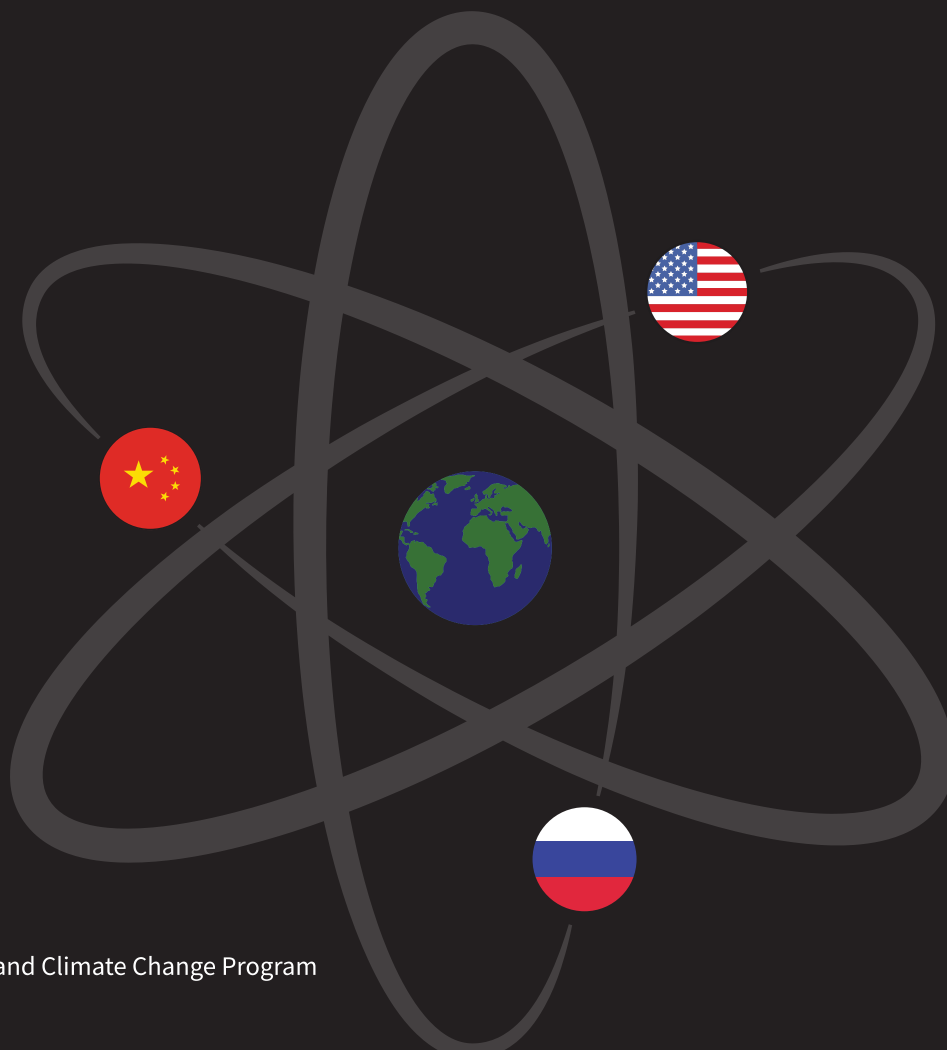
MARCH 2020

The Changing Geopolitics of Nuclear Energy

A Look at the United States, Russia, and China

AUTHOR
Jane Nakano



A Report of the Energy Security and Climate Change Program

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Center for Strategic & International Studies
1616 Rhode Island Avenue, NW
Washington, D.C. 20036
202-887-0200 | www.csis.org

Acknowledgments

The author would like to thank CSIS colleagues Sarah Ladislaw, Nikos Tsafos, Lisa Hyland, Scott Kennedy, Jeff Mankoff, Ian Barlow, Mary Margaret Allen, Jesse Barnett, and Manjia Gong for feedback and assistance; Mark Holt for reviewing an early draft; and Chris Gadomski for the valuable insights in the global nuclear market. Additionally, the author benefited greatly from the expertise of speakers at the CSIS workshop—Jonathan Hinze, Jessica Jewell, Jessica Lovering, Paul Murphy, and Adam Stulberg as well as from all the participants.

This report was made possible by the generous support of the Japan External Trade Organization and ClearPath Foundation.

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Chapter 1: Introduction

The nuclear industry of advanced industrialized countries is under significant pressure to remain competitive as the market landscape for new nuclear power opportunities changes. Traditional users in liberalized power markets—at the ratepayer, local utility, state, or country level—are rethinking their exposure to nuclear power generation given the prospect of long overruns in construction time and budgets, the high cost of capital, the uncertainty over power prices over the lifetime of nuclear power plants (NPPs), and social acceptance issues in some markets in the wake of the Fukushima nuclear accident in Japan. Countries where market considerations are secondary to other priorities, be it political, economic, or environmental, are expected to make up the bulk of new nuclear construction going forward. Many of these countries face considerable growth in population and energy needs but are short on the financial resources and governance capacity required to sustain nuclear power as a portion of their energy mix. On the supply-side, the industry recognizes the need to shift to new, yet-to-be-proven nuclear technologies that are likely to be the future of the industry but struggles to find support for these technologies in the marketplace without a sustained political commitment at the national level.

The United States, Europe, and Japan have long been leaders in conventional nuclear power generation technology, but that leadership position and the commercial competitiveness of the industry in each of those countries is declining. The relative decline of U.S. nuclear export competitiveness comes at a time when Russia is boosting its dominance in new nuclear sales; it leads the pool of global suppliers, accounting for two-thirds of the globally exported NPP projects under construction today.[1] Meanwhile, China is doubling down on its effort to become a leader in global nuclear commerce by proactively pursuing export deals in Argentina and the United Kingdom.

Over its history, having a highly competitive nuclear industry was thought to confer a number of strategic benefits, including a secure source of domestic power generation, the ability to establish and enforce nuclear safety and nonproliferation standards around the world, a vibrant nuclear innovation ecosystem, and some degree of geopolitical influence with other nations. These strategic benefits, along with the value of nuclear power as a

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1 State Atomic Energy Corporation Rosatom, *Performance in 2018* (Moscow: 2019), 41, http://rosatom.ru/upload/iblock/0ba/0ba23d180bc202e22b53b62ca57a25bb.pdf.

source of low greenhouse gas-emitting energy in the fight against climate change, become important to understand in greater detail as the United States considers the costs and benefits of fostering a competitive nuclear industry. In recent years, the rise of Russia and China as competitors in this sector have strengthened the need to better understand foreign policy influence from nuclear commercial relationships.

Nuclear commerce entails not only a multi-year effort for reactor construction but also an ongoing relationship between a supplier country and recipient country regarding fuel supplies and reactor maintenance. As such, nuclear commerce serves to create or maintain diplomatic, commercial, and institutional relationships, and therefore the link between nuclear commerce and geopolitics exists on multiple levels. In particular, the deep involvement of government in the nuclear power sector makes it a more geopolitically significant energy resource than many others. The depth and length of engagement, along with the perceived dependency created by the relationship, is often thought to give a supplier country influence over a recipient country.

This report illuminates how the changing market competition among the United States, Russia, and China will affect their future relations with nuclear commerce recipient countries and also considers the utility of nuclear commerce as an avenue of foreign policy influence. The report further discusses why Russia and China promote nuclear commerce, as well as which factors may alter their market competitiveness.

The key findings include:

1. **Nuclear power generation projects have never been a purely commercial endeavor in the United States, and civilian nuclear export is difficult to be viable as a purely commercial undertaking.** Throughout the history of nuclear energy in the United States, nuclear power generation undertakings required political support and economic incentives. Recognizing the nature of nuclear energy development and export is a necessary step toward a more informed public discussion on the role of the U.S. government in innovation and commercial competition.

2. **Global nuclear market dominance by state-led capitalist economies with limited accountability and governance capacities would endanger the future of global nuclear safety and nonproliferation.** Supplier countries that lack sound internal oversight and strong governance principles are more prone to overlook recipient country capacity deficits in the areas of regulation, and governance. Without the United States and other countries with strong accountability and governance as viable competitors, nuclear safety and security norms, standards, practices, and enforcement would likely become precarious or a secondary consideration.

3. **The U.S. retreat could bifurcate the use of nuclear power generation along similar political or economic systems.** The U.S. retreat may render both suppliers and recipients of nuclear technology to be predominantly countries that are state-led capitalist economies. If nuclear commerce becomes the exclusive domain of state-led capitalist economies whom the United States views as key geopolitical competitors, the use of nuclear power generation—including replacement of aging reactors—could come under scrutiny for its national security implications to critical infrastructure in the countries with liberal democratic traditions.

TABLE 1: Civilian Nuclear Power Sector Comparison: The United States, Russia, and China

COUNTRY	REACTOR UNITS (DOMESTIC)		INSTALLED CAPACITY	NUCLEAR SHARE IN NATIONAL POWER SUPPLY (2018)	FUTURE NET INSTALLED CAPACITY	SECTOR STRUCTURE	EXPORT UNITS UNDER CONSTRUCTION	PUBLIC FINANCING FOR NUCLEAR EXPORT
	ONLINE	UNDER CONSTRUCTION						
USA	96	2	98 GW	19.32%	92 GW [1]	Multiple private companies	None	Loan terms per OECD restriction; no equity
Russia	38	4	28 GW	17.87%	44 GW [2]	Vertically and horizontally integrated under 1 state corporation	7 (Belarus, India, Bangladesh, Turkey)	Loans & equity
China	48	11	45 GW	4.22%	120-150 GW [2]	Vertically integrated under 3 state corporations	2 (Pakistan)	Loans & equity

Source: "Reactor Database," World Nuclear Association, HYPERLINK "https://urldefense.com/v3/__https:/www.world-nuclear.org/information-library/facts-and-figures/reactor-database.aspx__;!!KRhing!NJduRuozGelokCC-SZ2urQCauracicX9IwSGOClSJKRfoXIY8EeK2Z_oOWmP$"https://www.world-nuclear.org/information-library/facts-and-figures/reactor-database.aspx. The sources for Future Net Installed Capacity are "Annual Energy Outlook 2020," U.S. Energy Information Administration; "Nuclear Power in Russia," World Nuclear Association; and various media reports for the China figure.

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[1] Projected for 2025 (EIA)   [2] 2030 target

4. **Nuclear commerce is geopolitical in nature and creates multi-decadal ties between supplier and recipient countries, but nuclear commerce may not be an effective tool of foreign policy leverage.** The export of nuclear reactor technology, plant construction, and related services can help create, strengthen, or preserve positive relations between the supplier and importing country governments. However, nuclear commerce is generally preceded by some level of mutual trust or positive diplomatic relations between the two countries. While nuclear commerce can have a foundational level of influence on geopolitical relationships, evidence of nuclear commerce serving as an effective tool of foreign policy leverage in specific instances is limited in nature and hard to substantiate.

