PACIFIC ENERGY SUMMIT

2018 Summit Working Paper

Pathways to Trans-Pacific Cooperation in the Nuclear Sector

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This working paper was commissioned by the National Bureau of Asian Research (NBR) for the 2018 Pacific Energy Summit. Opinions, conclusions, and recommendations expressed or implied within are solely those of the author and do not necessarily represent the views of the Air University, the U.S. Air Force, the Department of Defense, or any other U.S. government agency, or NBR.

EXECUTIVE SUMMARY

The U.S. and partners in Asia should leverage their respective strengths and increase cooperation in civil nuclear technology in order to bolster their nuclear power industries and address near- and long-term challenges.

Main Argument

The nuclear energy sector currently faces significant challenges on both sides of the Pacific. Contrary to predictions in the early 2000s, a U.S. nuclear renaissance has not come to fruition. Instead, the U.S. nuclear industry has experienced a series of early plant closings, delayed or canceled construction projects, and financial struggles. Meanwhile, Asia, led by China, is anticipated to be the primary growth market, despite current downward trends in nuclear energy production in countries such as Taiwan and South Korea. Nuclear energy is projected to remain a significant source of electricity in the near future and play a key role in reducing reliance on fossil fuels, but the nuclear industries on both sides of the Pacific must grapple with significant regulatory, investment, and social license challenges that could undermine the long-term viability of nuclear power. However, both sides of the Pacific have expertise that, if shared, could significantly bolster each other's nuclear industries. Finding pathways to further deepen nuclear cooperation on fuel cycle services, reactor construction, and reactor decommissioning between Asia and the U.S. will be vital to the future of nuclear power in the world.

Policy Implications

- Trans-Pacific cooperation can bolster the region's nuclear energy industries. Increasing nuclear collaboration by sharing technologies and methods and engaging policymakers in dialogues that establish best safety, security, and nonproliferation practices can reinvigorate the Indo-Pacific's nuclear industries and address social license concerns.
- The U.S. should leverage its expertise in areas that supplement nuclear industry needs in Asia. Providing decommissioning services or technology and interim storage technology and continuing to develop options for long-term nuclear waste management are two examples.
- Reinvigoration of the U.S. nuclear industry requires national, state, and local policymakers to modernize the regulatory environment and create economic policies that facilitate Asian investment in the U.S. Asian firms can bolster U.S. competitiveness in the industry through investments that offset U.S. nuclear deficiencies, such as building next-generation nuclear reactor technology on existing sites.

This century has opened with two declared revivals in the U.S. energy sector. In the early 2000s, a nuclear renaissance was projected, and about ten years later, the shale gas revolution promised to revitalize U.S. natural gas production. The latter revival has come to fruition, and for the first time since 1957, the United States was a net exporter of natural gas in 2017.[1] However, the former revival has fizzled. The U.S. nuclear industry has experienced a series of early plant closings, delayed or canceled construction projects, and financial struggles for nuclear firms over the past decade.

In addition to the development and deployment of new extraction technology, U.S. natural gas production has been driven by increased global demand for natural gas, particularly in Asia. Investors from Asia also have played an active and vital role in developing new natural gas fields and liquefaction capacity in the United States. Unlike in the United States, Asia has seen significant growth in nuclear power over the last fifteen years, and the region remains the primary growth market for nuclear power, despite some struggles in the Asian nuclear industry after the Fukushima disaster in 2011.

The nuclear sectors in the United States and Asia are projected to continue to be major sources of electricity in the near future and play a key role in transitioning away from fossil fuels. However, the nuclear industries on both sides of the Pacific still must grapple with economic, political, and social challenges that could undermine the long-term viability of nuclear power. Finding pathways to further deepen nuclear cooperation between Asia and the United States will be vital to the future of nuclear power in the world.

This paper will explore the role for policy in pursuing market-based and collaborative approaches to strengthening the nuclear energy industry in the United States and Asia. The first section will briefly review the development of nuclear power in the United States and in Asia. For this discussion, the countries in Asia that will be considered are Japan, South Korea, China, Taiwan, and India—countries with mature nuclear industries and that are likely to shape markets due to their consumption trends. The second section will examine the challenges and needs currently facing the nuclear industries on both sides of the Pacific and then identify potential pathways for cooperation between Asia and the United States that can boost the viability of the nuclear industry.

[1] "The United States exported more natural gas than it imported in 2017," U.S. Energy Information Administration, 19 March 2018, https://www.eia.gov/todayinenergy/detail.php?id=35392.

Nuclear Energy in the Asia-Pacific: A Brief History

Nuclear power production in the Asia-Pacific, and indeed in the world, dates back to 1951, when the Experimental Breeder Reactor I in Idaho became the first nuclear reactor in the world to produce a usable amount of electricity.[2] From this starting point, the U.S. nuclear industry grew rapidly from the mid-1960s to the early 1990s. Today, there are currently 99 operable reactors in the United States, down from a peak of 112 in the 1990s.

Many Asian countries followed suit, and in 1963 Japan became the first country in Asia to commercially generate nuclear power with the Japan Power Demonstration Reactor. India's first commercial nuclear reactor went online later in the 1960s, and South Korea and Taiwan started their first commercial reactors in the 1970s. India and South Korea have seen steady growth in the past twenty years, while Taiwan's industry has stagnated, staying at six operable reactors since 1985. China did not start commercial nuclear generation until 1991, but the Chinese nuclear industry has grown rapidly in the last fifteen years and is now on pace to overtake Japan as the possessor of Asia's largest fleet of operable nuclear reactors in the near future. China accounts for over half of the reactors under construction in the region and over 50% of nuclear generation in 2017 (see **Table 1**).

Table 1 *Nuclear power statistics in Asia in 2017*

Country	Operable reactors	Reactors under construction	Nuclear generation (TWh)	Nuclear share of generation (%)
China	40	17	247.5	3.94
India	22	7	34.9	3.22
Japan	42	2	29.1	3.61
South Korea	24	4	141.1	27.12
Taiwan	6	2	21.6	9.33
Total	134	32	474.2	5.32

Beyond this capture of any one country's demand curve, it is important to note that there already is a long history of nuclear commerce and cooperation between the United States and Asia. Starting with the Atoms for Peace program in the 1950s, U.S. nuclear reactor technology has been

[2] "Experimental Breeder Reactor-I," Idaho National Laboratory, http://www4vip.inl.gov/ebr/.

exported and indigenized in several Asian countries. Japan's first reactor was imported from the United Kingdom, and subsequent imports were of U.S. light water reactors (LWRs).[3] South Korea's first reactor was a U.S. LWR and also imported French LWR and Canadian heavy water reactor technology.[4] Both Japan and South Korea subsequently developed indigenous reactor designs based on imported LWR technology. All six of Taiwan's reactors are imported U.S. LWRs.[5] India's first two reactors at Tarapur are imported U.S. LWRs, but India turned to the development of heavy water reactors, initially imported from Canada, and the thorium fuel cycle after that. China imported reactor technology from France, Canada, and Russia, but the first U.S. LWRs are projected to enter operation in November 2018.[6] American and Asian firms have established strong partnerships in nuclear technology, such as the joint venture between General Electric and Hitachi. There also exist several bilateral and multilateral forums through which countries on both sides of the Pacific exchange experience and expertise in nuclear technology.

In addition to reactor technologies, the nuclear fuel cycle is an international process in Asia, with different fuel cycle services imported from the United States, Russia, Canada, France, Kazakhstan, the United Kingdom, and elsewhere (see **Table 2**). No country in Asia has a completely indigenous nuclear fuel cycle, and all Asian countries discussed here have imported nuclear materials and fuel cycle technologies from the United States.[7]

[3] "Nuclear Power in Japan," World Nuclear Association, June 2018, http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-power.aspx.

