Atlantic Council
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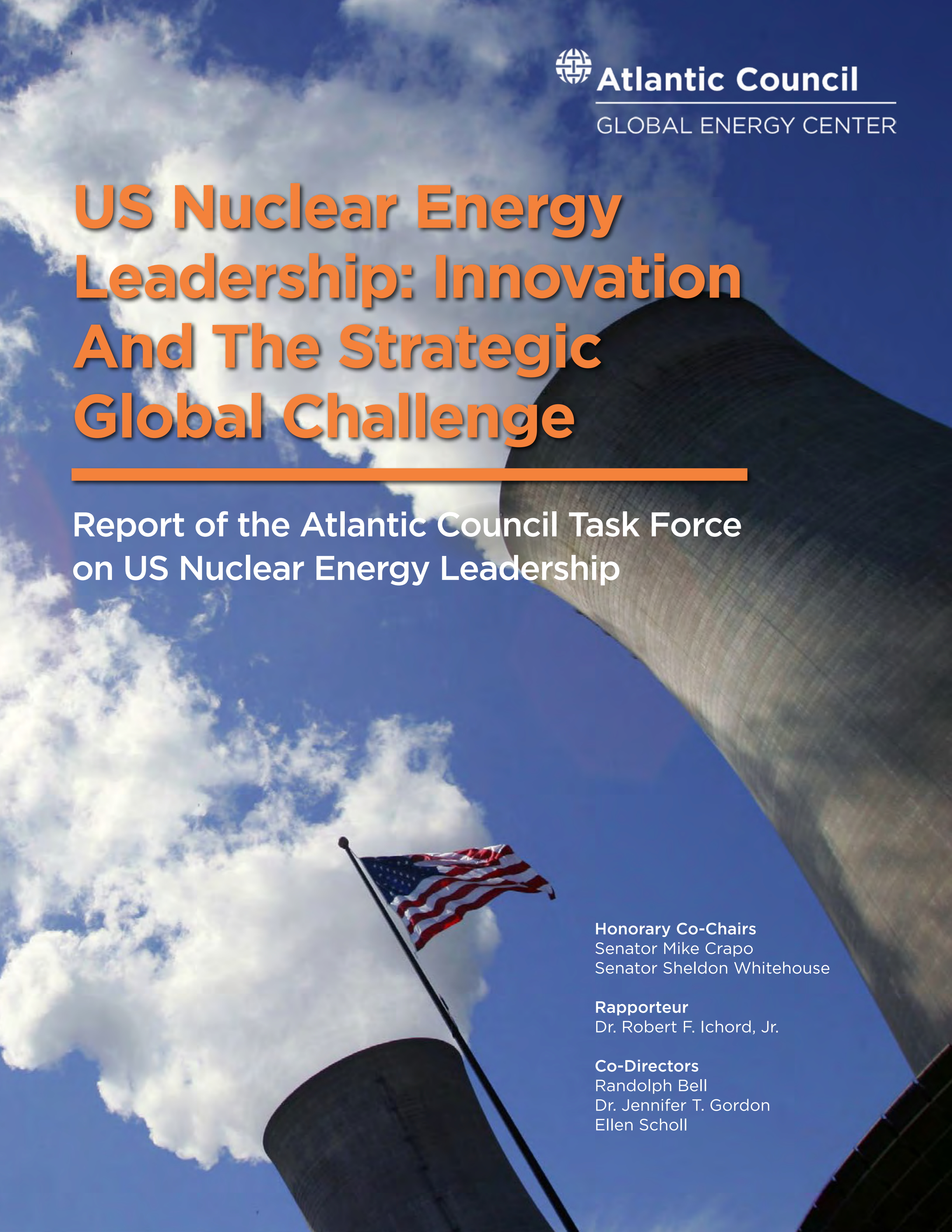
US Nuclear Energy Leadership: Innovation And The Strategic Global Challenge

Report of the Atlantic Council Task Force on US Nuclear Energy Leadership



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Rapporteur
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Cover: A US flag flutters in front of cooling towers at the Limerick Generating Station in Pottstown, Pennsylvania May 24, 2006. US President George W. Bush briefly toured the nuclear facility and spoke about energy and the economy. Source: REUTERS/Kevin Lamarque.