Chapter 2: Competitive Landscape

The United States: Industry Leader in Decline

Today the nuclear power industry occupies an important but increasingly tenuous position in the U.S. electricity sector. The nation's 96 operating commercial nuclear reactors account for about 20 percent of the country's total electricity production, but the fleet is aging fast, with the average age of reactors falling near 40 years.[2] Tennessee's Watts Bar Unit 2, which came online in 2016, was the most recent addition to the fleet. When completed, the two AP1000 units in Georgia will be the only Generation III/III+ designs in the U.S. fleet—the remainder being Generation II designs.[3]

The fleet's maturity is in part reflective of the current economics of nuclear power in the United States. Faced with sustained low prices of natural gas, ever-cheaper renewables, and low power demand, many plant owners have chosen to increase the maximum power output of their existing reactors (a process known as "uprating") rather than to build new nuclear plants. Uprating and shorter outages have allowed nuclear power supply in 2018 to mark slightly more than the previous peak in 2010, although nine plants (7 gigawatts) have retired since 2013, most recently the Three Mile Island NPP in Pennsylvania in September 2019.[4] In 2020 alone, two reactors—Indian Point Unit 2 (NY) and Duane Arnold (IA)—are scheduled to close.[5]

In the coming years, nuclear power output in the United States is forecast to decline, with 10 reactor units announced to retire through 2025. The capacity beyond the mid-2020s,

2 "Operating Reactors," U.S. Nuclear Regulatory Commission (NRC), https://www.nrc.gov/reactors/operating.html.
3 Three generations of nuclear power reactor designs are defined as follows: "Generation I" are the prototype and power reactors that launched civil nuclear power; "Generation II" began operation in the late-1960s and use traditional active safety features; and "Generation III/III+" are essentially Gen II reactors with evolutionary state-of-the-art design improvements in areas such as fuel technology, thermal efficiency, modularized construction, safety systems, and standardized design. See Stephen M. Goldberg and Robert Rosner, *Nuclear Reactors* (Cambridge, MA: American Academy of Arts and Sciences, March 2011), https://www.amacad.org/sites/default/files/publication/downloads/nuclearReactors.pdf.
4 "Despite closures, U.S. nuclear electricity generation in 2018 surpassed its previous peak," U.S. Energy Information Administration, March 21, 2019, https://www.eia.gov/todayinenergy/detail.php?id=38792.
5 Jared Anderson and William Freebairn, "Roughly 1.7 GW of US nuclear power capacity set to retire in 2020," S&P Global, December 20, 2019, https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/122019-feature-roughly-17-gw-of-us-nuclear-power-capacity-set-to-retire-in-2020.

however, is highly subject to the future prices of natural gas. By 2050, this ranges from the reduction of 51 gigawatts (GW), under the high oil and gas supply case, to 6 GW, under the low oil and gas supply case.[6] To date, there is no announcement for retirement in the latter half of the 2020s, and more reactors are seeking license extensions to 80 years. Moreover, several states have introduced mechanisms such as Zero-Emission Credits (ZEC) to compensate electricity generators for not emitting greenhouse gases in the production of electricity, as is the case with nuclear power generation. Currently, five states offer financial support to existing nuclear plants, and several others are considering introducing a similar mechanism.[7]

A confluence of economic, political, and national security factors in the aftermath of World War II enabled the United States to emerge as a leading force in global nuclear commerce as a supplier of nuclear power generation goods (e.g., reactors, equipment, and components) and services (e.g., refueling and maintenance), as well as a leading voice on nuclear safety and nonproliferation issues. In the subsequent half-century following the advent of nuclear technology for electricity generation, U.S. nuclear reactor technology has found a healthy demand, mostly in Western Europe and Northeast Asia. However, the dearth of new construction since the Three Mile Island accident of 1979 and the shrinking need for service provision at home[8] have put the domestic nuclear industry in distress as the economic competitiveness of the domestic supply chain and associated expertise erodes. Between the mid-1990s and late-2000s, the U.S. share in the global exports of nuclear reactors, major components, and equipment, as well as nuclear materials (e.g., uranium) declined although the value of U.S. exports of these goods and services remained stable.[9] In the last decade, the U.S. nuclear industry has increasingly found itself unable to maintain its leading position as the global reactor technology supplier.

The situation was only exacerbated by the delay and cost overrun for the V.C. Summer project (SC) and the Vogtle project (GA)—the first projects to obtain construction and operation licenses in the United States in nearly 40 years—not to mention Westinghouse's bankruptcy in March 2017. As of February 2020, the V.C. Summer project has been suspended, and the Vogtle project is about five years behind schedule and has proven almost twice as costly as the original budget.[10] Once home to four nuclear reactor vendors, the U.S. nuclear industry is now rallying behind Westinghouse for conventional capacity-light water reactor (LWR) exports, with the company recently emerged from bankruptcy and now under the greater North American brand after

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6 U.S. Energy Information Administration, "Electricity," *Annual Energy Outlook 2020*, 26, https://www.eia.gov/outlooks/aeo/pdf/AEO2020%20Electricity.pdf.

7 These states are New York, Illinois, New Jersey, Connecticut, and Ohio.

8 Nuclear power plant service work has been in a declining demand with the exception of decommissioning, for which demand is projected to grow as more plants built in the 1960s and 1970s begin to retire.

9 U.S. Government Accountability Office (GAO), Nuclear Commerce (Washington, DC: November 2010), 12, GAO-11-36, https://www.gao.gov/products/gao-11-36#summary_recommend.

10 The Vogtle project is currently scheduled to be completed in 2021 for Unit 3 and 2022 for Unit 4. "Roof placed over first Vogtle unit," World Nuclear News, December 12, 2019, https://world-nuclear-news.org/Articles/Roof-placed-over-first-Vogtle-unit; Dave Williams, "Georgia Power: Plant Vogtle still on budget and on schedule," *Atlanta Business Chronicle*, August 30, 2019, https://www.bizjournals.com/atlanta/news/2019/08/30/georgia-powerplant-vogtle-still-on-budget-and-on.html.

acquisition by Toronto-based Brookfield. Meanwhile, a few companies are focused on developing and commercializing small modular reactors and non-LWR.

A commercial challenge has arisen from the shift in the demand side, as well. As electricity demand growth has slowed in industrialized economies, including where established nuclear vendors are based, the economic development and attendant power demand growth in developing economies has turned them into potential customers. Notably, compared to the countries that introduced nuclear power generation in the decades immediately following World War II, the aspiring nuclear newcomers today are typically smaller economies with weaker financial capacity and less political stability.[11]

Today, the United States finds itself struggling to re-establish its leadership in the dynamic landscape. The primary challenge to U.S. NPP exports comes from Russia and China. Neither has a political system based on liberal democratic traditions or an economic system based on market-led capitalism. Moreover, neither was a leading exporter when the United States and other established nuclear exporters competed for market opportunities in the United Arab Emirates a decade ago. However, Russia and China have since become forces to be reckoned with in the global nuclear industry. While they have become a primary challenge to the United States in the area of nuclear energy commerce, Russia and China are materially different in terms of economic size, industrial structure, and nuclear sector configuration. As such, the challenge emanating from the two nuclear industries should not be conflated.

Russia: A New Leader?

Russia's nuclear industry suffered a serious reputational setback following the Chernobyl accident in 1986 but has managed a remarkable resurrection in the last decade. The existing fleet is smaller than that of the United States or China, but Russia currently has 38 reactor units online (meeting 18 percent of Russia's total power supply), with four units under construction to replace their retiring capacity.

Between 2009 and 2018, Russia accounted for 23 of 31 export *orders placed* around the world with a firm site selection and for about half of the 53 units under construction around the world today, including projects in Bangladesh, Belarus, Finland, Slovakia, Turkey, and Ukraine.[12] Particularly since the inception of the Russian State Atomic Energy Corporation (Rosatom) in 2007, the pace has picked up for Russian NPP construction abroad: construction began on 10 reactor units overseas between 2007 and 2017—a big uptick considering they began construction on just four reactor units between 1986 and 2007.[13]

11 Most of the existing countries with nuclear power launched the program between 1957 and 1976; Jessica Jewell, "Ready for Nuclear Energy?," *Energy Policy* 39, no. 3, (March 2011): 1041-1055, doi: 10.1016/j.enpol.2010.10.041.
12 Steve Thomas, "Russia's Nuclear Export Programme," *Energy Policy* 121, iss. C (2018): 236, https://econpapers.repec.org/article/eeeenepol/v_3a121_3ay_3a2018_3ai_3ac_3ap_3a236-247.htm; Rosatom, *Performance in 2018*, 41.
13 Thomas, "Russia's Nuclear Export Programme," 245.

Rosatom's foreign order book has been growing. According to its 2018 annual report, Rosatom has over $133 billion in overseas orders in its 10-year portfolio—about 70 percent from NPP construction, 10 percent from uranium product sales, and 20 percent from nuclear fuel assemblies and other activities.[14] In 2018, Rosatom had overseas revenue of $6.5 billion, compared to $6.1 billion in 2017. This increase was mainly driven by growth in overseas orders for NPP construction as well as sales of electricity and new products (including composite materials, security systems, and NPP maintenance services abroad).[15]

Russia's nuclear energy sector is organized under a single player, Rosatom. With over 360 subsidiaries, Rosatom serves as the direct arm of the state for both civilian and military nuclear energy work. Rosatom subsidiaries include Rosenergoatom (which operates the country's NPPs), Atomflot (which maintains Russia's nuclear-powered icebreakers), and various component manufacturers and research and development institutions. Also, Rosenergoatom itself has several subsidiaries, including a vendor specializing in exporting Russian reactors called Atomstroyexport and a nuclear fuel-cycle product trader called TENEX. TENEX is best known in the United States for its role as the Russian government designate to the 1993 agreement between the U.S. and Russian governments for the conversion of 500 metric tons of highly enriched uranium from Russian nuclear warheads to low-enriched uranium to fuel U.S. nuclear reactors (commonly known as the Megatons to Megawatts program).

Rosatom is entirely under the control of the Russian state, with its strategic objectives being set by the president of Russia.[16] The 2015 draft version of the *Energy Strategy of Russia up to 2035*—which has not yet been adopted by the Russian government—identifies the growth in exportation of Russian nuclear technologies, NPPs, and services as one of the five primary objectives of nuclear industry development.[17] As the sole entity representing the Russian nuclear industry to the global pool of existing and prospective customers, Rosatom serves the role of engineering, procurement, and construction (EPC) contractor for the entire nation.[18] What is more, under Russian law, Rosatom does not require approval from any Russian government agency to build or finance reactors in other countries and often signs agreements itself with foreign governments.[19] Export undertakings receive government support in the form of Rosatom's ability to place its personnel at key Russian embassies to facilitate dealmaking with the host governments, including Russia's embassies in Bangladesh, Belarus, China, India, Iran, Japan, Kazakhstan, and Turkey and trade missions in Argentina, the Czech Republic, France, Germany, Hungary, Vietnam, and the United Kingdom.[20] Yet, the uniqueness of Russia's nuclear

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14 Rosatom, *Performance in 2018,* 54.

15 Ibid., 15.

16 Névine Schepers, "Russia's Nuclear Energy Exports: Status, Prospects and Implications," Stockholm International Peace Research Institute, *Non-Proliferation and Disarmament Paper,* no. 61, February 2019, 2, https://www.sipri.org/sites/default/files/2019-02/eunpdc_no_61_final.pdf.

17 Nikita Minin and Tomáš Vlček, "Determinants and considerations of Rosatom's external strategy," *Energy Strategy Reviews* 17 (September 2017): 37-44, doi:10.1016/j.esr.2017.07.001.

18 Author's interview with Alexey Khokhlov, Skolkovo, January 22, 2020.

19 "Russian law increases Rosatom's political authority," World Nuclear News, December 28, 2017, https://www.world-nuclear-news.org/NP-Russian-law-increases-Rosatoms-political-authority-28121701.html.

20 Jian Liu and Ye Feng, "Analysis of the Competitiveness of Russia's Nuclear Energy Overseas Development, Industry

sector should not be overstated. Rosatom subsidiaries compete with their compatriots for a supply contract much the same way equipment and component suppliers do elsewhere, and Rosatom to them is less of a corporate entity than the country's nuclear industry itself.[21]

China: The Next Big Thing?

China has seen a remarkable expansion of its domestic nuclear power generation fleet that hints at the country's potential to become a leading global NPP supplier. The country did not see its first NPP come online until 1991, but China added the most nuclear power capacity in the world during the last decade, strongly aided by government promotion of nuclear power as a crucial tool to combat the grave air pollution the country faces. Between 2011 and 2019, China brought 35 reactor units online at home, nearly four times more than Russia and 10 units more than all of the non-Chinese new units combined.[22] China has 48 operating reactors (45 GW), making its fleet the third-largest in the world behind France (63 GW) and the United States (98 GW). Moreover, the country has 11 units (11GW) under construction and up to 18 units (20 GW) in advanced planning today.[23] Although the Fukushima accident tempered its original, robust expansion vision, China's installed nuclear capacity targets remain strong, at 96 GW by 2025, and 120-150 GW by 2030, overtaking France within a few years, and the United States by 2030.[24]

The Chinese government's desire to become a global leader in nuclear power can be traced back at least to 2014.[25] In an effort to propel China's rise in the global nuclear marketplace, Chinese firms are pursuing a number of nuclear power projects around the world, including in Argentina, Brazil, the Czech Republic, Kenya, Malaysia, Thailand, Turkey, South Africa, and Saudi Arabia. Thus far, however, the only host to Chinese reactors is Pakistan, where China's first reactor export came online in 2000. Having completed the construction of four reactors at the Chasma NPP by 2017, Chinese efforts have shifted to completing the construction of the Hualong One reactors for the Unit 2 and 3 at the Karachi NPP by late 2021 and 2022, respectively. When complete, the Karachi projects would signify the international debut for China's most advanced LWR.