[4] "Nuclear Power in South Korea," World Nuclear Association, December 2017, http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx.

[5] "Nuclear Power in Taiwan," World Nuclear Association, June 2018, http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx.

[6] "World's first AP1000 reactor set to debut in China in November: media," *Reuters*, 11 June 2018, https://www.reuters.com/article/us-china-nuclearpower/worlds-first-ap1000-reactor-set-to-debut-in-china-in-november-media-idUSKBN1J808G.

[7] China and India aim to become mostly self-sufficient in the fuel cycle. Japan must rely on uranium imports due to the lack of uranium reserves in the country but is developing some level of indigenous capacity in fuel cycle steps after that. South Korea and Taiwan employ open fuel cycles and are prohibited from enrichment or reprocessing activity per their nuclear cooperation agreements with the United States.

Table 2 *Sources of fuel cycle services in Asia*

Country	Mining and milling	Conversion	Enrichment	Fuel fabrication	Reprocessing
China	Domestic; Kazakhstan, Uzbekistan, Canada, Namibia, Niger, Australia	Domestic	Domestic; Russia, URENCO	Domestic; France, Kazakhstan, Russia	Domestic (French cooperation)
India	Domestic; Russia, Kazakhstan, Canada, AREVA	Domestic	Domestic; Russia	Domestic	Domestic
Japan	Australia, Canada, Kazakhstan, Uzbekistan, Namibia		Domestic; United States, Russia	Domestic	Domestic; France, United Kingdom
South Korea	Kazakhstan, Canada, Australia, Niger		Russia, France, URENCO, United States	Domestic	N/A
Taiwan				United States	

Looking Ahead: Business-as-Usual Scenarios for the Next Ten Years?

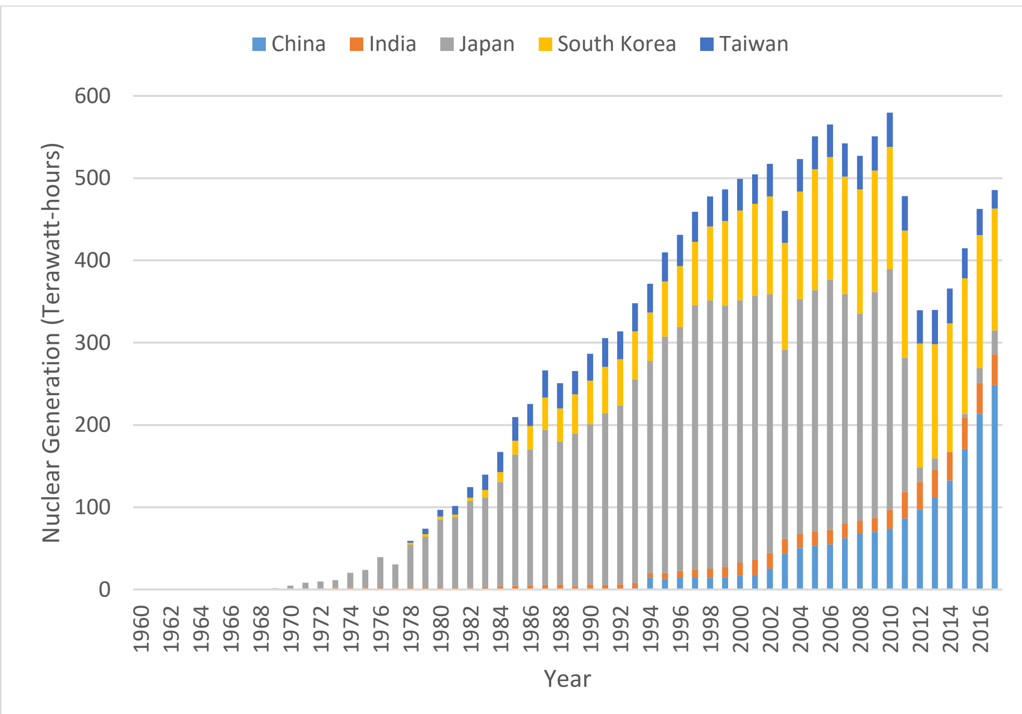
The U.S. nuclear industry is still the world's largest, both in terms of number of operable reactors and in nuclear generation. Yet growth in new nuclear power generation has stagnated in recent decades. The nuclear renaissance that was hoped for in the early 2000s appeared to gain momentum in the latter part of the decade as the Nuclear Regulatory Commission (NRC) received applications for combined construction and operating licenses (COLs) for 26 new reactors at 17 sites by 2010.[8] However, the NRC does not list any COL applications currently under review, and ten of the received applications are listed as withdrawn or suspended.[9]

[8] "COL Applications," World Nuclear Association, November 2016, http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/appendices/nuclear-power-in-the-usa-appendix-3-col-applicatio.aspx.

[9] "Combined License Applications for New Reactors," U.S. Nuclear Regulatory Commission, 25 April 2018, https://www.nrc.gov/reactors/new-reactors/col.html; The two reactors at Vogtle currently are projected to come online in November 2021 and November 2022, and the successful completion and operation of these will be critical to the future of nuclear power in the United States. "Generating Plants," Georgia Power, https://www.georgiapower.com/company/energy-industry/generating-plants.html; Despite the reduction in the

If we look to the other side of the Pacific, Asia is anticipated to be the growth market, led by China, yet with fundamentally different characteristics in its history to date in development and demand. After the 2011 Fukushima nuclear disaster, all nuclear reactors in Japan were gradually shut down while new nuclear regulations were created (see **Figure 1**).[10] The effect of the shutdown nuclear reactors and increased fossil fuel imports also hurt the ten regional power utilities in Japan, nine of which own nuclear reactors. The utilities raised electricity rates in response to higher fossil fuel costs, with adverse effects on businesses, particularly manufacturers.[11] Since the first reactors restarted in 2015, the nuclear share of overall generation in Japan has only been a very low percentage, down from around 30% before 2011.

Figure 1 *Nuclear generation in Asia from 1960 to 2017*



total number of operable reactors, nuclear generation has increased due to power uprates and improved operations that increased the fleet-wide capacity factors from around 70% in the early 1990s to around 90% by 2007. This also has kept nuclear power's share of overall electricity generation in the United States at around 20%.

[10] "Ohi-4 NPP Restarted, Kansai EP to Lower Rates 4%," Japan Atomic Industrial Forum, Inc., 10 May 2018, http://www.jaif.or.jp/en/ohi-4-npp-restarted-kansai-ep-to-lower-rates-4/.

[11] The utilities that have been able to restart reactors have fared somewhat better. "Keidanren Survey: Businesses Affected Adversely by Rising Power Rates," Japan Atomic Industrial Forum, Inc., 8 April 2015, http://www.jaif.or.jp/en/keidanren-survey-businesses-affected-adversely-by-rising-power-rates/.

The nuclear industries in South Korea and Taiwan face potentially more immediate existential crises, as the current presidents in both countries have vowed to phase out nuclear power. There has been steady growth of nuclear power in South Korea since the country's first reactor went online in 1977 to 2017, while Taiwan's nuclear sector has remained the same size since the mid-1980s (see **Figure 1**).

