Haddam Neck) and US$308 million for Trojan. OECD/NEA (2016, p. 76): Costs of Decommissioning Nuclear Power Plants. Paris.

[9] Office of the Inspector General (2016, p.5): Audit of the NRC's Decommissioning Funds Program. Washington, DC.

[10] Office of the Inspector General (2016, op cit., p. 10).

[11] Exelon shortfalls: Byron Station 2 US$83 million, Braidwood Station 1 US$6 million, and Braidwood Station 2 US$15 million. NRC (2016). The shutdown of the reactors is now scheduled for 2046/47.

[12] Office of the Inspector General (2016, op cit., p. 10).

[13]The amounts are estimated using existing data of 2011 and 2015 along with adding the calculated per-year production of new waste.

[14] In addition, 20,000 canisters of defense-related high-level radioactive waste need to be stored (Alley, Alley, 2013, p. xiv).

[15] Department of Energy (2013, p.2): Strategy for the management and disposal of used nuclear fuel and high-level waste. Washington, D.C..

[16] These damages have not been paid using money from the waste fund but from the taxpayer-funded Judgment Fund, which is overseen by the Department of Justice (BRC, 2012, p. 79)

References

Alley, W.M. & Alley, R. (2013). Too Hot to Touch: The Problem of High-Level Nuclear Waste. Cambridge, UK: Cambridge University Press.

BRC (2012). Blue Ribbon Commission on America's Nuclear Future. Report to the Secretary of Energy, Washington, D.C., USA, last accessed February 15, 2017 at https://energy.gov/sites/prod/files/2013/04/f0/brc_finalreport_jan2012.pdf.

Davis, L.W. (2012). Prospects for Nuclear Power. *Journal of Economic Perspectives*, 26(1), pp. 49–66.

Grubler, A. (2010). The Costs of the French Nuclear Scale-up: A Case of Negative Learning by Doing. *Energy Policy*, 38(9), pp. 5174–5188.

Lovins, A.B. (2013). The Economics of a US Civilian Nuclear Phase-Out. *Bulletin of the Atomic Scientists*, 69(2), pp. 44 – 65.

Rangel, L.E. & Lévêque, F. (2012). Revisiting the Cost Escalation Curse of Nuclear Power: New Lessons from the French Experience. Paris, France, last accessed March 11, 2013 at http://www.cerna.ensmp.fr/images/CostEscalationPaper.pdf.

Rhodes, K. (2016). Nuclear Reactions – Lessons Learned from Projects in Georgia and South Carolina Might Determine the Course of U.S. Nuclear Development for Decades to Come. *Econ Focus*, First Quarter, pp. 15 – 17, 21.

Rothwell, G. (2015). Economics of Nuclear Power. London, UK: Routledge.

Schneider, M., Froggatt, A., Hazemann, J., Fairlie, I., Katsuta, T., Maltini, F. & Ramana, M.V. (2016). World Nuclear Industry Status Report 2016. Paris, last accessed July 27, 2016 at http://www.world-nuclearreport.org/IMG/pdf/20160713MSC-WNISR2016V2-HR.pdf.