China's nuclear power sector is dominated by three nuclear utilities: the China National Nuclear Corporation (CNNC), the China General Nuclear Power Group (CGN), and the

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Insights," China Nuclear Industry, 2018, original in Chinese. http://www.cnki.com.cn/Article/CJFDTotal-ZHGY201605016.htm.

21 Author's interview with Alexey Khokhlov, Skolkovo, January 22, 2020.

22 Between 2011 and 2019, China led in new builds, followed by 9 units by Russia, 5 units by South Korea, 3 units each by India and Pakistan, and one unit each by Argentina, Iran, and the United States. International Atomic Energy Agency, "Power Reactor Information System," https://pris.iaea.org.

23 Jonathan Hinze, "China Nuclear Reactor Exports," (presentation, CSIS workshop, CSIS, Washington, DC, December 10, 2019).

24 China is highly unlikely to meet its installed capacity target of 58 GW by 2020 due to the 18-month long moratorium on new construction approval following the Fukushima accident and the attendant tightening of nuclear safety regulations.

25 Ravi Madhavan, Thomas G. Rawski, and Qingfeng Tian, "Capability Upgrading and Catch-Up in Civil Nuclear Power: The Case of China," in *Policy, Regulation and Innovation in China's Electricity and Telecom Industries*, edited by Loren Brandt and Thomas G. Rawski, (Cambridge University Press, May 2019), 453-454.

State Power Investment Group Corporation (SPIC). All of them are owned directly by the Chinese government. As such, their senior-level personnel matters are subject to the oversight by the State-owned Assets Supervision and Administration Commission (SASAC), and their overarching business directions must be in accordance to the priorities set by the national government, which in turn answers to the Communist Party of China. Since its inception, China's nuclear power program has been under the firm control of the central government, even if the details were left to company executives, whose interests might differ.[26]

These major nuclear state-owned-enterprises (SOEs) are organized like conglomerates, with various companies undertaking design and EPC work. The CNNC, spun out of China's former nuclear industry ministry in 1988, traditionally favored indigenous development of nuclear reactor technologies and is also the dominant player in uranium conversion, enrichment, fuel fabrication, and reprocessing activities.[27] The CGN, in contrast, was expressly formed by political direction to facilitate nuclear power development with foreign companies as a counterweight to the CNNC and is active in uranium mining activities at home and abroad.[28] The CNNC and CGN are known to be in fierce competition for market shares, and they typically spearhead the approval of new builds. The government, however, is known to predetermine which of the conglomerates will have responsibility for a particular market when it comes to export projects so that the three companies would not cannibalize each other overseas.[29]

Much like in Russia, nuclear energy and its related exports receive strong political support in China. For example, the 13th Five-year Plan (China's economic planning program covering the period 2016-2020) views the development of indigenous nuclear technologies for power generation important for upgrading and optimizing the country's energy structures.[30] China's "going out" policy and the Belt and Road Initiative (BRI) have also facilitated China's international cooperation on nuclear energy in the recent years, forging nuclear commercial ties with Pakistan, the United Kingdom, and Argentina.[31] Reportedly, 28 BRI countries have planned to develop nuclear power projects.[32] The strong market presence of Chinese manufactures of thermal power systems and equipment serves as a basis for China's global ambition for nuclear power

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26 Mark Hibbs, *The Future of Nuclear Power in China* (Washington, DC: Carnegie Endowment for International Peace, May 2018), 17, https://carnegieendowment.org/2018/05/14/future-of-nuclear-power-in-china-pub-76311.
27 NicobarGroup, "China's Nuclear Industry 2017-2018: A Tightly Coiled Spring," U.S. Department of Commerce, International Trade Administration, December 2017, 5, https://static1.squarespace.com/static/54a897dbe4b0631d0c50cdbc/t/5a5d7fed71c10bc094350a36/1516077082229/2017-2018_China+Nuclear+Power+White+Paper_+Nicobar+Group.pdf.
28 Hibbs, *The Future of Nuclear Power in China,* 16.*;* ibid.
29 Paul Murphy, "The Bear and the Dragon: The Competitive Challenges and Strategic Implications of Russian and Chinese Civilian Nuclear Deal-Making," (presentation, CSIS workshop, CSIS, Washington, DC, December 10, 2019), 11.
30 Kang Wu and Jane Nakano, *The Changing Political Economy of Energy in China* (Washington, DC: CSIS, 2016), 8, https://www.csis.org/analysis/changing-political-economy-energy-china.
31 This report, in the words of its author, is the first publicly issued blue paper that comprehensively expounds the development of nuclear energy in China and the main achievements the country made in 2017. Ling Chen and Yuhui Zheng, "The Going Global Strategy of China's Nuclear Power Industry: Situations and Prospects," in The Report on the Development of China's Nuclear Energy (2018), China Nuclear Energy Association (Social Science Academic Press—China).
32 Yan Xu, Junjie Kang, and Jiahai Yuan, "The Prospective of Nuclear Power in China," *Sustainability* 10, no. 6 (June 2018): 9, doi:10.3390/su10062086.

systems and equipment.[33] The industry estimates China's reactor export capacity to be 1 to 2 units annually through 2030 and targets both developing countries in Southeast Asia and the Middle East, as well as countries decommissioning many NPPs.[34] The industry expects that the combination of newcomer and replacement demand will accord China the opportunity to export over 10 units annually after 2030.[35]

The sector has enjoyed financial support from the government. For example, the nuclear SOEs have until recently been exempt from paying dividends to their government shareholders.[36] The companies have also enjoyed loans at favorable state-subsidized rates from China's policy banks, such as the China Development Bank, as well as controls on deposit interest rates that permit state-owned lenders to provide nuclear project financing at selected low discount rates.[37]

While China positions Hualong One as the flagship design for exports, there remains conflicting information as to how integrated Hualong One may be. Hualong One was initially developed separately by the CNNC (ACP1000 reactor) and the CGN (ACPR1000 reactor), and the companies were later ordered by the government to merge the design into what it is now known as the Hualong One reactor. Also, there remains some skepticism that Hualong One is Generation III in name only, as its development took too little time, with some suggesting the reactor may be an "enhanced version of the current CPR-1000—a reactor design that had been under robust production prior to the Fukushima nuclear accident.[38] Notwithstanding these concerns, China currently promotes Hualong One as the country's most advanced reactor for power generation. The CNNC chairman expects the reactor to obtain a 20 to 30 percent market share in over 40 countries within the BRI.[39]

33 Madhavan, Rawski, and Tian, "Capability Upgrading and Catch-Up in Civil Nuclear Power," 454.
34 Chen and Zheng, "The Going Global Strategy of China's Nuclear Power Industry."
35 Ibid.
36 Hibbs, *The Future of Nuclear Power in China,* 65.
37 Ibid., 65.
38 Ibid., 56; M. V. Ramana and Amy King, "A new normal? The changing future of nuclear energy in China," in *Learning from Fukushima*, edited by Peter Van Ness and Mel Gurtov, (Canberra: ANU Press, 2017), 116.
39 Ramana and King, "A new normal? The changing future of nuclear energy in China," in *Learning from Fukushima*, 115.

Chapter 3: Export Strategies

How the three countries approach the export of civilian nuclear goods and services and the means and tools available to their reactor vendors differs according to how their political systems and economic structures are organized. There also are some notable differences between the Russian and Chinese approaches to nuclear commerce, as the Russian nuclear industry is integrated both vertically and horizontally under Rosatom, while the Chinese nuclear industry is integrated vertically but not horizontally. This section examines the key differences and similarities among the three countries' civilian nuclear export strategies in the areas of government advocacy, financing, fuel supply arrangements, and human resource development.

The United States: Government in the Back Seat

Nuclear export is largely a private-sector endeavor in the United States, where private enterprises initiate, advance, and finalize nuclear export deals. The role of government is primarily to mitigate the proliferation risks that a commercial nuclear transaction could raise by finalizing government-to-government agreements that set the terms of reference and authorize nuclear cooperation that meets nonproliferation criteria (i.e., "the 123 Agreement"). Government also regulates the export and import of nuclear equipment and material (i.e., Part 110 from the U.S. Nuclear Regulatory Commission); technology for development, production, or use of reactors, equipment, and material (i.e., Part 810 by the U.S. Department of Energy); and "dual-use" items (the U.S. Department of Commerce).

The government does have a role in supporting civilian nuclear exports, but the role is much more reactive in nature in comparison to Russia or China. For example, the International Trade Administration under the U.S. Department of Commerce is tasked with helping U.S. companies navigate U.S. requirements relative to the export of civil nuclear technology and services, as well as with working with foreign governments. The U.S. government engages U.S. nuclear business stakeholders primarily through the Civil Nuclear Trade Advisory Committee, which advises the U.S. secretary of commerce.[40]

40 "Charter of the Civil Nuclear Trade Advisory Committee," U.S. Department of Commerce, International Trade Administration, https://legacy.trade.gov/mas/ian/build/groups/public/@tg_ian/@nuclear/documents/webcontent/tg_ian_005418.pdf.

Under the Trump administration, the U.S. government has become more proactive in seeking ways to support the domestic nuclear industry. For example, in early 2019, the U.S. Department of State introduced Nuclear Cooperation Memoranda of Understanding (NCMOUS) to help the United States "develop strategic civil nuclear cooperation relationships, support the U.S. civil nuclear industry, and advance our national security and nuclear nonproliferation goals."[41] NCMOUS are diplomatic instruments, as opposed to legally binding agreements, and do not themselves permit exports of nuclear materials or equipment for nuclear reactor projects.[42] How effective NCMOUS are as an instrument for cornering the market or countering the Russian attempt to corner the market, with its prolific signing of agreements, is yet to be determined.

In terms of financing export projects, the U.S. government does not have financial tools other than its export credit agency—the Export-Import Bank of the United States (EXIM). The terms of export credit by the EXIM are defined under the Arrangement on Officially Supported Export Credits of the Organization for Economic Cooperation and Development (OECD), as the United States is an OECD member and thus subject to its rules and regulations. The Sector Understanding on Export Credits for Nuclear Power Plants of the Arrangement on Officially Supported Export Credits, last updated in January 2019, stipulates what is acceptable for credit repayment terms, repayment frequencies, and rates, among other issues[43]; the agreement also prohibits the provision of free nuclear fuel or services as well as "aid support" in conjunction with the export credit.[44]

The U.S. Development Finance Corporation (USDFC) is another U.S. government entity that provides loan guarantees and other funding to support U.S. exports, but it is currently constrained from providing loans to NPP projects. The USDFC came into existence in October 2019, after subsuming the Overseas Private Investment Corporation (OPIC) and the Development Credit Authority of the U.S. Agency for International Development. OPIC, which was established in 1971 and provided development finance, had restrictions on financing for nuclear power projects under its Environment and Social Policy Statement. This restriction, which is guidance and not law, has reportedly been grandfathered into USDFC.[45] Moreover, the U.S. government does not have the means to invest equity into NPP projects abroad, although an NPP-importing government has commonly come to expect reactor technology bidders to bring not only debt but also equity to the transaction as a show of serious commitment to the project completion.

The United States has long been regarded as a leader in nuclear reactor technology, a factor that has served as the decisive determinant in the eyes of countries considering an NPP project. Such technological edge, however, is beginning to be outweighed by Russian and

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41 Bureau of International Security and Nonproliferation, "Fact Sheet: Nuclear Cooperation Memoranda of Understanding (NCMOU)," U.S. Department of State, May 30, 2019, https://www.state.gov/nuclear-cooperation-memoranda-of-understanding-ncmou/.

42 Ibid.

43 Organization for Economic Cooperation and Development, "Annex II: Sector Understanding on Export Credits for Nuclear Power Plants," in *Arrangement on Officially Supported Export Credits* (Paris: January 2019), 45-48, https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?doclanguage=en&cote=tad/pg(2019)1.

44 Ibid.

45 John Siciliano, "Old rule obstructs Trump nuclear agenda," *Washington Examiner,* June 13, 2019, https://www.washingtonexaminer.com/policy/energy/old-rule-obstructs-trump-nuclear-agenda.