South Korea's Ministry of Trade, Industry and Energy (MOTIE) announced a draft of the 8th Basic Plan for Long-Term Electricity Supply and Demand in December 2017, and it called for a decrease in installed nuclear capacity from 22.5 gigawatts (GW) to 20.4 GW by 2030. Nuclear power's share of electricity generation also would modestly decrease to 23.9%, while renewables and natural gas would see significant expansion in installed capacity and share of generation.[12]

South Korean president Moon Jae-in outlined his phase-out plan at the closing of South Korea's first nuclear reactor, Kori-1, in June 2017. He said that existing reactors would not be allowed to operate beyond 40 years and that no new reactors would be planned.[13] Moon's announcement placed in doubt reactors currently under construction in South Korea, but a government commission approved the resumption of the construction of two new reactors, Shin Kori-5 and Shin Kori-6, in October 2017.[14] Two other reactors, Shin Hanul-1 and Shin Hanul-2, are expected to go online in 2018 and 2019, respectively, but the Moon government does not support any further reactor construction or planning.[15] If Moon's gradual phase-out policy stands, South Korea's last reactors would shut down by the early 2060s. Thus, the policy would not have a large impact immediately in terms of electricity generation.

Taiwan president Tsai Ing-wen assumed office in 2016 and announced that Taiwan would phase out nuclear power by 2025, when all currently operable reactors would reach at least 40 years of age. Two additional reactors that are partially completed also would be abandoned without

[12] "Ministry announces 8th Basic Plan for Electricity Supply and Demand," Republic of Korea Ministry of Trade, Industry and Energy, 15 December 2017, http://english.motie.go.kr/en/pc/pressreleases/bbs/bbsView.do?bbs_cd_n=2&bbs_seq_n=605.

[13] "Korea's nuclear phase-out policy takes shape," World Nuclear News, 19 June 2017, http://www.world-nuclear-news.org/NP-Koreas-nuclear-phase-out-policy-takes-shape-1906174.html.

[14] Kim Eun-jung, "Resumption of construction for 2 nuclear reactors to affect gov't plan," Yonhap News Agency, http://english.yonhapnews.co.kr/business/2017/10/20/7/0501000000AEN20171020003952320F.html.

[15] "Design work suspended for new Shin Hanul units," World Nuclear News, 26 May 2017, http://www.world-nuclear-news.org/NN-KHNP-design-work-suspended-for-new-Shin-Hanul-units-2605174.html.

ever entering service.[16] Tsai's policy is stipulated by law: an amendment to the Electricity Act approved in 2017 requires all nuclear power operations to end by 2025.[17] Taiwan plans to increase its share of renewable generation as it phases out nuclear power.[18]

This review of challenges for the nuclear industries in Japan, South Korea, and Taiwan should not be understood as suggesting that nuclear power in China or India does not face similar challenges. Both China and India are far from completing their planned closed fuel cycles, and public anxiety over nuclear power and spent fuel management may be rising in both countries. In China, protests by local residents in Lianyungang in 2016 led to the suspension of the development of a site for a reprocessing facility, and no new site has been selected yet.[19] In India, local protests against the construction on units 1 and 2 at the Kudankulam nuclear power plant broke out after the Fukushima nuclear disaster in 2011, but the two reactors eventually went online in 2013 and 2016, respectively.[20] As the nuclear industries in China and India grow, both countries will also have to better address spent fuel management and public acceptance.

Opportunities and Challenges for Stimulating Innovation

With this context in mind, what does this mean for the future of demand for nuclear energy in Asia and the prospects for forging new and deeper Asia-Pacific ties? There are three major trends that highlight the needs and uncertainties inhibiting nuclear energy development that are important for policymakers.

[16] "Nuclear Power in Taiwan," World Nuclear Association, June 2018, http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx.

[17] "President Tsai reiterates goal of phasing out nuclear energy by 2025," Focus Taiwan News Channel, 11 March 2018, http://focustaiwan.tw/news/aipl/201803110015.aspx.

[18] "Taiwan's New Energy Policy," Taiwan Ministry of Economic Affairs, 26 April 2018, https://www.moea.gov.tw/MNS/ietc_e/content/Content.aspx?menu_id=21511.

[19] David Stanway and Geert De Clercq, "So close yet so far: China deal elusive for France's Areva," *Reuters*, 11 January 2018, https://www.reuters.com/article/us-areva-china-nuclearpower-analysis/so-close-yet-so-far-china-deal-elusive-for-frances-areva-idUSKBN1F01RJ.

[20] Vidya Venkat, "The story of Kudankulam: From 1988 to 2016," *The Hindu*, 20 September 2016, https://www.thehindu.com/news/national/The-story-of-Kudankulam-From-1988-to-2016/article14564027.ece.

First, nuclear power has become a significant source of electricity and helped fuel economic development and industrial growth in major economies across the Asia-Pacific. Prospects for further growth in the near future for the nuclear industries in Asia and the United States are in question primarily due to economic and political challenges. However, these political and economic problems could be addressed, in part, through improving current technologies or by developing and deploying new technologies, as will be explored in this section.

Second, China is the exception to the decreasing utilization of nuclear energy in the region, which raises important questions for safety and security in the nuclear technology export market. Safety, security, and nonproliferation technology and practices have been heavily influenced by the United States due to U.S. dominance in the export market, but China could become a dominant exporter with the directions of the two countries' nuclear industries. Advanced reactors are intended to have stronger inherent safety, security, and nonproliferation design features, but China also will be expected to export robust safety, security, and nonproliferation practices. Whether Chinese nuclear firms will adhere to standards similar to U.S., Japanese, or South Korean exporters is a significant question.

Finally, although the challenges facing each country's nuclear industries are unique, the effects of a struggling nuclear industry are not isolated, and these consequences may reverberate across the region, particularly in relation to energy and environmental security. Cooperation between Asia-Pacific countries is necessary and future efforts can build on previous collaborative attempts. To this end, the next seven subsections explore critical areas where increased collaboration could alleviate some of the challenges facing nuclear industries and consider what potential collaborative pathways forward might look like.

Decommissioning

Retiring and decommissioning a nuclear reactor is a normal and necessary part of a reactor's life cycle, but in recent years several reactors have permanently shut down before their current operating license expired. A commercial power reactor in the United States typically receives an initial 40-year operating license from the NRC, and reactor operators can apply for 20-year license extensions. Only two closed reactors in U.S. history operated for at least 40 years, and those two reactors had received license extensions.[21]

Commercial reactor operators can choose either decontamination (DECON) or safe storage (SAFSTOR) for decommissioning. DECON is the faster method, taking at least 7 years, but SAFSTOR can reduce the cost of decommissioning by spreading the process out for 50 or more years. Current decommissioning activities in the United States will take until nearly 2080, as four of the six reactors shut down since 2013 are using the SAFSTOR method of decommissioning.[22]

Decommissioning can cost hundreds of millions to upward of $1 billion per reactor, and reactor operators establish a decommissioning fund during construction. Per the World Nuclear Association, nearly two-thirds of the total estimated cost for decommissioning the entire U.S. reactor fleet has already been collected, and a 2016 report by S&P Global Ratings said that "no U.S. nuclear utilities were facing a 'serious funding gap' in meeting future reactor decommissioning costs."[23] However, as the U.S. Energy Information Administration pointed out, "when reactors are retired earlier than planned, shortfalls in funding may result in additional expenses to electric ratepayers."[24] As reactors continue to shut down, operators will have to commit more money to decommissioning, with the possibility that sufficient decommissioning funds were not collected prior to being shut down.

Cooperation pathway: Decommissioning technology. The United States has had over 30 reactors enter decommissioning, with other reactors slated for shutdown in the near future.[25] Japan has nearly 20 reactors shut down and in some stage of decommissioning, and more reactors surely will shut down in the coming years. The U.S. Department of Commerce's International Trade

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[21] See information on Crystal River 3, Kewaunee, Vermont Yankee, and Fort Calhoun at "Status of Initial License Renewal Applications and Industry Initiatives," U.S. Nuclear Regulatory Commission, 4 May 2018, https://www.nrc.gov/reactors/operating/licensing/renewal/applications.html.