May 2019

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STATEMENT BY HONORARY CO-CHAIRS

We commend the work of the Atlantic Council Task Force on US Nuclear Energy Leadership in bringing together diverse minds to assess the challenges facing the future of nuclear energy. This report adds a critical global perspective to conversations about the role of the United States in fostering advanced nuclear energy in a carbon-constrained world and offers innovative policy recommendations.

In the 115th US Congress, we were proud to lead bipartisan efforts to foster innovation in advanced nuclear energy and reduce barriers to the commercialization of advanced next-generation nuclear technologies that will provide emissions-free energy. These efforts led to the enactment, as discussed in this report, of two bills:

- Nuclear Energy Innovation Capabilities Act (NEICA), which aims to foster development of advanced reactors at US national labs with private industry; and

- Nuclear Energy Innovation and Modernization Act (NEIMA), which requires the US Nuclear Regulatory Commission to develop a regulatory framework workable for advanced reactor concepts.

This report applies a wider lens to these bipartisan efforts, highlighting the global effect of the United States' needed leadership on this issue. While the policy recommendations in this report do not necessarily reflect our own personal opinions, we share the overarching conclusion of the Task Force that a deliberate, whole-of-government effort needs to be undertaken to reassert US leadership in nuclear energy innovation and development while maintaining adequate safety measures.

The failure of the energy marketplace to reward nuclear power for the carbon-free nature of its power remains an economic problem for the industry. The prospect of next-generation nuclear technologies using present hazardous nuclear waste as a fuel source remains one of this industry's great opportunities.

We congratulate the Task Force on the completion of this report and look forward to continued partnership with the Atlantic Council, our colleagues in Congress and the executive branch, and other stakeholders on this important issue.

Senator Mike Crapo (R-ID)

Senator Sheldon Whitehouse (D-RI)

ATLANTIC COUNCIL TASK FORCE ON US NUCLEAR ENERGY LEADERSHIP

Throughout 2018, the Atlantic Council Global Energy Center convened a "Task Force on US Nuclear Energy Leadership," comprised of civilian and military experts in foreign policy, defense, and nuclear energy, with Senators Mike Crapo and Sheldon Whitehouse as honorary co-chairs, to address the national security implications of the decline of the US nuclear power industry. Their insights, analysis, and recommendations provided the foundation for this study. The conclusions and recommendations of this report do not necessarily reflect all the views of the honorary co-chairs, members, and other participants of the task force.

Honorary Co-Chairs
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Acknowledgments

This report benefited from discussions with many energy, foreign policy, defense, and scientific experts who provided comments and other contributions. The co-directors and honorary co-chairs are extremely grateful for their insights and interest in this project, and they wish to express their gratitude to those listed below and to thank Dr. Robert F. Ichord, Jr. for serving as rapporteur for this report. This listing implies no general or specific endorsement of the report and its recommendations by those mentioned.

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EXECUTIVE SUMMARY

The US civilian nuclear power industry is a strategic asset of vital importance to US national security. Civilian nuclear reactors currently provide just under 20 percent of the nation's electricity supply and the majority of electricity from noncarbon fuel sources. The nuclear energy supply chain provides fuel, equipment, and services not only to the civilian nuclear industry, but also to US nuclear-powered aircraft carriers and submarines. The domestic nuclear industry-scientific complex, including our national and private laboratories, universities, utilities, and equipment and service companies, represents a deep reservoir of scientific and technological expertise that is a pillar of the nation's technical innovation capacity.