Chinese deals that combine "good enough" technologies with attractive financing that is outside the bounds of OECD regulations (neither is an OECD member country). In fact, both Russia and China have offered financing that is large (in total amount provided), cheap (with low interest rates) and long-lived (with long repayment periods), and both have been willing to invest equity in projects.[46] Also, Russian and Chinese lending has gone primarily to countries that are below investment grade (See Table 2). These factors may make the deals commercially unsound in market-led capitalist terms. In the United States, every single company must find its own individual piece of the deal to be compelling, as a U.S. company can only look to the short-term effect of the commercial considerations within the contract that pertains to its role in the deal. Under the state-led export model, however, an EPC contract that barely breaks even may still be viable if the deal enables profits through other aspects over multiple decades. The provision of fuel supply, spare parts, plant services, and operating services are commercially low-risk areas with strong profit margins.[47]

TABLE 2: The Terms of Financing for Russian and Chinese Nuclear Export Deals*

EXPORTER	IMPORTER	PROJECT	UNITS	DEBT			EQUITY	COUNTRY CREDIT RATING		
				AMOUNT BILLION USD	INTEREST RATE	REPAYMENT YEARS		MOODY'S	S&P	FITCH
RUSSIA	**Bangladesh**	Rooppu	2	$12.65	1.75%[1]	28 [2]	-	Ba3	BB-	BB-
	Belarus	(Untitled)	2	$10.00	-	25	-	B3	B	B
	Egypt	El Dabaa	4	$25.00	3.00%	22 [3]	-	B2	B	B+
	Finland	Hanhikivi	1	$2.20	-	-	34%	Aa1	AA+	AA+
	Hungary	Paks 2	2	$13.30	Var. [4]	21 [5]	-	Baa3	BBB	BBB
	Jordan (Canceled)	(Untitled)	2	-	-	-	49.90%	B1	B+	BB-
	Turkey	Akkuyu	4	-	-	-	100% [6]	B1	B+	BB-
	Vietnam (Canceled)	Ninh Thuan 1	2	$9.00	-	-	-	-	-	BB
CHINA	**Argentina**[7]	Atucha 3 & Unit V	2	See notes [8]	-	-	-	Ca2	CCC-	CC
	Pakistan	Karachi	2	$6.50	See notes [9]	20	-	B3	B-	B-
	United Kingdom	Hinkley Point C	2	-	-	-	33.5%[10]	Aa2	AA	AA

Source: Adapted from Murphy, "The Bear and the Dragon," 16-17.

* Dash (-) indicates information not publicly available. For Finland and Hungarian debt amounts, U.S. dollar value was added by the author using the average rate of exchange by *statista* in the year the financing arrangements were made: 2015 (€1 = US$1.11) for Finland, and 2014 (€1 = US$1.33) for Hungary (https://www.statista.com/statistics/412794/euro-to-u-s-dollar-annual-average-exchange-rate/).

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[1] 4% cap
[2] 10-year grace period
[3] Starting 2029
[4] Below 4% for 11 years, then 4.5%, then 4.95%
[5] Starting at COD for second unit
[6] Goal to sell down to 51%; Russia-owned project; company must source all financing
[7] Initial deal canceled; revised project structure under negotiation (only a Hualong One project)
[8] 85% of project costs across two projects (Atucha 3, plus a Hualong One project; linked financing)
[9] "to be repaid at concessional rate"
[10] Plus 20% equity in Sizewell C (2 units), plus rights to Bradwell site for a Hualong One project (2 units)

46 Murphy, "The Bear and the Dragon," 11-12.
47 Ibid., 16-17.

Russia: Perfecting a Model

Russia's rise as the dominant reactor technology supplier today is also attributable to its ability to adapt its business models to a changing market. Rosatom is both vertically and horizontally integrated, providing reactor technology, plant construction under an EPC contract, fuel, operational capability (including training), maintenance services, decommissioning, spent nuclear fuel reprocessing, and regulatory support, as well as generous financing (debt and equity) to both established markets and newcomers. For example, its uranium enrichment services count the United States and a few other established nuclear energy economies such as France, Japan, and the United Kingdom as customers. The integrated structure affords Russia the ability to engage a foreign client through a single point of contact in contractual engagements. The one-stop-shop approach has a particular appeal to newcomer countries that are too limited in experience to develop and deliver a project as complex as an NPP project. By providing a single point of entry for negotiation, the Russian approach makes it more palatable for countries to build NPPs.

Also, spent fuel takebacks are a feature unique to Russia's NPP export strategy. Under this approach, Russia takes back spent nuclear fuel from overseas customers for reprocessing and keeps the waste if the fuel is of Russian origin.[48] France also reprocesses spent fuel from other countries, but they return the waste to the countries of origin. Russia sees that the takeback approach is valuable for attracting countries that are unable to afford comprehensive spent fuel management systems on their own, as well as for helping to safeguard against proliferation by stemming a recipient country ability to develop a weapons program from a nuclear power generation program. The takeback clause is not mandatory in agreements, so Russia could legally sign agreements whether or not a client country agrees to including the clause.[49]

Russia is also proactive in providing technical training in newcomer countries. Such training can cultivate a network of technical experts and policymakers who are familiar with Russian reactor technologies and, better yet, may thus be inclined to choose a Russian project over others. Rosatom has offered scholarships to young nuclear experts from African countries, including Ghana, Kenya, and Nigeria, for study and training in Russia.

Additionally, the Russian nuclear energy export approach is notable for the aggressive signing of agreements—commonly something more concrete than a simple memorandum of understanding but less concrete than EPC contracts and supporting project documentation and financing.[50] These have the effect of locking down the country for

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48 Russia also takes back the spent fuel from NPPs that were built by the Soviet Union in Eastern Europe and Finland. Anatoli Diakov and Pavel Podvig, "Russia," in *Managing Spent Fuel from Nuclear Power Reactors* (International Panel on Fissile Materials, 2011), 74-75, http://fissilematerials.org/library/rr10.pdf.

49 International Institute for Strategic Studies, *The Geopolitics of Nuclear Energy: New Dynamics of Supply and Demand* (Moscow: November 2018), 7, https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=4&ved=2a-hUKEwiJ7oCd0_LnAhVHip4KHTBOCY8QFjADegQIBBAB&url=https%3A%2F%2Fwww.iiss.org%2F-%2Fmedia%2Fim-ages%2Fcomment%2Fanalysis%2F2018%2Fdecember%2Fiiss-ceness-moscow-workshop-report-2018.pdf%-3Fla%3Den%26hash%3D81DABE0B5BBF56D1F6FDDB569ADCCF76C41B8A7F&usg=AOvVaw2Hpd-ebtgLFb5qS0K-97WH.

50 Author's interview with Paul Murphy, Murphy Energy & Infrastructure Consulting, LLC, September 18, 2019.

Russia and locking out the competition.[51] Can Russia deliver on all the projects it has been negotiating and agreeing to build? These deals—if they proceed simultaneously in a critical mass—would severely constrain not only Russia's financial resources but also its supply chain capacity. However, Russia's assumption seems to be that these projects will not proceed simultaneously.

China: Learning by Doing

Given China's dearth of a track record in nuclear reactor exports, it is difficult to make generalizations about China's nuclear deals in terms of approaches, strategies, and tactics beyond their offer of generous financing. China's most active export efforts underway in the United Kingdom and Argentina, however, suggest that China uses financing and a willingness to execute projects others find unattractive as a lever to land additional nuclear projects that can advance its interest.[52]

For example, the Chinese investment for a 33.5 percent share in the Hinkley Point C project in the United Kingdom has helped to assuage the British apprehension over construction of China's Hualong One reactor at the Bradwell site in the future. The U.K. government under the leadership of Prime Minister David Cameron (2010-2016) welcomed the Chinese financing as a necessary means to finance the country's carbon reduction efforts, as all but one of the United Kingdom's 16 reactors had been slated to shut down by 2023 (when Hinkley Point C was originally slated to come online). The deal briefly came under review by Prime Minister Theresa May (2016-2019) over the high guaranteed strike price of £92.5 per MWh but was approved soon afterward in September 2016. The diminishing trade and investment opportunities that will likely ensue following the U.K. departure from the European Union in January 2020 reinforce the difficulty the United Kingdom faces in financing its infrastructure plans, including the modernization of its nuclear power generation fleet. As the owner and operator of nearly all of the U.K. nuclear fleet, majority state-owned Électricité de France (EdF) also welcomed the Chinese financing, as the company was under a major financial strain at the time.

Likewise, the Chinese financing has essentially led Argentina to forgo its original plan to use CANDU reactor technology from Canada and to agree in 2017 to proceed only with China's Hualong One reactor, although financing challenges continue to delay the final deal. China's 2014 agreement with Argentina, under President Cristina Fernandez de Kirchner (2007-2015), provided for Nucleoeléctrica Argentina—the Argentinean nuclear utility and a holder of rights to CANDU technology—to serve as designer, architect-engineer, builder, and operator of a new CANDU reactor plant, while the CNNC was to assist Nucleoeléctrica by providing goods and services under long-term Chinese financing.[53] About half a year later, the two countries also agreed on cooperation over constructing a Chinese reactor in Argentina that would entail "the maximum local content" for Argentine companies.[54] President Mauricio Macri (2015-2019) was initially

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51 Ibid.

52 Murphy, "The Bear and the Dragon," 15.

53 "China signs Candu deals with Romania and Argentina," World Nuclear News, July 25, 2014, https://www.world-nuclear-news.org/Articles/China-signs-Candu-deals-with-Romania-and-Argentina.

54 "Hualong One selected for Argentina," World Nuclear News, February 5, 2015, https://www.world-nuclear-news.org/

apprehensive about the nuclear deal given the country's economic woes, but his concern was partially assuaged by an agreement from the Industrial and Commercial Bank of China to finance up to 85 percent of the construction cost.[55] By 2019, Macri had decided to downsize the project to one plant, effectively scrapping a CANDU reactor plan for a Hualong One reactor plan.[56]

Meanwhile, China is proactive in providing personnel training. For example, since 2012, China has been hosting master's- and doctoral-level students from emerging nuclear power countries under the Atomic Energy Scholarship, whose selection process is facilitated by the International Atomic Energy Agency.[57] Since 2017, China's Atomic Energy Scholarship has been hosting 35 to 40 students annually to study the basics of nuclear engineering, as well as to gain some operational training using practice rooms and simulators.[58] Also since 2017, with strong support of the three nuclear SOEs, Tsinghua University has been providing full scholarships to foreign students in nuclear engineering and management, not only to support the development of human resources in emerging nuclear countries but to "make contributions to the cooperation between China and their motherlands after graduation."[59]

NN-Hualong-One-selected-for-Argentina-0502154.html.

55 "China, Russia Looking to Build Nuclear Plants in Argentina," *POWER Magazine,* June 30, 2019, https://www.powermag.com/china-russia-looking-to-build-nuclear-plants-in-argentina/.

56 Fermin Koop, "Argentina crisis prompts shift in Chinese investment," chinadialogue, October 25, 2019, https://www.chinadialogue.net/article/show/single/en/11606-Argentina-crisis-prompts-shift-in-Chinese-investment.

57 "China Trains Nuclear Engineers from Nuclear Newcomer Countries – IAEA Facilitates Selection Process," International Atomic Energy Agency, May 2019, https://www.iaea.org/newscenter/news/china-trains-nuclear-engineers-from-nuclear-newcomer-countries-iaea-facilitates-selection-process.

58 Ibid.

59 "Specialties," Tsinghua University International, https://www.tsinghua.edu.cn/publish/epen/1400/index.html.

Chapter 4: Export Motivations

The availability of strong political support and generous resources for nuclear energy exports is a key distinguisher between the United States and the two state-led capitalist countries. But, why do Russia and China support nuclear energy exports? What value do the three countries see in preserving a competitive program for nuclear reactor technology and service exports?

The United States: More Than Business

A full-fledged government support for nuclear energy and its export has been illusive for much of the history of nuclear power in the United States, driven in large part by the diversity of views on their economic value as well as the plurality of beliefs on the appropriate role of government in technology development and commercialization. During the technology's infancy, for instance, much of the initial enthusiasm for civilian nuclear technology was non-economic in nature. Many of the scientists, technicians, and policymakers that worked on the development of the first nuclear weapons began to publicly advocate for explicitly non-military nuclear applications as a means of assuaging any guilt that still lingered over their part in the bombings of Hiroshima and Nagasaki.[60] When coupled with a booming post-war economy and a broader faith in the emerging possibilities of the technology, these social efforts resulted in the 1954 Atoms for Peace program and the passage of the Atomic Energy Act of 1954.