[22] "Decommissioning nuclear reactors is a long-term and costly process," U.S. Energy Information Administration, 17 November 2017, https://www.eia.gov/todayinenergy/detail.php?id=33792.

[23] "US Nuclear Fuel Cycle," World Nuclear Association, June 2018, http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-fuel-cycle.aspx.

[24] "Decommissioning nuclear reactors is a long-term and costly process," U.S. Energy Information Administration, 17 November 2017, https://www.eia.gov/todayinenergy/detail.php?id=33792.

[25] "Decommissioning Status for Shutdown U.S. Nuclear Plants," Nuclear Energy Institute, April 2016, https://www.nei.org/resources/statistics/decommissioning-status-for-shutdown-us-plants.

Administration cites decommissioning as a growing industry, with Japan "quickly becoming the largest nuclear decommissioning and decontamination (D&D) market in the world behind the United States."[26] South Korea also saw its first reactor enter decommissioning last year. Economically and environmentally successful decommissioning will be vital to demonstrate the full life cycle viability of nuclear power and to build public trust in nuclear power.

The United States has more experience decommissioning reactors than nuclear industries in Asia, but both sides of the Pacific could benefit from more robust sharing of decommissioning technologies and methods. U.S. decommissioning technology has been promoted for use in Japan, and likewise technologies and methods that are successfully developed and employed in Japan, South Korea, China, or elsewhere in Asia should be studied for potential use in the United States. Different regulatory and social environments could make transferring some technologies or methods difficult, but certainly some decommissioning technologies could have potential for universal use.

Early Reactor Closures and Construction Delays

The economic viability of currently operable nuclear reactors, particularly so-called at-risk reactors, is one of the most pressing issue facing the nuclear industry in the United States and several other countries today. All six U.S. reactors that have closed since 2013 have done so prior to the expiration of their operating license at the time of shutdown. According to the think tank Third Way, twelve more reactors have announced retirement dates through 2025, and five more are being considered for retirement.[27]

Nuclear operators also have not been able to replace retired reactors, as only three reactors have come online since 1990, leading to a decline in the total number of operable reactors in the United States. Studies estimate that one-half to two-thirds of nuclear power plants in the United States are at risk of early closure due to poor economic conditions.[28]

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[26] "Japan - Nuclear Decommissioning and Decontamination," U.S. Department of Commerce International Trade Administration, 25 September 2017, https://www.export.gov/apex/article2?id=Japan-Nuclear-Decommissioning.

[27] Ryan Fitzpatrick, "Nuclear Closures Undo Years' Worth of Climate Progress," Third Way, 10 April 2018, https://www.thirdway.org/memo/nuclear-closures-undo-years-worth-of-climate-progress.

[28] Ryan Fitzpatrick, "Nuclear Closures Undo Years' Worth of Climate Progress," Third Way, 10 April 2018, https://www.thirdway.org/memo/nuclear-closures-undo-years-worth-of-climate-progress.

Reactor construction projects have experienced long delays and cost overruns, which makes it uncertain when investors will recoup the large, upfront capital costs associated with building nuclear reactors, contributing to the trend of reactor closings outpacing openings. A variety of factors have caused construction delays. An increasingly complex, stringent regulatory environment plays a role in prolonging the design and construction of new reactors, and there has long been discussion of the need to streamline the regulatory process in the United States. A variable energy market that has included dips in electricity demand and the surge in natural gas production in the last decade also have affected investor decisions to push forward with nuclear reactor construction. But the lack of standardization and recent experience building nuclear plants may be the main reason for delays. These factors lead to uncertainties in plant design, project management, supply chain management, and regulatory oversight. Constructing a nuclear reactor is an incredibly complex project, especially when building a new kind of reactor. There is no substitute for experience, which is lacking in the United States with the over 20-year gap between new reactor orders.

In a recent example of this, the delays and cost overruns in the VC Summer and Vogtle construction projects led to the bankruptcy of one of the main nuclear vendors in the United States, Westinghouse. In March 2017, Westinghouse filed for Chapter 11 bankruptcy protection, and Southern Nuclear took control of project management at Vogtle, with Bechtel managing construction efforts.[29] Toshiba, Westinghouse's parent company, was forced to sell Westinghouse. The sale of Westinghouse to Canada-based Brookfield Business Partners was approved by U.S. bankruptcy court in March 2018. Westinghouse is reorganizing around its nuclear service business, which the company claims is still profitable, while moving away from its nuclear construction business.[30] While the bankruptcy only affected Westinghouse's U.S. operations, the future viability of the company in both domestic and overseas operations will be vital.[31]

[29] Aaron Larson, "Westinghouse Reorganization Approved by Bankruptcy Court," *POWER*, 28 March 2018, http://www.powermag.com/westinghouse-reorganization-approved-by-bankruptcy-court/.

[30] Jonathan Randles, "Judge Approves Brookfield's $4.6 Billion Deal for Westinghouse," *Wall Street Journal*, 27 March 2018, https://www.wsj.com/articles/judge-approves-brookfields-4-6-billion-deal-for-westinghouse-1522181877.

[31] "Court approves Westinghouse reorganisation plan," World Nuclear News, 28 March 2018, http://www.world-nuclear-news.org/C-Court-approves-Westinghouse-reorganisation-plan-2803184.html.

In addition to the difficult economics of building new reactors in the United States, national security concerns also would be raised regarding foreign firms building nuclear reactors in the United States, especially for Chinese firms. Immediate issues likely would include supply chain security and quality control. There would be concerns that foreign vendors, particularly Chinese entities, could embed technology in components to conduct espionage or sabotage on U.S. nuclear plants. Others may worry that foreign reactors would not be as safe or reliable as U.S. reactors, which would affect the economic viability of the U.S. nuclear industry. Although such concerns should be partly assuaged by the fact that foreign-supplied reactors would still be subject to stringent NRC safety and security regulations, there would be additional concerns that the United States is ceding control over a critical technology that has long been viewed as having national security implications. Foreign firms building nuclear reactors in the United States could be viewed as a sign that U.S. leadership in nuclear technology is waning, resulting in declining U.S. influence on global norms for nuclear security, safety, and nonproliferation. While those would be valid concerns, the experience building new reactors at Vogtle and VC Summer shows that foreign suppliers may be necessary now to keep the U.S. nuclear industry alive beyond the current fleet of reactors. In addition, U.S. nuclear firms already utilize a global supply chain and have experience collaborating with Asian partners.

Cooperation pathway: Build reactors on existing reactor sites. The lack of new reactor construction over the last 30 years and the bankruptcy of Westinghouse leave the United States with a diminished fleet of reactors and without one of its major nuclear construction firms. Asian nuclear firms, particularly in China and South Korea, have much more recent experience building nuclear reactors. While new construction still faces economic challenges, there could be opportunities for Asian firms to invest in existing reactor sites and deploy new reactor technologies.

The NRC issued two early site permits (ESPs) for new reactors on existing reactor sites in Illinois and New Jersey, and one ESP application is under review for a small modular reactor in Tennessee.[32] Only one of the eight issued COLs and the one ESP under review are for reactors on

[32] "Early Site Permit Applications for New Reactors," U.S. Nuclear Regulatory Commission, 13 September 2017, https://www.nrc.gov/reactors/new-reactors/esp.html.

new sites, and the other COLs and ESPs are for new reactors on existing sites. [33] Prospects clearly appear better for building new reactors on existing sites rather than developing new sites.