Nuclear energy represents a source of export earnings from fuel, equipment, and technical services for nuclear power plants around the world. Nuclear exports fortify US efforts to maintain international standards that ensure safe operation of nuclear power plants and leadership of global nonproliferation through deep and long-lasting trade relationships that enable US influence in key foreign policy areas. Nuclear power contributes to the overall diversification of the US energy mix, while enhancing the reliability of the electricity supply. Finally, nuclear energy has a lower carbon footprint than fossil fuels, due to its zero-emissions power generation, which confers health and environmental benefits.

The Ohio-class ballistic-missile submarine USS Maryland prepares to get underway in March for routine operations from Naval Submarine Base Kings Bay, Georgia. Ohio-class submarines are nuclear powered and carry Trident ballistic missiles. Source: US Navy and US Army/Mark Turney.

For decades, the United States has been the global leader in civilian nuclear power and the international nuclear safety and nonproliferation system that supports it. The United States has held that role in close cooperation with allies in civilian nuclear technology development, including Japan, France, the United Kingdom (UK), Germany, Canada, and the Republic of Korea. However, US leadership is under strain, challenged by the continuing and premature closure of US nuclear plants, the decline of our domestic nuclear fuel-cycle capabilities, and the ambitious domestic and international nuclear energy programs of Russia and China.

Russia and China today are building more than 60 percent of new nuclear plants under construction worldwide, while the United States is plagued by continuing difficulties in building new plants, as exemplified by the abandonment of the V.C. Summer nuclear power project in South Carolina and the ongoing challenges in the construction of two new US nuclear plants in Georgia. Additionally, the US nuclear industry faces supply chain atrophy, financial difficulties of leading US nuclear energy companies, and a long-disempowered Export-Import Bank. Given this juxtaposition of circumstances, the international credibility of the United States in nuclear power is in question.

Key allies of the United States are also under strain in the nuclear space. Although the UK remains committed to building new nuclear plants, its Cumbria plant is imperiled by Toshiba's decision to withdraw from the country; Germany is phasing out nuclear power; France is planning an eventual cutback; and South Korea's future nuclear direction is unclear, despite the decision to complete two reactors under construction and the apparent success in completing new reactors in the United Arab Emirates (UAE).

Despite these difficulties, substantial efforts by the United States, Canada, Japan, South Korea, France, and the UK—as well as China, Russia, and India—are underway to develop and commercialize a new generation (Generation IV) of advanced nuclear reactors. While the cost of developing these new systems will be considerable, many of these Generation IV designs have the potential to be substantially less costly than their predecessors. Additionally, the potential benefits of future large-scale deployment of Generation IV reactors are great and suggest that the United States, with its design expertise and previous experience with some of

Hundreds of spectators and media witness the commissioning of the Navy's nuclear-powered aircraft carrier USS Ronald Reagan (CVN 76), while the ship's crew stand at parade rest during the ceremony. Ronald Reagan is named after the 40th President of the United States and is the ninth Nimitz-class aircraft carrier. Naval Station Norfolk, Virginia, July 12, 2003.
Source: US Navy/Photographers Mate 1st Class Brain Tallette.

these reactor types, needs to accelerate its efforts in this critical area of technological innovation.

To consider the US response to this challenge, the Atlantic Council's Global Energy Center convened a "Task Force on US Nuclear Energy Leadership," comprising distinguished experts and officials from the private sector, nonprofit organizations, and former military and civilian government officials involved in energy, environment, nuclear policy and technology, and national security. Senators Crapo (R-ID) and Whitehouse (D-RI)—champions of forward-looking action on nuclear development—agreed to serve as honorary co-chairs of the Task Force, indicating the high level of strong bipartisan concern and interest in this issue. The Task Force consulted with US government and congressional officials and outside experts in four major areas:

- preserving the domestic fleet of nuclear power plants
- developing and commercializing advanced reactors
- exporting and competing in global nuclear markets
- strengthening the fuel cycle: supply, safety, and nonproliferation

The Task Force's central conclusion is that the United States should mount a determined national mission to regain US leadership by developing, demonstrating, and deploying a new generation of reactors, while maintaining the current nuclear fleet and meeting national standards for safe operation and international standards for proliferation resistance. The report argues that a serious commitment to the US nuclear industry and its future growth and technological development can bring significant security, economic, and environmental benefits to the United States, as well as put the US in a position to better compete internationally. This national mission must happen quickly because regaining international leadership will take multiple years of sustained effort.