This early political and social embrace of nuclear power was not, however, initially sufficient to overcome the industry's early barriers. Despite a bipartisan consensus on the desirability of peaceful nuclear applications, early pro-nuclear power legislation, such as the ill-fated Gore-Holifield Bill of 1956, foundered on the emerging division between the Republican Party's preference for free markets and their Democratic peers' inclinations for relatively more government intervention. Also, the economics of nuclear power projects were highly uncertain, and what evidence did exist indicated that the underlying

60 This sentiment is illustrated in David Lilienthal, *Change, Hope and the Bomb* (Princeton, NJ: Princeton University Press, 1963); Peter Pringle and James Spigelman, *The Nuclear Barons* (London: Sphere Books, 1981); and Paul Ham, *Hiroshima and Nagasaki: The Real Story of the Atomic Bombings and Their Aftermath* (New York, NY: Thomas Dunne Books, 2014).

technology still lagged behind coal and natural gas, with the first nuclear reactor at Shippingport producing electricity that was at least 10 times more expensive than its coal-fired competitors on a levelized cost basis.[61] Moreover, popular associations of all things nuclear with the destructive potential of nuclear weapons made insurers reluctant to extend comparably priced underwriting to utilities and project sponsors. While this situation was somewhat ameliorated by the 1957 Price-Anderson Act, NPP orders remained anemic from 1953 to 1963, averaging just 2.1 orders per year.[62]

In the mid-1970s, the winds began to turn more favorable for nuclear power generation when General Electric and Westinghouse began to structure their sales as turnkey contracts that were priced at a level competitive against coal- and gas-fired power plants, whereby the first-wave of more-expensive NPPs would act effectively as loss-leaders but demonstrate the advantages of nuclear and catalyze enthusiasm for future sales. This strategy provided the financial assurances that utilities needed and launched a surge of NPP orders.

However, the unexpected slowdown in electricity market demand—from nearly 7 percent annually pre-1974 to around 3 percent post-1974—combined with rising capital costs tempered the enthusiasm for nuclear power.[63] Although utilities placed over 70 orders for new NPPs between 1973 and 1979, all were eventually canceled.[64] The economic rationale behind nuclear power generation came under further scrutiny following the Three Mile Island (TMI) nuclear accident of 1979. The TMI accident brought the already slowing expansion of the U.S. nuclear fleet to a halt, as additional regulations and increasingly attractive alternative sources of generation led most utilities to abandon any new nuclear projects. Without new additions to the fleet, utilities and the nuclear industry focused their efforts on maintaining and extending the lives of existing nuclear projects. In the subsequent five years, U.S. utilities cancelled 51 nuclear power reactor orders, and the Nuclear Regulatory Commission (NRC) did not issue its next construction permit for a new plant until 2012.[65]

In the absence of a vibrant domestic market for NPPs, the export market has become the important means to sustain the domestic supply chain, which relates closely to the vitality of the nuclear Navy supply chain as well as the nuclear defense program. Yet, U.S. leadership on nuclear nonproliferation may suffer the most without U.S. export competitiveness, even if domestic demand for nuclear energy returns. Besides scientific and technological prowess and military strength, the competitiveness of U.S. nuclear

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61 Gerard H. Clarfield and William M. Wiecek, *Nuclear America: Military and Civilian Nuclear Power in the United States, 1940 – 1980* (New York, NY: Harper & Row Publishers, 1984).

62 Joint Committee on Atomic Energy, Hearings, R*eports and Prints of the Joint Committee on Atomic Energy* (Washington, DC: U.S. Government Printing Office, 1969), 992. https://books.google.com/books?id=Lf43AAAAIAAJ&pg=PA992&lpg=PA992&dq=nuclear+ordered+1953+to+1963&source=bl&ots=m8myaV9tMV&sig=ACfU3U2UzhjJY-qvPkb4ZV7OlhNWY1k-DIA&hl=en&sa=X&ved=2ahUKEwj73IePno7oAhUIgXIEHfIRAUAQ6AEwFXoECAwQAQ#v=onepage&q=nuclear%20ordered%201953%20to%201963&f=false.

63 Pietro S. Nivola, "The Political Economy of Nuclear Energy in the United States," Brookings Institution, Policy Brief no. 138, September 2004, https://www.brookings.edu/research/the-political-economy-of-nuclear-energy-in-the-united-states/.

64 "Cancelled Nuclear Units Ordered in the United States," https://web.archive.org/web/20120123212944/http:/clonemaster.homestead.com/files/cancel.htm.

65 Ibid.

energy exports has played a significant role in enabling U.S. leadership in nuclear safety and nonproliferation. For example, in 1978, the United States made nuclear exports conditional on a recipient country's acceptance of safeguards on all of its nuclear facilities, including those not provided by the United States.[66] Moreover, bilateral agreements that allow U.S. exports of nuclear goods and services contain provisions that require inspection of U.S. nuclear exports to verify they were not diverted for non-peaceful purposes, essentially providing U.S. insight into a foreign country's nuclear sector. A number of technical nuclear cooperation agreements the United States has concluded around the world have made the country the most active participant in knowledge transfer, training, nuclear safety and security, and regulation, whereby the United States is involved in more than half of safety and security cooperation around the world.[67]

This logic resonates in a U.S. government report from 1974 that argued, "[A] vigorous US program of commercial nuclear cooperation with other nations can help maintain influence over foreign programs through proper safeguards, dependence on external supply, and the confidence of a constructive association in peaceful programs."[68] In essence, the promise of peaceful nuclear exports and the threat of cutting these exports off have been an element of U.S. strategy for preventing proliferation.[69] The United States continues to maintain influence over existing nuclear power programs abroad, but the influence can decline parallel to the decline in U.S. nuclear exports.

Russia: Preserving Relevance and Influence

The Russian state sees strategic value in its energy exports. As early as 2003, Russia recognized that "[its] significant energy resources and power fuel-energy complex were instruments for conducting domestic and foreign policy" and that "the role of the country on global energy markets to a great degree determined its geopolitical influence."[70] Key parts of Russia's national security establishment view civilian nuclear exports as an "important tool for projecting influence overseas."[71] Against the backdrop of rising energy prices in the early part of the last decade, Russian leaders began seeing that the country's energy influence is an effective enabler in a strengthened position in the Commonwealth of Independent States or for forging a new type of relationship with the European Union.[72]

Even in the current period of relatively low energy prices, Russia's energy deals are complicating the European Union's ability to shape consensus over energy issues and

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66 Sharon Squassoni, "Looking Back: The 1978 Nuclear Nonproliferation Act," *Arms Control Today*, December 4, 2008, https://www.armscontrol.org/act/2008_12/lookingback_NPT.

67 Jessica Jewell, Marta Vetier, and Daniel Garcia-Cabrera, "The International Technological Nuclear Cooperation Landscape," *Energy Policy* 128 (2019): 849, doi:10.1016/j.enpol.2018.12.024.

68 Nicholas L. Miller, "Why Nuclear Energy Programs Rarely Lead to Proliferation," *International Security* 42, no. 2 (Fall 2017), 51, doi:10.1162/ISEC_a_00293.

69 Tristan Volpe and Nicholas Miller, "Geostrategic Nuclear Exports: The Competition for Influence in Saudi Arabia," Carnegie Endowment for International Peace, February 7, 2018, https://carnegieendowment.org/2018/02/07/geostrategic-nuclear-exports-competition-for-influence-in-saudi-arabia-pub-75472.

70 Minin and Vlček, "Determinants and considerations of Rosatom's external strategy," 37.

71 Andrew S. Weiss and Eugene Rumer, "Nuclear Enrichment: Russia's Ill-Fated Influence Campaign in South Africa," in *The Return of Global Russia.* (Washington, DC: Carnegie Endowment for International Peace, December 2019), 1.

72 John Lough, "Russia's Energy Diplomacy," Chatham House, Briefing Paper, May 2011, 4, https://www.chathamhouse.org/sites/default/files/19352_0511bp_lough.pdf.

projects among its member states. Specific to NPP projects, the Russian NPP project in Hungary is bolstering Russia's relevance in European affairs. A member of the European Union since 2004, Hungary is adding two new Russian reactors to its fleet of four reactors at the Paks site (built by Soviet Russia) after Viktor Orban's government side-stepped an open tender process. The Orban government's support for Russia-favored energy projects, such as the South Stream gas pipeline project and the Turkish Stream gas pipeline project, may be due in part to Russia's generous 80+ percent loan for the €12 billion NPP project. The decision to award Rosatom without an open tender process adds to a series of practices in recent years that illuminates the deterioration of legal principles and regulatory standards, let alone political values, in Hungary in contravention to the ideals EU membership ordinarily stands for.

Moreover, nuclear energy exports have become a tool to preserve Russia's relevance in world politics as well. Rosatom's nuclear project at Akkuyu in Turkey has a strategic value to Russia in that the project has significantly complicated diplomatic relations between the United States and Turkey, which is a member of the North Atlantic Treaty Organization (NATO). Although Turkey has had a bilateral nuclear cooperation agreement with the United States since 1955, "a string of unstable governments, military coups and successive economic crises," combined with its insistence on commercially difficult terms of tenders, have confounded the Turkish government's effort to acquire a nuclear power program.[73] When Turkey opened a tender in 2008, Rosatom was the only bidder, as the U.S. industry did not see it commercially feasible to supply reactors to Turkey.[74]

The four-reactor Akkuyu NPP project, per the intergovernmental agreement between Russia and Turkey in 2010, seeks to realize the country's first nuclear power project on the build-own-operate (BOO) model by the early-2020s. Under the BOO model, Russia would not only build but also own and operate the plant, thereby bearing all the financial, construction, operating, and country risks. This arrangement aims to remove many technical and regulatory barriers a nuclear newcomer may encounter in introducing nuclear energy and has likely reduced a significant level of financial barriers for Turkey.

The Turkish embrace of a Russian-owned NPP on its soil, which survived the diplomatic tension over the Turkish downing of a Russian fighter jet in 2015, could raise a serious security concern to the United States, especially over the existing U.S.-led security architecture in Europe. How would the United States and NATO respond if a foreign power attacked the Russian-owned reactor on NATO member land? What would be the rights and obligations of NATO in response if Russia responded to such an attack with military deployment in Turkey? Moreover, the Akkuyu NPP deal may have helped to unlock other trade deals with additional foreign policy implications, as exemplified by the Moscow-Ankara agreement in 2017 for the sale of Russia's S-400 surface-to-air-missile batteries, which the United States views as a major security threat to its F-35 stealth fighter jets, which are being rolled out among NATO allies.

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73 Jessica C. Varnum, "Closing the Nuclear Trapdoor in the U.S.-Turkey 'Model' Partnership: Opportunities for Civil Nuclear Cooperation," Brookings Institution, *Turkey Project Policy Paper* no. 1, 3, https://www.brookings.edu/wp-content/uploads/2016/06/17-us-turkey-nuclear-partnership-cooperation-varnum.pdf.
74 Ibid., 5.