There is also an opportunity to utilize newer technologies on these existing sites. Generation III LWRs are not new designs, but they would be a generational upgrade from the current fleet of Generation II LWRs in the United States. China, Japan, and South Korea all have operable Generation III LWRs, and China and South Korea have the most recent experience constructing Generation III LWRs. U.S. utilities should explore using Asian firms to lead construction of Generation III LWRs at existing reactors sites. The two most promising designs arguably are the AP1000 designed by Westinghouse and the APR1400 designed by Korea Electric Power Corporation (KEPCO).

Chinese firms may be best positioned to take on AP1000 construction projects, as they are already working with Westinghouse on multiple AP1000s. Unit 1 of the Sanmen power plant in China became the first AP1000 in the world to enter operations on June 30, 2018, and three additional AP1000s are anticipated to come online in China by the end of 2019.[34] Westinghouse also partnered with China's State Nuclear Power Technology Company to develop a supply chain for AP1000 construction projects, including in the United States. [35] The major challenge to overcome with completing AP1000 construction projects is convincing power utilities that building and operating new reactors would be commercially viable given current and projected market conditions. Chinese nuclear firms have the advantage of government backing, but market conditions in particular U.S. states would determine if U.S. utilities want to move forward with building new reactors.

Asian firms also could move to secure contracts for new reactors at the sites granted ESPs by the NRC. AP1000s could be an option for those sites, and another option could be the Korean-

[33] Among the eight issued COLs, five are for Westinghouse AP1000 reactors, the first of their kind in the United States, including at the active construction project at the Vogtle plants in Georgia, the suspended construction project at the Summer plant in South Carolina, and the planned construction project at the Turkey Point plant in Florida. With Westinghouse effectively exiting the reactor construction business in the United States, an Asian firm could look to take over construction and component supply for these unfinished AP1000s projects.

[34] "First AP1000 unit begins generating power," World Nuclear News, 2 July 2018, http://www.world-nuclear-news.org/NN-First-AP1000-unit-begins-generating-power-0207184.html.

[35] Lucy Hornby and Ed Crooks, "China set to supply components to US nuclear power plants," *Financial Times*, 30 October 2013, https://www.ft.com/content/e8a83158-4164-11e3-9073-00144feabdc0.

designed APR1400.[36] The first APR1400, Shin Kori-3, went online in 2016, and four other APR1400s are under construction in South Korea. After the APR1400 receives NRC design certification, KEPCO's current experience building APR1400s could make them an attractive bidder to take on new reactor projects at an existing reactor site in the United States, and KEPCO certainly will seek export contracts with the uncertainty regarding the future of nuclear power in South Korea.

Another specific option is completing the Bellefonte nuclear power plant in Alabama. Montreal-based SNC-Lavalin agreed to buy the partially completed two-reactor plant in June 2018 and is now working to close the deal.[37] The partially completed reactors were originally Babcock & Wilcox pressurized water reactors, but it is possible that the plant site could be revamped for an AP1000, APR1400, or another reactor that an Asian firm could provide.

Of course, much more would have to be worked out than just selecting the right construction vendor and reactor type. Each reactor construction project would have to fit with the local economic and social conditions. Utilities and vendors involved would have to work with federal, state, and local officials in the United States to best arrange financing and ensure the future economic viability of new reactors. Potential national security concerns also would have to be addressed with the U.S. government. Much research and negotiations would have to come before such construction projects could begin, but they would breathe new life into the U.S. nuclear industry.

Spent Fuel Management

Long-term management of spent nuclear fuel has been a vexing issue for the industry for decades. No country has a functioning method for managing long-term spent nuclear fuel, and countries are pursuing different technologies to address this problem. There exists some trans-Pacific cooperation on spent nuclear fuel management, such as the ten-year joint fuel cycle study between South Korea and the United States on pyroprocessing aimed at reducing the volume of

[36] The NRC is reviewing a design certification application for the APR1400 submitted by the Korea Electric Power Corporation (KEPCO) and Korea Hydro and Nuclear Power (KHNP) in 2014. "Design Certification Application Review - Advanced Power Reactor 1400 (APR1400)," U.S. Nuclear Regulatory Commission, 25 September 2017, https://www.nrc.gov/reactors/new-reactors/design-cert/apr1400.html.

[37] "SNC-Lavalin signs agreement on Bellefonte completion," World Nuclear News, 7 June 2018, http://www.world-nuclear-news.org/NN-SNC-Lavalin-signs-agreement-on-Bellefonte-completion-0706188.html.

waste.[38] China and Japan have imported French PUREX reprocessing technology, but there currently is no interest in commercial reprocessing in the United States. R&D efforts like the joint fuel cycle study should continue, and any major breakthroughs in spent nuclear fuel management technology could be welcomed by the U.S. industry in the future.

For the time being, the United States is deploying interim storage technology until a final repository is completed. It may be U.S. firms that see an export opportunity, since the United States currently has a lead in deployable interim storage technology. As spent nuclear fuel fills up storage pools, Asian reactor operators may seek interim storage technology as long-term management options are developed.

In the United States, the Nuclear Waste Policy Act of 1982 stipulated that the Department of Energy must begin receiving spent nuclear fuel by 1998 and dispose of it in a federal repository, and the Yucca Mountain in Nevada was designated as the federal repository in 1987.[39] After suspending review in 2008, the NRC resumed licensing activities in 2013 after a federal court order, and there has been growing momentum in Congress to resume development and licensing of Yucca Mountain.[40]

By 2020, there will be an estimated 88,000 metric tons of spent nuclear fuel in interim storage awaiting final disposal.[41] Even if Yucca Mountain opens, that repository's design capacity is 70,000 metric tons, so interim storage options will be critical for the nuclear industry to manage current and future inventories of spent nuclear fuel. Interim storage also allows further time to explore alternative back-end fuel cycle technologies that could be preferable to direct disposal in a permanent repository.

[38] "Fuel Cycle," Korea Atomic Energy Research Institute, https://www.kaeri.re.kr/english/sub/sub04_03.jsp.

[39] "US Nuclear Fuel Cycle," World Nuclear Association, June 2018, http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-fuel-cycle.aspx.

[40] Michael Collins, "Congress works to revive long-delayed plan to store nuclear waste in Yucca Mountain," *USA Today*, 3 June 2018, https://www.usatoday.com/story/news/politics/2018/06/03/yucca-mountain-congress-works-revive-dormant-nuclear-waste-dump/664153002/.

[41] "US Nuclear Fuel Cycle," World Nuclear Association, June 2018, http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-fuel-cycle.aspx.

In Japan, spent fuel currently is stored in spent fuel pools at nuclear plants, and there are two small dry-cask storage facilities in operation.[42] Development of interim storage in dry casks has lagged in part due to government policy requiring the reprocessing of spent fuel, but an interim storage facility being developed for spent fuel from the Tokyo Electric Power Company and Japan Atomic Power Company reactors aims to open later this year.[43] With most of Japan's reactors not operating, the accumulation of spent fuel in pools has slowed, but all reactor operators will eventually have to move spent fuel out of pools at some point.

The Japanese central government remains nominally committed to developing a closed fuel cycle and related technology, such as spent nuclear fuel reprocessing, fast neutron reactors, and MOX fuel fabrication. Yet development of all of those technologies is not progressing as planned and delays pose long-term challenges for spent fuel management.[44] Japan has about 47 tons of separated plutonium stored domestically and in Europe that are a point of criticism and concern from a nonproliferation and security perspective. Delays in opening these fuel cycle facilities will continue to hinder Japan's ability to consume and reduce its plutonium stockpile.[45]

South Korea stores all spent fuel onsite at nuclear plants and has plans to open interim storage and a permanent repository in 2035 and 2051, respectively.[46] However, no sites have been selected for either facility, and South Korea also is exploring pyroprocessing or overseas storage

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[42] Toshiari Saegusa, "Metal Cask Storage As Compared With Pool Storage of Spent Nuclear Fuel In Japan," NAPSNet Special Reports, 7 July 2017, https://nautilus.org/napsnet/napsnet-special-reports/metal-cask-storage-as-compared-with-pool-storage-of-spent-nuclear-fuel-in-japan/.