The Trump Administration and Congress are already taking important steps to further this goal and mobilize public and private resources, including catalytic efforts by the US Department of Energy (DOE) and US Department of Defense (DOD). The Task Force applauds the work of Congress and the Trump Administration in the passage of the Nuclear Energy Innovation Capabilities Act (NEICA) and the Nuclear Energy Innovation and Modernization Act (NEIMA). The Task Force supports the passage of the Nuclear Energy Leadership Act (NELA),[1] which was reintroduced in March 2019 by Senator Lisa Murkowski (R-AK) with over a dozen bipartisan supporters. However, significantly more needs to be done.

Further, the Task Force concludes that nuclear energy should be elevated in US national security strategy. Although President Donald Trump called for a civilian nuclear review in June 2017, no major policy or strategy has been publicly announced. There is an urgent need for leadership and direction on this issue and for an effective Executive Office of the President-led interagency process. The Task Force recommends that President Trump direct the Executive Office of the President—including the National Security Council, National Economic Council, Office of Management and Budget, and Office of Science and Technology Policy—to organize a high-level interagency process to forge a consensus on critical steps forward and enhance public-private partnership efforts with the following three main goals, which will be accompanied by specific action recommendations in this report:

1 Maintain and expand the domestic nuclear fleet, both preserving and strengthening the US civilian nuclear industry and its supply chain and research base

2 Create a conducive environment for new technologies

- Improve and streamline the regulatory and licensing process for new advanced reactors
- Increase US government support for advanced reactor technologies; for example, by indexing the nuclear production tax credit (PTC) for inflation while eliminating or raising the 6000 MW capacity limit, and extending the terms of federal power purchase agreements (PPAs) to forty years
- Mobilize private financing for advanced nuclear technology research, development, and demonstration, as well as advanced manufacturing and construction
- Further the development of high-assay low-enriched uranium (HALEU) fuel production and fabrication capacity

3 Encourage and facilitate exports

- Provide competitive US government financial support for US nuclear exports, including through the Export-Import Bank and the newly established United States International Development Finance Corporation (USDFC)
- Streamline US export controls under Part 810 of Title 10, Code of Federal Regulations (CFR); apply and maintain standard Section 123 requirements in international agreements
- Build an effective and adequately-funded US government international nuclear-cooperation and market-development program

The adoption of this Task Force proposal would complement broader US economic and energy policies, enhance the package of energy technologies and services that the United States can bring to our global foreign policy and commercial engagement, and position the United States to compete in countries that have committed to deep decarbonization. This is particularly true in emerging markets in the developing world, which are expected to account for between 85 percent and 90 percent of world electricity growth between now and 2040. To seize these opportunities, the United States must make a long-term commitment and drive down the costs and installation times of new-build nuclear systems. Despite the uncertainties inherent in the nuclear innovation process, the risks are outweighed by the potential US and global economic growth, environmental benefits, and the national security importance of US advancement in this strategic arena of technological competition.

1 For the full text, please see the following: Nuclear Energy Leadership Act, S.903, 116th Congress, https://www.congress.gov/bill/116th-congress/senate-bill/903/text.