In ascertaining the amount of leverage nuclear commerce may create, whether nuclear energy deals accord Russia geopolitical leverage similar to pipeline natural gas deals is a frequent point of debate. Does nuclear fuel provision create influence or leverage over the importer country as much as, if not more than, pipeline gas supply? Some see a strong analogy between the two. In fact, some believe that the relative dearth of nuclear fuel manufactures and exporters makes nuclear fuel provision a more potent tool for foreign policy influence. While "oil and gas risks are primarily short-term shocks" which can be dealt with by strategies such as excess storage and supplier diversification, "nuclear power risks entail long-term dependencies which cannot be addressed as simply since they lock client countries into particular dependencies that cannot be easily addressed."[75] For example, Russia is the nuclear fuel supplier in 43 percent of nuclear technology agreements, while the country's supply of natural gas accounted for about one-fifth of internationally-traded natural gas in 2016.[76] Others see the analogue to be inaccurate, as NPPs do not require an uninterrupted supply of fuel or particular infrastructure for transportation the way thermal power plants do, making it less vulnerable to political manipulation.[77]

The highly proprietary nature of nuclear reactor technologies and fuels renders it complex and costly, but the sourcing of nuclear fuel from an alternative supplier is possible. For example, Ukraine, which has been in a diplomatic, economic, and (since 2014) territorial conflict with Russia, has been receiving Westinghouse nuclear fuel since 2005 that is compatible with its Russian reactors "in a bid to cut its dependence on Russia."[78] The arrangement was initially born out of the U.S. government effort to dissuade Ukraine from supplying gas turbines for the Bushehr nuclear plant in Iran in the late-1990s by offering a host of economic and technological incentives, including access to U.S. nuclear reactor technology and fuel.[79] The U.S. government under the Ukraine Nuclear Fuel Qualification Project has supported testing necessary to confirm that Westinghouse-manufactured fuels are compliant with design parameters and reliable for use in Soviet-designed VVRE-1000 reactors operating in Ukraine. To the Ukrainians, the arrangement meant an opportunity to reduce Ukraine's total dependence for Russian fuel. By 2025, Westinghouse would be delivering nuclear fuel to 7 of Ukraine's 15 nuclear power reactors.[80]

While Russia's recognition of the linkage between nuclear commerce and foreign policy influence is clear, the motivation to export NPPs does not lack economic and commercial rationale. First, as in the United States, the nuclear industry in Russia sees NPP exports as the means to help make up for the slowdown in domestic new builds. The country's "federal target program to 2020," released in 2007, had targeted the annual addition of 4 GW from 2016 to 2020, but the reduced power demand growth and financial constraints

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75 Jewell, Vetier, and Garcia-Cabrera, "The International Technological Nuclear Cooperation Landscape," 850.
76 Ibid.
77 Minin and Vlček, "Determinants and considerations of Rosatom's external strategy," 42.
78 Svetlana Burmistrova, "Ukraine to use U.S. nuclear fuel to cut dependence on Russia – Energoatom," Reuters, September 11, 2014, https://af.reuters.com/article/commoditiesNews/idAFL5N0RC3VA20140911.
79 Victor Zaborsky, "Us-Ukrainian Nuclear Cooperation: Is Kyiv Ready for It?" *The Nonproliferation Review* (Spring-Summer 1999), 133, https://www.nonproliferation.org/wp-content/uploads/npr/zabor63.pdf.
80 "Westinghouse expands Ukraine presence with new nuclear fuel deal," Reuters, January 29, 2018, https://www.reuters.com/article/uk-ukraine-power-westinghouse/westinghouse-expands-ukraine-presence-with-new-nuclear-fuel-deal-idUSKBN1FI0V5.

led to a major downsizing of earlier plans by 2009.[81] The decade through 2017 saw only seven reactor units begin construction.[82] In order to sustain the capacity for manufacturing reactors, equipment, and components, Rosatom sees a strong reason to explore foreign buyers to make up for the domestic shortfalls, as Russian suppliers account for 60 to 70 percent of the content value for NPP exports.[83]

Following the financial crisis of the late-2000s, Rosatom's leadership viewed international expansion as means for sustaining intellectual and technical capabilities inside Russia and funding vital programs.[84] Foreign orders have helped to sustain the country's nuclear industry through domestic economic turmoil. In the years that followed the collapse of the Soviet Union, when Russia had very limited financial resources for domestic development, the construction of the Bushehr NPP in Iran and the Tianwan NPP in China revived Russia's fresh fuel production business, as they enabled Russia to afford the construction of the Novoibirsk Chemical Concentrates Plant to supply fuel rods for the two overseas projects.[85]

Second, nuclear commerce contributes significantly to the Russian economy. Specifically, nuclear projects abroad raise Russian GDP at a rate of nearly two-to-one over money invested.[86] In 2018, Rosatom and related organizations paid RUB 188.2 billion ($2.83 billion) in taxes, "including RUB 71.4 billion ($1.07 billion) to the budgets of the federal subjects of Russia and local budgets."[87] By 2024, Rosatom is expected to more than double the revenue from its overseas business, from $6.6 billion in 2018 to $15 billion.[88] Interestingly, Rosatom's current strategy is for its revenue from businesses that are not directly related to NPPs (e.g., NPP construction and fuel assembly) to make up at least 30 percent of the total revenue by 2030[89]; these "new businesses" include projects in the areas of nuclear medicine, wind power, composite materials, additive manufacturing, lasers, robotics, and supercomputers. Notwithstanding the benefit to the national economy, there exists a major uncertainty as to whether Russia would be ready to absorb unexpected costs—should they arise—in their export projects with a fixed price provision underway, such as in Bangladesh, Belarus, Hungary, and Iran.[90] Also, Rosatom is hoping to reduce its financial exposure to the Akkuyu project by seeking an investor to help reduce its stake in the project to 51 percent.

There is also an indirect manner in which the nuclear sector contributes to the Russian economy. One primary example is the modernization and expansion of nuclear-powered icebreaker fleet. Russia is increasingly focused on the development of the Arctic for

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81 "Nuclear Power in Russia," World Nuclear Association, https://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx.
82 Thomas, "Russia's Nuclear Export Programme," 236.
83 "Rosatom explains benefits of state backing to plant projects," World Nuclear News, February 2016, https://www.world-nuclear-news.org/C-Rosatom-explains-benefits-of-state-backing-to-plant-projects-11021601.html.
84 Weiss and Rumer, "Nuclear Enrichment," 9.
85 Minin and Vlček, "Determinants and considerations of Rosatom's external strategy," 39.
86 Ibid., 40.
87 Rosatom, *Performance in 2018,* 26.
88 "Rosatom expects foreign business income to double by 2024," World Nuclear News, May 10, 2019. https://world-nuclear-news.org/Articles/Rosatom-sees-income-from-foreign-business-doubling.
89 Rosatom, *Performance of State Atomic Energy Corporation Rosatom in 2017* (Moscow: 2018), *55.*
90 Thomas, "Russia's Nuclear Export Programme," 244.

commercial transport. Owner of the only nuclear-powered icebreaker fleet in the world, Russia seeks to capitalize on this asset to facilitate the country's economic development.[91] The Northern Sea Route has become particularly important as a "strategic shipping route" that can shorten the duration of a voyage from Europe to Asia by more than one-third when compared to the Southern Sea Route—a notable advantage as Russia has embarked on the development of liquefied natural gas (LNG) export projects in the area, such as the Yamal LNG Project and the Arctic LNG 2 Project.

Third, nuclear commerce helps to diversify Russia's overall export profile, which is traditionally heavily reliant on natural resources such as oil and gas. For example, oil and gas revenues accounted for 59 percent of goods exported in 2018 and 61 percent (estimate) in 2019.[92] Moscow deems state support for NPP projects abroad "logical" because they are "high-tech products."[93] As NPP and service exports are much less vulnerable to the type of cyclical price fluctuations common in oil and gas markets, civilian nuclear exports may actually be a source for counter-balancing Moscow's overreliance on oil and gas tax income.

China: Expanding Economic Power

Nuclear power is "a nexus of clean energy, economic incentives and international prestige" for the Chinese, and the country's desire to increase its role in the international economy drives the interest in nuclear exports.[94] As such, the sector is among the top focuses for the country's economic and industrial strategy.

Under Made in China 2025—the Chinese government's 10-year plan released in 2015—China seeks to modernize the country's manufacturing base by rapidly developing 10 high-tech industries and making China globally dominant in high-tech manufacturing through the strategic use of government subsidies, SOEs, and intellectual property acquisition.[95] While the plan does not name nuclear energy as one of the 10 discrete industries, the emphasis on manufacturing upgrades in the country's nuclear power supply chain is clearly aligned with this policy. For example, the industrial policy involving over 300 entities participating in research and development as well as manufacturing[96] has helped China to be able to manufacture up to 90 percent of the key equipment for Hualong One reactor (including main pump, steam generator, container and fuel element).[97] China's NPP construction capacity continues to improve, with the localization rate reaching 85 percent, enabling—at least in theory—

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91 Rosatom, *Performance in 2018,* 97.

92 "Balance of Payments of the Russian Federation," (Estimate. Analytical Presentation), Central Bank of the Russian Federation, January 17, 2020, https://www.cbr.ru/eng/statistics/macro_itm/svs/.

93 "Rosatom explains benefits of state backing to plant projects," World Nuclear News, February 2016, https://www.world-nuclear-news.org/C-Rosatom-explains-benefits-of-state-backing-to-plant-projects-11021601.html.

94 Madhavan, Rawski, and Tian, "Capability Upgrading and Catch-Up in Civil Nuclear Power," 453.

95 Wayne M. Morrison, "The Made in China 2025 Initiative," Congressional Research Service, updated April 12, 2019, https://fas.org/sgp/crs/row/IF10964.pdf.

96 Liu Chenyao, "The Main Work Begins for China's UK-Based 'Most Expensive Nuclear Power Project'," China News Network, May 9, 2017, http://www.chinanews.com/ny/2017/05-09/8219126.shtml.

97 Xu, Kang, and Yuan, "The Prospective of Nuclear Power in China," 9.

the production of eight sets of nuclear equipment annually.[98] Overall, nuclear power equipment manufacturing is a $7 billion business in China (per annum) as of 2019-2020.[99]

Nuclear energy export appears to be as much a tool for promoting the BRI as it is an area for promotion under the BRI. One observation suggests that BRI policy "virtually requires" the three nuclear SOEs and their major SOE equipment suppliers to "aggressively pursue overseas marketing opportunities."[100] In fact, China first proposed nuclear export policy as part of the BRI against the background of slow economic growth and serious overcapacity problems.[101] China's stated willingness to export NPPs to countries "where installed energy capacity is limited, economics weak, and industrial levels low, but have good relationships with China"[102] suggests how China values NPP exports as a means to address overcapacity problems rather than a revenue generator.

There are some positive official assessments, as exemplified by a 2015 article by Xinhua, that "China's nuclear technology export has contributed to the country's international cooperation of nuclear industry and the concrete implementation of BRI."[103] However, concrete achievement has thus far been limited to the Hualong One project underway in Pakistan, which is a key participant in the BRI through the China-Pakistan Economic Corridor (CPEC). Pakistan is already aligned with China due to their common rivalry against India, so it is unclear how much value China accords to the Karachi NPP project as a tool to advance its foreign policy influence over Pakistan, particularly as the latter has already been home to Chinese nuclear reactor technology since 2000.

Meanwhile, the geopolitical implications may be larger for Chinese involvement in the UK program. Approval from highly regarded UK regulators would help launch the Hualong One reactor for the global market, including in the advanced industrialized economies. Also, UK approval for Hualong One construction at the Bradwell site marked a notable precedence in that a leading OECD economy allowed investment into NPPs by state-owned companies from a state-led capitalist economy, which was later termed by the European Union as "a systemic rival promoting alternative models of governance."[104]

This was not the first time that the United Kingdom accepted Chinese involvement in its critical infrastructure, however.[105] Huawei—a Chinese company under scrutiny for its ties to the Chinese government—has supplied equipment for UK telecommunication networks

98 Ibid., 6.

99 Shujun Wang, (speech, People's Political Consultative Conference, June 19, 2019), http://www.rmzxb.com.cn/c/2019-06-19/2366913.shtml.

100 Madhavan, Rawski, and Tian, "Capability Upgrading and Catch-Up in Civil Nuclear Power," 429.

101 Ira Martina Drupady, "Emerging nuclear vendors in the newcomer export market," *Journal of World Energy Law and Business* 12, no. 1 (March 2019), 13, doi:10.1093/jwelb/jwy033.

102 Chen and Zheng, "The Going Global Strategy of China's Nuclear Power Industry."

103 Xu, Kang, and Yuan, "The Prospective of Nuclear Power in China," 9.

104 "Commission Reviews Relations with China, Proposes 10 Actions," European Commission, March 12, 2019, https://ec.europa.eu/commission/presscorner/detail/en/IP_19_1605.

105 The UK defines its Critical National Infrastructure (CNI) as "certain 'critical' elements of infrastructure, the loss or compromise of which would have a major, detrimental impact on the availability or integrity of essential services, leading to severe economic or social consequences or to loss of life." Intelligence and Security Committee, *Foreign involvement in the Critical National Infrastructure* (London: 2013), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/205680/ISC-Report-Foreign-Investment-in-the-Critical-National-Infrastructure.pdf.

since 2005.[106] In January 2020, the UK government decided to further allow Huawei in the country's 5G network system, albeit in the non-core elements, over strong U.S. objections due to security concerns. The UK National Security Council has reportedly stipulated that Huawei would be banned from sensitive sites, including for NPPs and military bases.[107] If true, this is a perplexing notion because the UK government has already approved not only Chinese investment in its NPP projects but also the construction of a Chinse NPP in the United Kingdom. The NPP export serves as a yardstick for China's economic influence abroad rather than a tool for influence.

Balancing Act: The Value of the Deal Is in the Eyes of the Beholder?