[43] Eric Johnston, "Kansai Electric denies it plans to ship nuclear waste from Fukui plants to Aomori site," *The Japan Times*, 9 January 2018, https://www.japantimes.co.jp/news/2018/01/09/national/kansai-electric-denies-plans-ship-nuclear-waste-fukui-plants-aomori-site/.

[44] The government decided to decommission the prototype fast reactor, Monju, in 2016. "Regulator approves Monju decommissioning plan," World Nuclear News, 28 March 2018, http://www.world-nuclear-news.org/WR-Regulator-approves-Monju-decommissioning-plan-2803185.html; Japan's experimental fast reactor, Joyo, has been shut down since 2007 due to damage, but with the closing of Monju, the government aims to restart Joyo in 2021. "Fast Neutron Reactors," World Nuclear Association, June 2018, http://www.world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx; The opening of the reprocessing plant and MOX fuel fabrication plant at Rokkasho also have been delayed until 2021 and 2022, respectively. "Rokkasho plant will not start until 2021," International Panel on Fissile Materials, 22 December 2017, http://fissilematerials.org/blog/2017/12/rokkasho_plant_will_not_s.html.

[45] Phyllis Genther Yoshida, "Japan's Plutonium Question," Sasakawa Peace Foundation USA, 13 June 2018, https://spfusa.org/research/japans-plutonium-question/.

[46] "Nuclear Power in South Korea," World Nuclear Association, December 2017, http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/south-korea.aspx.

as options for reducing the burden of long-term disposal of spent fuel domestically. Taiwan also is planning on developing a geological repository for spent fuel disposal, with an operation date of 2055, but no site has been selected for the repository yet.[47] Although planned nuclear phase-outs in South Korea and Taiwan would reduce the accumulation of spent fuel, spent fuel in South Korea and Taiwan, as in Japan, will have to be removed from pools sooner rather than later.

Meeting Domestic Needs of the Front End of the Fuel Cycle

Of the steps in the nuclear fuel cycle, uranium mining, milling, and enrichment presents unique challenges for U.S. policy regulation and industry development, as the United States has only about 1% of global terrestrial uranium reserves.[48] The sole operating U.S. uranium enrichment facility, a gas centrifuge facility located in New Mexico operated by URENCO USA, can meet only about one-third of current U.S. demand for enrichment services, with the remaining demand met by overseas providers. The NRC issued licenses for two other enrichment facilities, a gas centrifuge facility in Idaho and a laser enrichment facility in North Carolina, but construction on both of those facilities is currently not proceeding.[49]

Another gas centrifuge facility operated by Centrus Energy in Ohio ran a test cascade of a new centrifuge technology called the American Centrifuge from 2013 to 2016.[50] Centrus is now decommissioning the facility but continues to conduct R&D on its centrifuge technology at Oak Ridge National Laboratory in Tennessee.[51]

Recent success by U.S. researchers in extracting uranium from seawater in laboratory-scale tests at Pacific Northwest National Laboratory presents new possibilities, and researchers in China

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[47] "Nuclear Power in Taiwan," World Nuclear Association, June 2018, http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx.

[48] "Supply of Uranium," World Nuclear Association, December 2016, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/uranium-resources/supply-of-uranium.aspx.

[49] "Fuel Cycle Facility Licensing and Construction," U.S. Nuclear Regulatory Commission, 28 March 2017, https://www.nrc.gov/materials/fuel-cycle-fac/new-fac-licensing.html.

[50] American Centrifuge," Centrus Energy Corp., https://www.centrusenergy.com/what-we-do/national-security/american-centrifuge/.

[51] "Fuel Cycle Facility Licensing and Construction," U.S. Nuclear Regulatory Commission, 28 March 2017, https://www.nrc.gov/materials/fuel-cycle-fac/new-fac-licensing.html; "American Centrifuge," Centrus Energy Corp., https://www.centrusenergy.com/what-we-do/national-security/american-centrifuge/.

and Japan also are working on methods to extract uranium from seawater.[52] Methods to extract uranium from seawater will have to be made economically competitive with terrestrial mining to become commercially viable, or the price of uranium will have to rise to make seawater extraction more attractive.[53] This could be an area for R&D cooperation and presents a new need for review and regulatory understanding.

Cooperation pathway: Unfinished uranium enrichment plants in the United States. Working to construct and operate the enrichment facilities in Idaho and North Carolina is a potential cooperation pathway. The one operating enrichment facility in the United States can only fulfill about one-third of the demand from U.S. reactors for enrichment services, so a fuel supply security argument could be made for finishing these plants to provide enrichment services to U.S. reactors.

China, Japan, or South Korea could be interested in using U.S. enrichment services for either their domestic or export markets. Japan also has one operational enrichment plant, a gas centrifuge plant at Rokkasho, which met about one-third of the enrichment demand for Japan's reactors prior to the Fukushima nuclear disaster in 2011.[54] If more Japanese reactors restart, then domestic demand for enrichment services will increase. South Korea does not operate any enrichment facilities and is effectively barred from doing so per the terms of its nuclear cooperation agreements with the United States (the so-called 123 agreements). Investing in U.S. enrichment facilities could be a way for South Korea to provide more robust fuel cycle services for nuclear export customers. China is rapidly expanding its domestic enrichment capacity to meet domestic demand, and it also could see investment in U.S. enrichment services as an opportunity to support its reactor exports.

The main problem with this pathway is that there is a significant surplus of enrichment capacity in the world, and Centrus acknowledges that "current market conditions do not support building a full-scale uranium enrichment plant for commercial purposes." Russia possesses over 40% of global enrichment capacity and could provide additional enrichment services if demand

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[52] "First yellowcake from seawater for US team," World Nuclear News, 14 June 2018, http://www.world-nuclear-news.org/UF-First-yellowcake-from-seawater-for-US-team-1406187.html.

[53] David C Wagman, "Researchers Fish Yellowcake Uranium From the Sea With a Piece of Yarn," IEEE Spectrum, 22 June 2018, https://spectrum.ieee.org/energywise/energy/nuclear/pulling-uranium-from-seawater-continues-to-entice-researchers.

[54] "Rokkasho Reprocessing Plant and other Nuclear Facilities," Citizens' Nuclear Information Center, http://www.cnic.jp/english/topics/cycle/rokkasho/rokkashodata.html.

increases. The European Union and China also possess significantly more enrichment capacity than the United States.

Investors would need to have incentives or strong preferences for investing in U.S. enrichment capacity rather than contracting with Russian, Chinese, or European firms. The promise of new or improved enrichment technologies, such as the laser enrichment plant that would be the first of its kind, could be such an incentive. South Korea or Japan also could prefer to work with U.S.-based firms rather than with Russian or Chinese firms to provide enrichment services for export customers. The United States has been a trusted partner for both Japan and South Korea in nuclear technology for many decades, and continuing civil nuclear commerce with the United States could be seen as part of the broader alliance relationships. Seoul and Tokyo also could be concerned that Beijing would use nuclear reactor exports as leverage over the Japanese and South Korean economies.