1 INTRODUCTION: AN URGENT NATIONAL SECURITY PROBLEM

The United States is facing a serious challenge to its historical leadership in the global civilian nuclear power market. Although the United States still has the largest number of operating reactors globally at ninety-eight units, which provided 19.3 percent of US electricity and 55.2 percent of its carbon-free generation in 2018[2], the US nuclear power fleet is aging, facing continuing and intense price competition from gas and renewables in competitive regional markets, and operating in an uneven regulatory and highly fragmented policy environment. As many as 20 percent of operating US nuclear reactors may be forced to close prematurely by 2030 and an even larger percentage will close by 2050 without further extension of their operating licenses. Such closure would adversely affect the nuclear supply chain and US human resources capabilities—mainly knowledge and expertise in civilian nuclear power—as well as services to the US military. Only two civilian reactors are currently under construction in the United States, while most new reactors are being built in China, Russia, India, and other Asian and Middle Eastern countries by non-US companies. There is also intense international competition to build the next generation of reactors, including small modular reactors (SMRs) and advanced non-light water reactors, which could find substantial markets in developing countries as well as in the United States.

These risks and strains facing the US nuclear power sector have significant national security and foreign policy ramifications for the United States. Russia and China present a multidimensional challenge that includes not only their use of nuclear power exports and financing as a way of increasing their political and economic influence in countries of strategic importance to the United States, but also intense technological and commercial competition to develop new nuclear technologies to meet rapidly growing energy demand in emerging markets and developing countries while also mitigating global environmental and climate change problems.

US leadership in nuclear power is critical due to its importance to both national security and foreign policy interests. The United States has been the prime architect of international nonproliferation, safety standards, and safeguards system, working with allies in the Group of Seven (G7) and South Korea as well as the International Atomic Energy Agency (IAEA) and Nuclear Suppliers Group. Russia's expanded efforts and the emergence of China in overseas nuclear power markets weaken the United States' ability to establish and enforce standards that prevent the diversion of sensitive nuclear materials for military or terrorist use. Russia is committed to a full nuclear fuel cycle, including enrichment and reprocessing, while China has "stated it intends to become self-sufficient . . . in the production of fuel for [nuclear power] plants."[3] Both have historically been less concerned about proliferation than the United States and will likely continue this attitude as they seek to expand their presence in new developing-country markets. Although the new generation of fast-spectrum reactors, with their long-refueling intervals, offers the prospect of safer and more proliferation-resistant systems, there will still be security risks from nation-state operators, especially in environments where institutions, governance, and regulatory oversight is weak. The United States needs to be at the forefront of international efforts to develop new norms, standards, and monitoring systems for the new generation of reactors as well as strong, enforceable, and transparent Section 123 agreements.

From a foreign-policy perspective, US technological leadership and the credibility of the nation's nuclear capabilities allow the United States to present a viable, carbon-free option to countries intent on addressing their energy demand and security needs while also meeting climate goals. Given the strategic importance of the energy and electricity sector and its projected global growth, the United States should not abdicate its global leadership position to Russia and China. Additionally, civilian nuclear power sales agreements—

2 "Nuclear By the Numbers," Nuclear Energy Institute, March 2019, https://www.nei.org/resources/fact-sheets/nuclear-by-the-numbers.

3 "China's Nuclear Fuel Cycle," World Nuclear Association, accessed January 2019, http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-fuel-cycle.aspx.

Sequoyah Nuclear Power Plant near Chattanooga, Tennessee, October 25, 2008. Source: Wikimedia Commons/ Photorush.

which, due to their longevity, can be a source of geopolitical stability—present an opportunity for the United States to establish and maintain long-term political and economic relationships with purchasing countries.

Nuclear power can also continue to contribute to US energy security and domestic energy-supply diversification. In 2017, the US Energy Information Administration estimated that 20 percent of domestic power was derived from nuclear energy.[4] This share dropped slightly in 2018 to 19.3 percent.[5] A diverse electricity mix is critical to managing system risk and helps to increase grid reliability; maintaining existing nuclear power and developing advanced, new nuclear generation can complement variable renewable energy sources, produce dispatchable, zero-emission electricity with low air pollution (i.e., no sulfur or nitrogen oxides or particulates), from a relatively small geographic footprint.