Nuclear export pursuits have foreign policy implications whether they are a primary, explicit, or even discrete objective. Meanwhile, a bad deal has reputational consequences. The inability to keep a project under budget and on schedule can diminish a supplier country's ability to land future deals. Moreover, politicizing NPP exports could gravely diminish their appeal to future customers. In fact, nuclear SOEs—such as Rosatom, the CNNC, and the CGN—seem to have the challenge of optimizing government support without over-politicizing the projects.

Fundamentally, however, their SOE status sometimes obligates them to go along with economically unsound projects. Rosatom's ill-fated NPP undertaking in South Africa is a prime example. In 2014, the Russian government and the South African government, under President Jacob Zuma (2009-2018), quietly sealed a $76 billion NPP construction deal. Although the deal appeared to be a loss-leader, the company was "forced to undertake a massive construction project with uncertain upfront financing and equally uncertain prospects for long-tern commercial gain" because "even bad deals can make for good geopolitics" in the eyes of the Kremlin.[108] To some veteran Russia analysts, the South Africa case also illustrated the "limits of Russia's reach and its modest tool kit for projecting power and influence in regions far beyond its periphery."[109]

106 Concerns by senior U.S. officials include the fact that new Chinese laws require Chinese companies to assist in national intelligence work. See Raymond Zhong, "Who Owns Huawei? The Company Tried to Explain. It Got Complicated," *New York Times*, April 25, 2019, https://www.nytimes.com/2019/04/25/technology/who-owns-huawei.html; Huawei was one of many companies that were selected to supply equipment required for the United Kingdom's rationalization and upgrade project, commonly known as the 21st Century Network. The contract was signed in 2005 and Huawei's transmission and access equipment were deployed beginning in 2007. Ibid.

107 Helen Warrell et al., "US condemns US decision to give Huawei limited role in 5G network," *Financial Times,* January 29, 2020, https://www.ft.com/content/e3d38d0e-41c5-11ea-a047-eae9bd51ceba.

108 Weiss and Rumer, "Nuclear Enrichment," 10, 13.

109 Ibid., 12.

Chapter 5: Variables for Future Competitiveness

The future trajectory for sector growth and export competitiveness is by no means linear. Both internal and external developments could affect how the nuclear power sectors of the three countries operate, and such developments can be political, regulatory, economic, and technological in nature. Which key developments could alter the competitiveness of nuclear exports by the United States, Russia, and China?

Russia: Can It Walk the Walk?

A major domestic variable that may reduce Russia's market competitiveness relates to the linkage between nuclear commerce and the country's oil and gas export revenues. How dependent is nuclear commerce on state funding, which itself relies significantly on oil and gas export revenue? The declining share of federal budget funds for new nuclear power capacities in Russia leading up to 2015 may suggest that low oil and gas prices reduced the state allocation of funding for nuclear projects. In fact, the share of state funding declined steadily from 46 percent in 2009 to 16 percent in 2015.[110] There was a collapse in global crude oil prices in the latter half of 2014, but there was also a turn of events following Russia's annexation of Crimea which began to drain foreign sources of financing for Russian projects. In light of the economic difficulty, whether Rosatom will replicate the once-famed "Build-Own-Operate (BOO)" model beyond the Akkuyu NPP project in Turkey warrants attention. Although it was once seen as a clever business model, it has proven to be expensive, costing Russia $22-25 billion. Many nuclear industry observers in Russia as well as in the West seem to doubt that Rosatom will offer it for another export contract ever again.[111]

Moreover, how competitive is Rosatom in the global commercial marketplace without major state funding? In fact, state support for NPP constructions has been due for

110 Leonid Andreev, *The Economics of the Russian Nuclear Power Industry* (Oslo: Bellona Foundation, 2011), 12, https://network.bellona.org/content/uploads/sites/3/fil_Economics-of-the-Russian-Nuclear-Power-Industry-English.pdf.
111 Schepers, "Russia's Nuclear Energy Exports," 4; and about a dozen interviews with U.S. and western nuclear industry observers and analysts.

termination for some time, initially by 2015 and most recently by 2020.[112] Rosatom has traditionally received funds allocated from the federal budget, which are transferred into the corporation's account as "asset contributions" to supplement Rosatom's own funds for construction.[113] In 2016, Russia's deputy finance minister announced a decision to suspend granting any new loan to foreign countries, including for nuclear projects, due to budget cuts.[114] The National Wealth Fund also seems to be off-limits for future NPP export projects, after the Finnish project was exempted.[115] The new direction heightens Rosatom's need to "master how to become self-sufficient," especially in light of the stagnating domestic orders that would be inadequate to maintain the current size of Rosatom business.[116] Whether and when Rosatom can achieve its goal of becoming more self-sustained warrants close attention. Once free of state funding, how will the interests of the Kremlin and Rosatom be reconciled over commercially unsound projects with geopolitical and diplomatic benefits?

Another key variable is whether Russia can broaden its penetration into countries with traditions of more stringent regulatory standards. Rosatom has multiple types of designs that can meet different market demands. Russia before Rosatom, however, was largely inexperienced in meeting international expectations, as their export markets were predominantly within its geopolitical sphere of influence, such as the former Soviet republics, where the customers and regulators had little influence over the plants Russia was selling.[117]

China: Eager for a World Debut

Ascertaining the future competitiveness of China's nuclear reactor exports requires monitoring several factors. First and foremost is the pace of Chinese economic growth in the coming decades, particularly its significant implications for electricity demand growth. Nearly 15 years of rapid economic growth since 2000 led to strong growth in energy consumption, at around 8 percent.[118] A structural shift began in the mid-2010s, with economic growth slowing. The GDP growth rate in 2019 was 6.1 percent—the lowest since 1990. The economic slowdown reduced utilization rates for various power generation assets, including NPPs. The economic slowdown has also reduced utilization rates for nuclear component manufacturing. In 2018, component manufacturing in China only used 55 percent of total capacity.[119] However, how the prolonged slowdown in economic and energy demand growth might affect the competitiveness of its nuclear

112 "Country Nuclear Power Profiles: Russian Federation," International Atomic Energy Agency, updated 2019, https://cnpp.iaea.org/countryprofiles/Russia/Russia.htm.
113 Andreev, *The Economics of the Russian Nuclear Power Industry,* 12.
114 Thomas, "Russia's Nuclear Export Programme," 245.
115 Ibid.
116 "Rosatom chief outlines commercial vision," World Nuclear News, March 8, 2017, https://www.world-nuclear-news.org/C-Rosatom-chief-outlines-commercial-vision-08031701.html.
117 Thomas, "Russia's Nuclear Export Programme," 239.
118 Ramana and King, "A new normal?," 106.
119 China Electrical Equipment Industry Association, "Analysis of China's overcapacity in the Electrical Equipment Industry (In Chinese)," in *DQGY*, (2018), 39.

energy exports is far from certain.[120] On one hand, the slowdown and attendant reduction in domestic power demand may put Chinese equipment and component manufactures under increased pressure to seek markets outside. On the other hand, the slowdown could begin to constrain the government budget, not to mention generous bank loans, for NPP projects abroad.

The nuclear energy sector is also facing a period of uncertainty as the country's power sector undergoes a multi-year reform. As the sector transitions away from the system based on annual administrative allocation of operational dispatch hours to a system which will include economic dispatch, inter-fuel competition is rising. This transition is happening unevenly, so different provinces have made different amounts of progress. As the transition continues, the economic basis for nuclear-generating SOEs may come under an enormous pressure, and their financing capacity for exports may weaken.

Additionally, the competitiveness in reactor construction costs China has come to be known for may not be a useful benchmark for Hualong One construction abroad for some time, as China's latest designs, including the Hualong One, are expected to be more expensive to build than those dominating its domestic fleet. For example, the deputy chief designer for Hualong One believes that the Hualong One is estimated to cost at least $2,500 per kilowatt when its production is scaled up, while CPR1000—a standard reactor in its domestic fleet—was $1,750 per kilowatt.[121]

Another domestic variable to watch is future development under the Military-Civilian Fusion national plan. Announced in 2015 as part of China's national strategy, the plan seeks to strengthen coordination between economic development and the efforts to build a strong military. While a senior CNNC executive has stated the company's commitment to promoting "nuclear energy as the main battlefield for military-civilian fusion," little is publicly known about the mechanics and timeline of such fusion relative to nuclear energy.[122]

How formidable will China be in exporting nuclear reactor technology and related goods and services around the world? The current export undertakings, namely the project in Pakistan, are largely political in nature and fall short of serving as a benchmark for China's ability to compete with other global suppliers on an economic basis. China still has a way to go to fulfill the goal of establishing a nuclear power supply system that is independent and indigenous.[123] Among the areas for continued improvement—as identified by the Chinese nuclear industry—are the localization of key electrical equipment, such as instrumentation and control (I&C) system, valve actuation devices and cables, and more strategic use of its enormous foreign exchange reserves to support NPP exports.[124]

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120 According to the "Insights from the evolving transition scenario—China," under *the BP Energy Outlook—2019,* China's energy demand growth is forecast to slow to 1.1 percent per annum through 2040.
121 Ramana and King, "A new normal?," 117.
122 "Creating a State-owned Investment Company for the Nuclear Industry with Military-Civilian Integration," China National Nuclear Corporation, November 29, 2018, http://energy.people.com.cn/n1/2018/1129/c71661-30431340.html.
123 Xu, Kang and Yuan, "The Prospective of Nuclear Power in China," 1-21.
124 NicobarGroup, "China's Nuclear Industry 2017-2018," 14; Meng Zhang, *Research on Russia's Nuclear "Going Out" Experience (Part 2)* (China Institute of Nuclear Information and Economics, 2016), https://mp.weixin.qq.com/s/h5ZZm73ZCMa6vqdYfekBZw (In Chinese).

In October 2019, the U.S. Department of Energy (DOE) announced a framework to restrict U.S. exports of nuclear technology, equipment, and components to China, especially light water SMRs and non-light water advanced reactors.[125] Through this move, the Chinese nuclear industry believes the DOE has "[brought] new challenges on the international cooperation (which includes exporting) by China's nuclear industry," but the Chinese also appear largely dismissive of the market competitiveness of the United States due mainly to the significant loss of project management expertise.[126] Russia is different, however. China views Russia as "a strong competitor in technology, price, and financing conditions for a long time in the future" and appears to admire Russia for its integrated industrial chain for the nuclear fuel cycle.[127] Nonetheless, its large capital and fast technological advancement have made China a threat even to Russia.[128]

The pace of Chinese technological advancement is certainly remarkable. Just a little over a decade ago, China looked to the United States to improve its domestic reactor research and development capabilities. In 2007, China awarded Westinghouse the contract to build two AP-1000 reactor units each at the Sanmen site in Zhejiang province and the Haiyang site in Shandong province after a year-long technology evaluation by some 200 experts.[129] Although the reactor design was significantly incomplete, the Chinese deemed the AP1000 purchase highly valuable because the sales agreement entailed full technology transfer involving 75,000 documents from Westinghouse.[130] The United States and Japan (through Toshiba's acquisition of Westinghouse) reluctantly agreed to technology transfer, hoping that the sale would lead to additional AP1000 projects in China as well as in the United States, for the latter by helping to build confidence among prospective U.S. customers who were reluctant to be the first to build a reactor using the new design. Neither vision has come to fruition, although a wave of interest from U.S. utilities did follow the Chinese sale.

Technology Transition as a Variable

The development of small modular (SMR) and advanced nuclear reactor technologies (also known as "Generation IV" nuclear technologies) is a new inflection point in the global market competition among the three supplier countries. SMR—defined by the IAEA as a reactor under 300 MW—has been around since the 1950s, prominently for naval use. SMR garners attention today for the way it is constructed with pre-fabricated modules, an approach that could reduce capital costs. Meanwhile, advanced reactors are

125 Paul K. Kerr and Mary Beth D. Nikitin, "New U.S. Policy Regarding Nuclear Exports to China," U.S. Congressional Research Service, December 17, 2018, https://fas.org/sgp/crs/nuke/IF11050.pdf.

126 "The New Situations and Prospects of China's Nuclear Energy Industry," in *China's Nuclear Energy Development—2019* (China Nuclear Energy Association), 142; Ling Chen and Yuhui Zheng, "The Going Global Strategy of China's Nuclear Power Industry: Situations and Prospects," in *China's Nuclear Energy Development—2018* (China Nuclear Energy Association).

127 Ibid.

128 Author's interview with Alexey Khokhlov, Skolkovo, January 22, 2020.

129 "Nuclear Power in China," World Nuclear Association, https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx.