Developing and Standardizing New Technologies

A problem with securing utility or other industry backing for building any type of new reactor in the United States is the same problem that has crippled new construction in the United States for decades: high upfront capital costs made even higher by cost overruns and delays during construction. Estimates for total construction costs for the two new reactors at Vogtle have grown from $14 billion in 2008 to $23 billion.[55] One way to bring down construction time and costs is to standardize reactor design and have the same team repeatedly build that design, allowing only for small, incremental changes.[56]

Chinese and South Korean firms have done better at staying on schedule and on budget through standardization, and their recent experience could make them better suited to economically build new reactors in the United States, too. These firms do have the advantage of being wholly or partly state-owned, which can provide more financial and policy stability throughout a construction project. Of course, the current South Korean administration shows that changes to

[55] Kristi E. Swartz, “Vogtle costs too much for customers to bear, PSC staff says,” *E&E News*, 4 December 2017, https://www.eenews.net/stories/1060067953.

[56] Michael Shellenberger, “If Innovation Makes Everything Cheaper, Why Does It Make Nuclear Power More Expensive?” *Forbes*, 21 June 2018, https://www.forbes.com/sites/michaelshellenberger/2018/06/21/if-innovation-makes-everything-cheaper-why-does-it-make-nuclear-power-more-expensive/.

national policy can affect nuclear construction, but explicit state backing can be advantageous to long-term domestic viability and to export projects. Chinese and South Korean nuclear firms would have to adapt to the U.S. market, and they would have to learn to operate in the U.S. regulatory environment. But the regulatory process also becomes more efficient with standardized designs and construction. It is worth pursuing new reactor technology, but delays and cost overruns with constructing first-of-a-kind reactors, such as the Power Reactor Innovative Small Module (PRISM), should be expected.

Cooperation pathway: Demonstrate new reactor technologies. The current fleet of nuclear reactors in the United States are so-called Generation II reactors, and the two new reactors being built at the Vogtle plant would be the first Generation III reactors in the United States. Building Generation III LWRs could be seen as a way for the United States to keep up with Asian nuclear industries, particularly China. As with the natural gas industry, demonstrating even newer reactor technology, such as small modular reactors (SMRs) or Generation IV reactors, could return the United States to the forefront of the global nuclear industry. These new reactor technologies could present opportunities for cooperation and address concerns about nuclear power by improving reactor safety and efficiency, being more proliferation resistant, and easing spent nuclear fuel management challenges.

SMRs may hold more near-term commercial potential, as the Department of Energy has promoted LWR-type SMR development in the United States for several years now, specifically NuScale SMRs at the Idaho National Laboratory[57] and mPower SMRs at Clinch River in Tennessee.[58] However, both reactor types have experienced delays in being granted permits. A potential candidate to replace mPower could be South Korea's System-integrated Modular

[57] "Design Certification Application – NuScale," U.S. Nuclear Regulatory Commission, 24 October 2017, https://www.nrc.gov/reactors/new-reactors/design-cert/nuscale.html; and UAMPS CFPP projects the first reactor to enter commercial operation in 2024, with a 12-module plant operational in 2025. "Utah Associated Municipal Power Systems (UAMPS) Carbon Free Power Project (CFPP) Progresses," NuScale Power, LLC, http://www.nuscalepower.com/our-technology/technology-validation/program-win/uamps.

[58] "Early Site Permit Application - Clinch River Nuclear Site," U.S. Nuclear Regulatory Commission, 18 June 2018, https://www.nrc.gov/reactors/new-reactors/esp/clinch-river.html; and Will Davis, "mPower Consortium Halts Project," ANS Nuclear Café, 16 March 2017, http://ansnuclearcafe.org/2017/03/16/mpower-consortium-halts-project/.

Advanced Reactor (SMART), which was developed by the Korea Atomic Energy Research Institute.[59]

SMART would have to submit a design certification application to the NRC before being able to be built in the United States. The NRC usually gives preference to design certification applications for which a utility customer is identified, so a commercial agreement between the Tennessee Valley Authority (TVA), owners of the Clinch River site, and the SMART Power may also be necessary. This could be another pathway for South Korean reactor technology to enter the U.S. market, which would be a highly desirable export market for South Korea's nuclear industry.

GE-Hitachi Nuclear Energy's Generation IV SMR (PRISM) is designed to reprocess its own fuel using an electrometallurgical process (sometimes called pyroprocessing), which is a type of spent nuclear fuel processing that South Korea is highly interested in developing. Yet, as with SMART, an identified utility customer would help PRISM through the licensing process, and TVA officials have said that they do not plan to construct SMRs in the next ten to twenty years.[60] Private investment and backing from both sides of the Pacific for PRISM, SMART, or other SMRs would help, but ultimately finding a utility customer for SMRs will be necessary.

Although the South Korean–designed SMART and the GE-Hitachi Nuclear Energy–designed PRISM were identified as two possible designs to explore for demonstration of advanced reactors in the United States, there are many SMR and Generation IV designs being developed. These reactors can be used to meet a variety of commercial needs, but in general they promise improved safety and efficiency. Whether these reactor designs can deliver on that promise can only be known by building and operating them. With the difficult situations in their domestic markets, Japanese and South Korean investors and nuclear firms may be interested in demonstrating SMR or Generation IV designs in the United States as a way to reinvigorate interest at home.

There are existing forums for cooperation on new reactor technology R&D, such as the Generation IV International Forum, which includes China, Japan, South Korea, and the United States. This forum selected six reactor technologies and envisions commercial deployment of

[59] "Development History," SMART Power Co., Ltd., http://www.smart-nuclear.com/tech/d_history.php.

[60] Aaron Larson, "Could Advanced Reactor Technology Save the Nuclear Industry?" *POWER*, 1 May 2018, http://www.powermag.com/could-advanced-reactor-technology-save-the-nuclear-industry/.

Generation IV reactors starting in 2030.[61] Such cooperation certainly should be continued and broadened where possible, but at this point much of the cooperation on R&D is done between national laboratories, other government-funded organizations, and international organizations. Opportunities for commercial cooperation or investment by Asian firms in Generation IV reactor technologies in the United States may be a few years or more down the road.

Articulating the Role for Nuclear in an Evolving Power Mix

Cheap natural gas, growth of renewables, and slowing electricity demand growth have been cited as the financial stressors that have challenged the economic competitiveness of current nuclear reactors.[62] Deregulation of the electricity market by some U.S. states also has cut into nuclear power's economic competitiveness, and only two of the seventeen reactors with announced or considered retirement dates operate in a regulated state market.[63] The Trump administration is reportedly preparing measures aimed at saving at-risk reactors for the sake of national security, but even if these measures are implemented, it is uncertain how many reactors would be saved.[64]

Nuclear power has long been associated with national security, and U.S. dominance in the global nuclear reactor market has provided the United States with influence over norms on nuclear safety, security, and nonproliferation. In addition, consultant Edward Kee wrote of the range of public benefits that nuclear power provides: environmental benefits (such as very low carbon emissions), electricity system benefits (such as fuel diversity, long-term cost stability, and the ability to dispatch electricity when it is needed to meet peak demand), and economic benefits (for example, the positive impacts of providing jobs and paying taxes).[65] Yet Kee also argued that the

[61] "Generation IV Systems," Generation IV International Forum, https://www.gen-4.org/gif/jcms/c_59461/generation-iv-systems.

[62] Sonal Patel, "More Premature Nuclear Unit Retirements Loom," *POWER*, 1 February 2018, http://www.powermag.com/more-premature-nuclear-unit-retirements-loom/.

[63] "Nuclear Plants in Regulated and Deregulated States," Nuclear Energy Institute, July 2015, https://nei.org/resources/statistics/nuclear-plants-in-regulated-and-deregulated-states.

[64] Jennifer A. Dlouhy, "Trump Prepares Lifeline for Money-Losing Coal Plants," Bloomberg, 1 June 2018, https://www.bloomberg.com/news/articles/2018-06-01/trump-said-to-grant-lifeline-to-money-losing-coal-power-plants-jhv94ghl.