This report addresses these domestic and international issues. The second section considers the international context and the growing geopolitical challenge of Russia and China. The third section lays out the defense, economic, and environmental rationale for US leadership. The fourth section highlights the innovation challenge facing US industry and the technological competition to develop advanced reactors. The fifth section summarizes current executive branch and congressional policies and actions to address these challenges, including the role of nuclear power in the US national security strategy and expanded efforts to stimulate development and investment in new advanced reactors. The final section contains strategic and programmatic recommendations to strengthen and complement these efforts and enhance the US public-private nuclear partnership.

4 “What Is U.S. Electricity Generation by Energy Source?,” US Energy Information Administration, accessed October 29, 2018, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

5 “Nuclear by the Numbers.”

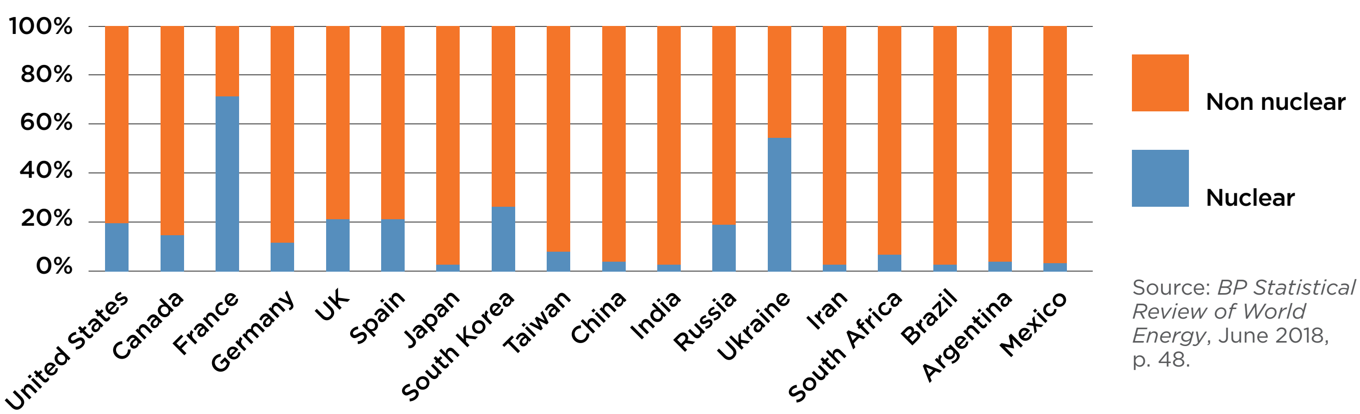
2 THE INTERNATIONAL CONTEXT OF CIVILIAN NUCLEAR POWER

The challenge to US international nuclear energy leadership is occurring on multiple fronts. While Russia and China are valued partners for much of the US nuclear industry, the growing dominance of Russia and China in current nuclear construction and export—with Russia's far greater international presence and China's growing ambition—is an immediate concern from a geopolitical standpoint as well as a safety and security perspective. A key driver of international competition is the expanding need for electricity, especially in emerging markets and developing countries, and the global effort to move to cleaner energy sources.

Given the military origins of nuclear power and concerns about nuclear proliferation, the civilian nuclear power industry has always been viewed as a strategically and geopolitically important sector. US national laboratories at Oak Ridge in Tennessee, Idaho Falls in Idaho, and Argonne in Illinois collaborated with US companies—including Westinghouse Electric Co., General Electric Co., Babcock & Wilcox Enterprises Inc., and Combustion Engineering Inc.—to develop reactors for US submarines as well as the current generation of commercial light water reactors, the first of which went into operation in 1958. These US companies helped Japan, South Korea, and Western European countries to develop their first reactors, which began operating in the early 1970s. Toshiba acquired Westinghouse Electric Company in 2006 and, in 2007, GE and Hitachi formed a joint venture, GE Hitachi Nuclear Energy (GEH), which is based in the United States and in which GE holds a 60 percent stake. GEH serves the global market, with the exception of Japan and the UK, which are served by a second joint venture led by Hitachi-GE.