130 Leslie Hook, "US group gives China details of nuclear technology," *Financial Times*, November 23, 2010, https://www.ft.com/content/fcac14a8-f734-11df-9b06-00144feab49a.

those that use innovative fuels and alternative coolants (i.e., coolants that are not high-pressured water, such as high temperature gas, molten salt, and liquid metal).

Russia has a notable menu of advancements in reactor applications as well as technologies. *Akademik Lomonosov*, a floating LWR-based SMR plant, was connected to the grid in Russia's Far East in December 2019.[131] Russia positions *Akademik Lomonosov* as a pilot project for a future fleet of floating NPPs. Also, *Ural*, a new LWR-based nuclear-powered icebreaker, was launched in May 2019. *Ural* will be part of the Russian Arctic fleet that includes nine nuclear-powered and four non-nuclear powered icebreakers, and are scheduled to be completed by 2035.[132] Meanwhile, Russia's nuclear innovation focus is on fast-breeder reactors with a closed fuel cycle, centered on the *Proryv* (Breakthrough) project. The Breakthrough project, carried out under the Advanced Nuclear Technologies Federal Programme 2010-2020, seeks to eliminate the production of long-lived radioactive waste from power generation. Rosatom's *Development Strategy to 2030* calls for the commercialization of this technology by 2030.[133]

Led by the state, Chinese companies are working on several SMR designs, both light-water based and non-light water based. In the former category, the CNNC is developing ACP100 (or "LingLong One") for a floating NPP, while the CNG is also developing ACPR designs, including ACPR50S for an offshore application.[134] In the latter category, for example, China is developing two small-scale, high-temperature gas-cooled reactor units, originally based on German technology, to come online in 2020.[135] Also, China has spent over $300 million on molten-salt technology, with a design demonstration target in the 2020s and commercial demonstration target in the 2030s.[136]

In contrast to the state-driven effort to develop SMRs and advanced nuclear reactor technologies, private companies and universities are on the forefront of the endeavor in the United States. As of 2019, there were 64 private-sector advanced nuclear projects in the United States and Canada.[137] NuScale, a U.S. company based in Oregon that submitted designs to the NRC for review in January 2017, is leading the pack of SMR designs under development and commercialization. As of the end of 2019, the NRC completed the fourth phase of its six-phase design certification process for NuScale's SMR. The NRC review is scheduled for completion by September 2020, and the first NuScale plant is planned for deployment at the Idaho National Laboratory in the mid-

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131 Russia connects floating plant to grid," World Nuclear News, December 19, 2019, https://www.world-nuclear-news.org/Articles/Russia-connects-floating-plant-to-grid.

132 "Russia, eyeing Arctic future, launches nuclear icebreaker," Reuters, May 25, 2019,https://www.reuters.com/article/us-russia-arctic-icebreaker/russia-eyeing-arctic-future-launches-nuclear-icebreaker-idUSKCN1SV0E4.

133 Nazrin Mehdiyeva, "Development Strategy of State Corporation Rosatom to 2030," *Russian Studies Series* 3, no. 19 (March 2019), http://www.ndc.nato.int/research/research.php?icode=584#_ednref4.

134 "Nuclear Power in China," World Nuclear Association, updated January 2020, https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx.

135 Jessica Lovering, (presentation, CSIS workshop, CSIS, Washington, DC, December 10, 2019).

136 Jessica Lovering, written testimony to the U.S.-China Economic and Security Review Commission Hearing on Technology, Trade, and Military-Civil Fusion: China's Pursuit of Artificial Intelligence, New Materials, and New Energy, June 7, 2019, 3, https://www.uscc.gov/sites/default/files/June%207%20Hearing_Panel%203_Jessica%20Lovering_China's%20Capabilities%20and%20Ambitions%20in%20Clean%20Energy%20Technologies.pdf.

137 "2019 Advanced Nuclear Map," Third Way, October 17, 2019, https://www.thirdway.org/graphic/2019-advanced-nuclear-map.

2020s.[138] In the meantime, in December 2019, the NRC issued its first site license to the Tennessee Valley Authority's Clinch River site for the construction of an SMR.[139] While license to build and operate is a separate requirement, the site license is an important milestone for the U.S. effort for the commercial scale deployment of SMRs in the United States. As for non-LWR reactor technologies, by mid-2019, six reactor designers had formally notified the NRC of their intention to seek design approval, including three molten-salt reactors, one high-temperature reactor, one fast neutron reactor, and the Westinghouse *eVinci* heatpipe reactor.[140]

This is not to say that the U.S. government has been indifferent in the development and commercialization of SMRs and advanced reactor technologies. Since 2012, the DOE has actively pursued ways to support the development and commercialization of SMRs, including the $452 million cost-share grant to Babcock & Wilcox and NuScale; micro-reactor technology work under the DOE's Advanced Research Projects Agency-Energy (ARPA-E); and the 2015 establishment of the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative. In fact, GAIN has demonstrated how the federal government has an important role to play to spur energy technology innovation, particularly in nuclear technology.

High-level political support is also clearly on the rise recently. The 2017 National Security Strategy identified the development of advanced nuclear reactors as the key means to improve the U.S. technological edge in energy.[141] Meanwhile, the U.S. Congress passed the Nuclear Energy Innovation Capabilities Act (2018), which aims to foster public-private collaboration on the development of advanced reactors, and the Nuclear Energy Innovation and Modernization Act (2019), which seeks to "develop an optimal regulatory framework suitable for advanced reactor concepts."[142]

As illustrated by the number of projects underway in North America, innovation remains the key to the U.S. competitive edge. However, whether the development and commercialization of new nuclear technologies in the U.S. market or abroad will truly be competitive is still an open question.

138 "SMR design review enters final phases," World Nuclear News, December 13, 2019, https://www.world-nuclear-news.org/Articles/SMR-design-review-enters-final-phases.
139 "US regulator approves first SMR site license," World Nuclear News, December 18, 2019, https://www.world-nuclear-news.org/Articles/US-regulator-approves-first-SMR-site-licence.
140 "Small Nuclear Power Reactors," World Nuclear Association, updated December 2019, https://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx.
141 The White House, *The National Security Strategy of the United States of America* (Washington, DC: 2017), https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf.
142 Arostegui and Holt, "Advanced Nuclear Reactors."

Chapter 6: Conclusion

This report makes the following recommendations regarding the U.S. approach to continued commercial competitiveness in nuclear energy:

- Ensure a stable and strong budgetary environment for DOE initiatives to support the private-sector effort to develop and commercialize advanced reactor technologies.
- Remove the current restrictions on the U.S. government financing for NPP projects overseas.
- Support safety and security work that would position the United States as the continued leader on operational safety and nuclear nonproliferation in what may be the age of SMRs and advanced reactor technologies.

Successful revitalization of U.S. market competitiveness in the international market requires greater political consensus on the value of nuclear energy as a strategic industry and as part of a broader vision for national competitiveness. The 2017 National Security Strategy captured this linkage when it identified nuclear energy as one of the major sources of "America's central position in the global energy system as a leading producer, consumer, and innovator."[143] The ongoing effort under the leadership of the DOE to leverage public-sector human resources, facilities, materials, and data to further the private-sector effort to develop advanced nuclear reactors merits long-term political and budgetary support. The existing constraints on NPP export finance, as well as the lack of equity options for an NPP export project by the United States, is another area that warrants scrutiny.

The export of nuclear technologies and services is central to Russia's effort to remain relevant in global affairs, as the country has limited means to underpin such efforts. Meanwhile, nuclear export is part of China's effort to enhance its economic influence around the world. While the underlying factors may differ, the two supplier countries from the state-led capitalist tradition are beginning to shape the future of the global nuclear industry while U.S. market competitiveness declines. Nuclear commerce provides them with a tool to preserve or strengthen ties to recipient countries, sometimes fostering a

143 The White House, *The National Security Strategy of the United States of America* (Washington, DC: 2017), https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf.

public sentiment or policy environment favorable to their causes whether or not foreign policy influence is explicitly or discretely an objective.

Besides its implications for U.S. national competitiveness, the rise of Russia and China in the global nuclear commercial landscape also raises nuclear safety and proliferation concerns in light of growing interest in nuclear power generation from countries with limited economic means and governance capacity. Since the end of World War II, the United States has put in place a variety of restraints to counterbalance the capacity of a nuclear energy program to enhance a country's technical capability to build nuclear weapons and has further played a dominant role in the global nonproliferation regime, creating institutions and frameworks, such as the International Atomic Energy Agency.[144] The conventional wisdom is that it is in the interest of major suppliers to adopt and enforce high safety and nonproliferation standards to mitigate potential reputational damage arising from a nuclear accident or proliferation incident.

Notwithstanding such commercial incentives, it would be premature to assume that Russia and China would succeed the United States as leading voices on safety and security issues. China has come to accept a variety of nonproliferation principles in the recent years, but the country is known for generally prioritizing commercial benefits over values in much of its economic endeavors around the world.[145] Meanwhile, inasmuch as nuclear energy exports are among a very limited menu of tools Russia has for geopolitical prestige and revenue, concern is warranted that Russia may become more inclined to compromise on safety and nonproliferation standards, especially if its economy weakens. Already, Russia is more tolerant of countries acquiring enrichment and reprocessing capabilities although Russia's framework agreements with recipient countries include provisions related to compliance with export controls and nonproliferation obligations in accordance with Nuclear Suppliers Group guidelines, which aim to implement best practices related to nuclear commerce to prevent proliferation.[146] The United States has a significant interest in managing these risks whether or not it chooses to use nuclear energy for power generation at home or to export reactor technologies, components, or services. These risks could be costly if nuclear trade revolved around supplier countries with weak internal oversight and accountability and recipient countries with weak governance or political instability.

As the United States has embarked on the public-private collaboration on advanced reactor technologies to regain its technological edge and market competitiveness, it also must make an earnest effort to identify safety and security concerns associated with a robust deployment of advanced nuclear reactors and begin considering ways to mitigate the potential safety and security challenges, which may be legal, technical, or organizational in nature. A proactive approach is essential if the United States is to preserve its global leadership on nuclear safety and nonproliferation issues.

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144 Miller, "Why Nuclear Energy Programs Rarely Lead to Proliferation," 46.

145 Ibid., 72.

146 Robert Einhorn, "Prospects for U.S.-Russian nonproliferation cooperation," Brookings Institution, February 26, 2016, https://www.brookings.edu/research/prospects-for-u-s-russian-nonproliferation-cooperation/; Schepers, "Russia's Nuclear Energy Exports," 5.

Moreover, while nuclear energy innovation is a matter of national competitiveness, it does not and should not preclude the United States from working with other countries that uphold a similar set of standards in regulatory, legal, and governance issues that have complementary expertise to offer. For example, Canada has embarked on a major effort to emerge as a global leader on advanced reactor technologies and small modular reactors, seeking to strategically leverage its various resources to this goal. Canada is also known for its "step-wise pre-licensing design review processes" that are conducive to timely review and licensing of new reactor technologies. In fact, the NRC and its Canadian counterpart, the Canadian Nuclear Safety Commission, have been conducting the first joint technical review of an advanced non-LWR since 2019. Also, South Korea has a strong supply chain for nuclear equipment and components and an industry that is eager for overseas contracts because the current government policy constrains domestic opportunities. Japanese equipment and component manufactures are skilled yet under-utilized as well. Such partnerships would expand the U.S. ability to respond to varying needs of customer countries while also re-enforcing best practices in operational safety and strengthening the global nonproliferation regime.

About the Author

Jane Nakano is a senior fellow in the Energy Security and Climate Change Program at the Center for Strategic and International Studies (CSIS). Her areas of expertise include U.S. energy policy, global market and policy developments concerning natural gas, nuclear energy and coal, and energy security issues in the Asia-Pacific region. She frequently writes and speaks on these issues at domestic and international conferences and to media around the world. She has also testified before Congress on U.S. liquefied natural gas (LNG) exports and before the U.S.-China Economic and Security Review Commission on U.S.-China nuclear energy cooperation. Prior to joining CSIS in 2010, Nakano worked in the Office of Policy and International Affairs in the U.S. Department of Energy, where she covered a host of energy, economic, and political issues in Asia. From 2001 to 2002, she served at the U.S. embassy in Tokyo as special assistant to the energy attaché. Nakano graduated from Georgetown University's School of Foreign Service and holds a master's degree from Columbia University's School of International and Public Affairs.

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1616 Rhode Island Avenue NW
Washington, DC 20036
202 887 0200 | **www.csis.org**