[65] Edward D. Kee, "'Market failure' and nuclear power," Bulletin of the Atomic Scientists, 4 August 2016, https://thebulletin.org/2016/08/market-failure-and-nuclear-power/.

U.S. market approach does not account for the public benefits of nuclear power, which has led to market failure and early closure of reactors. Fixing this market failure will be critical to preserving these public benefits.

Political and Social License

To an extent, each of the previous opportunities assumes two things: (1) that policymakers value a sustained role for nuclear power in how they envision achieving energy and environmental security goals, and (2) that policymakers have sufficient social license to move forward on any one of these issues or that social license could be developed.

While the Japanese government is still struggling to rebuild social license, it still remains committed to transitioning to a low-carbon society. The government's Strategic Energy Plan projects nuclear power to account for 20%–22% of the country's electricity generation by 2030.[66] The Japanese government also continues to support a nuclear export industry, and Japanese nuclear firms have pursued reactor projects in Europe and Asia, partly in response to the struggling domestic nuclear industry. Yet nuclear power generation continues to be vigorously debated in the public, in the courts, and at the ballot box, and the future of Japan's domestic and export nuclear industries remains uncertain.

Similar to Japan, both South Korea and Taiwan lack significant domestic energy resources, and nuclear power was seen as a way to boost economic growth while reducing dependence on energy imports. Yet President Moon and President Tsai both have set the eventual elimination of nuclear power as pillars of their respective energy policies.[67] Public concerns over the safety of nuclear power plants have grown since the Fukushima disaster in 2011, and Moon and Tsai claim to be responding to their citizens' concerns by emphasizing renewable energy over nuclear power. Both South Korea and Taiwan have experienced significant political and social opposition to siting

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[66] "Draft of Revised Strategic Energy Plan Aims for Firm Implementation of 2030 Energy Mix, Eyeing 2050 As Well," Japan Atomic Industrial Forum, Inc., 18 May 2018, http://www.jaif.or.jp/en/draft-of-revised-strategic-energy-plan-aims-for-firm-implementation-of-2030-energy-mix-eyeing-2050-as-well/.

[67] It is worth noting that, under the current South Korean constitution, presidents can only serve one five-year term, and thus Moon will have to leave office in 2022. Just as his energy policy is a significant departure from that of his predecessors, the next South Korean president could significantly alter Moon's nuclear phase-out policy. Energy policy will likely be an issue debated during the next presidential campaign. Tsai is eligible to be re-elected to a second four-year term in Taiwan's next presidential elections scheduled for 2020, so she could nearly see out her administration's nuclear phase-out policy.

nuclear waste facilities, and renewables or other energy sources may appear easier to win public support for.

Although many uncertainties surround domestic outlooks, the possibility to export nuclear technologies remains very attractive. As discussed earlier, China, Japan, and South Korea all have experience exporting nuclear technologies and would like to grow their nuclear export businesses. Despite having a policy of phasing out nuclear power domestically, the Moon administration continues to support reactor exports. South Korea currently is building four APR1400 nuclear reactors in the United Arab Emirates (UAE), and MOTIE expressed support for South Korean firms' efforts to secure reactor contracts in the United Kingdom, the Czech Republic, and Saudi Arabia.[68] KEPCO's experience in the UAE was cited as a reason for becoming the preferred bidder for the British nuclear power project.[69] MOTIE also stated that exporting reactors "would provide the domestic industry with opportunities to effectively utilize assets and know-how it has accumulated."[70] Taiwan has not been a major nuclear technology exporter, but it certainly has the industrial capacity to supply or support nonnuclear components for reactors or fuel cycle facilities.

Domestic anxieties over the safety of nuclear power emphasize the need for policymakers to stay engaged with other nuclear states. Creating an earnest, candid forum that discusses safety and security concerns and establishes best practices is one way to build the necessary social license to operate. In particular, behind much of this need for increased communication and discussion is a concern that China will supplant Japan, South Korea, and the United States as a top global vendor of nuclear reactors. Besides the loss of prestige and leadership in nuclear technology, the concern is that Chinese reactor sales would not meet the nuclear safety, security, and nonproliferation standards of Japanese, South Korean, or U.S. vendors. Yet given the trajectories of their respective nuclear industries, it is inevitable that China will be a major competitor in the reactor export market for years to come.

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[68] "South Korea's KEPCO shortlisted to bid for Saudi nuclear project," *Reuters*, 1 July 2018, https://www.reuters.com/article/us-southkorea-nuclear-saudi/south-koreas-kepco-shortlisted-to-bid-for-saudi-nuclear-project-idUSKBN1JR1GA.

[69] Adam Vaughan, "Korean energy firm rescues UK's Moorside nuclear power project," *The Guardian*, 6 December 2017, https://www.theguardian.com/business/2017/dec/06/korean-energy-firm-kepco-rescue-moorside-nuclear-power-project.

[70] "Ministry to support nuclear reactor exports," Republic of Korea Ministry of Trade, Industry and Energy, 12 October 2017.

There are numerous multilateral mechanisms through which the United States can engage China on concerns over reactor exports, and the Department of Energy and other government agencies have worked bilaterally with China on nuclear safety, security, and nonproliferation. For example, since 2007, the Department of Energy has led an annual interagency meeting with Chinese government counterparts to discuss bilateral civil nuclear cooperation as part of the U.S.-China Peaceful Uses of Nuclear Technology (PUNT) Agreement. Building on the PUNT meetings and similar to the industry engagement that resulted in the Nuclear Power Plant Exporters' Principles of Conduct, the U.S. government should form public-private working groups to engage with China on the reactor export business.[71] Not only could such groups help the United States push for strict standards, but the United States could learn from China what has and has not worked in the Chinese nuclear industry. These working groups also could explore commercial opportunities for Chinese nuclear firms in the United States, perhaps through joint ventures. Chinese nuclear firms operating in the U.S. market would be held to U.S. standards on safety, security, and nonproliferation. As China has established itself as a major player in the global nuclear industry, the United States must engage with it in order to avoid falling behind in global nuclear leadership

Conclusion and Recommendations

Regulatory burdens; government policies at the federal, state, and local level; social license concerns; and alternative fuel options are all factors that affect the economic viability and political and social approval of nuclear power. However, nuclear industries could be bolstered by exploring the trans-Pacific cooperation pathways identified here.

To be fair, some of these pathways would not be easy to industry, government stakeholders, or civil society groups. The surplus in global enrichment capacity, difficult economic conditions facing existing U.S. nuclear plants, cost overruns and delays in new construction, and uncertainty regarding the long-term management of spent nuclear fuel present significant challenges to cooperation throughout the fuel cycle. There also are sensitivities about foreign involvement in an

[71] The China National Nuclear Corporation was involved in the drafting of the Principles of Conduct but did not adopt them. See "History," Nuclear Power Plant and Reactor Exporters' Principles of Conduct, http://nuclearprinciples.org/about/history/.

industrial sector that has national security implications, although foreign firms, such as URENCO and Hitachi, are already active in the U.S. nuclear industry.

Yet, although the outlook can appear bleak when looking at the myriad challenges facing the nuclear industry in the United States, the industry is far from dead. Nuclear power will remain an important part of the U.S. energy mix for the foreseeable future. By comparison, natural gas production in the United States declined and stagnated for decades, with many thinking that the domestic natural gas industry was in terminal decline. Yet new extraction technology, investment from abroad, and increased global demand has revived U.S. natural gas production.

As the excitement and momentum from the nuclear renaissance at the beginning of this century has faded, the United States should look to its partners in Asia for ways to reinvigorate the U.S. nuclear industry. The United States remains a leader and desirable partner in nuclear technology, but its global standing could be boosted through cooperation with Asia.