All of the G7 countries went on to establish nuclear power plants (NPPs) in their electricity sectors, although Italy phased out its nuclear units by 1990. Operating reactors in G7 countries still accounted for an estimated 53 percent of total world nuclear electricity generation in 2017.[6] The United States, with an installed nuclear capacity of 99.2 gigawatts (GWs), was the largest generator of nuclear power in 2017, with electrical generation of 847.3 terawatt hours (TWh) and 32.1 percent of global nuclear generation, followed by France (15.1 percent); China (9.4 percent); Russia (7.7 percent); and South Korea (5.6 percent). The following table shows the relative role of nuclear power in key countries, notably the large share in France and Ukraine, followed by South Korea, Spain, the UK, and the United States (at or over 20 percent).

Figure 1: Nuclear Power's Role in Electricity Generation of Major Countries 2017 (percent)



Source: *BP Statistical Review of World Energy*, June 2018, p. 48.

6 *BP Statistical Review of World Energy*, BP, June 2018, https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf.

The rise of China, both as a technological and industrial power as well as a ravenous energy consumer, has had a significant impact on the nuclear energy sector. China's national energy strategy includes rapid expansion of its domestic nuclear fleet; its current national target is 58 GW by 2020, although it is unlikely to be attained.[7] Toshiba-Westinghouse and the Shaw Group entered into agreements in 2007 to build four AP-1000 reactors, two at Sanmen in Zhejiang Province and two at Haiyang in Shandong Province. These units, after delays due to equipment problems and the three-year moratorium following the Fukushima accident, have been completed, connected to the Chinese grid, and began commercial operation in 2018. The successful completion is in sharp contrast to the construction and financial problems of the planned US AP-1000s in South Carolina (discontinued) and Georgia (delayed and over budget), which led to Westinghouse's bankruptcy and Toshiba's sale of its shares to a unit of Brookfield Asset Management—a large Canadian private equity firm—which was finalized in August 2018.

In this context, Russia and China have stepped up their nuclear export efforts, particularly in the Middle East, South Asia, and Eastern Europe. President Vladimir Putin of Russia has been personally involved in pushing Russian nuclear engagement overseas, and President Xi Jinping of China is offering a package of financing for power and infrastructure as a carrot for collaborating with China's nuclear companies.

Figure 2, compiled mainly from World Nuclear Association data, shows that sixty-seven nuclear power units are currently in tender, under construction, or recently completed around the world. Russia and China are building, hosting, or financing more than two-thirds of these plants.

Figure 2: New Reactors in Advanced Planning, Tendering, Under Construction, or Completed

	Major International Vendor Countries					
	United States*	**Russia**	**China**	**South Korea**	**France**	**Canada**
Reactor Type	• **AP-1000** • **ABWR**	• **Mainly VVER-1200**	• **CAP1000** • **HPR-1000 Hualong 1** • **ACP1000** • **CAP1400**	• **APR-1400**	• **EPR**	• **Candu 6**
Recipient Country	• **United States** (2) • **China** (4 operating) • **Japan** (2)	• **Bangladesh** (2) • **Belarus** (2) • **India** (2) • **Egypt** (4) • **Turkey** (4) • **Hungary** (2) • **Russia** (7) • **China** (2) • **Uzbekistan** (2) • **Iran** (2) • **Finland** (2) • **Slovakia** (2)	• **Pakistan** (2) • **Argentina** (1) • **China** (11 indigenous)	• **UAE** (4) • **South Korea** (2)	• **UK (1)** (Chinese financing with EDF for EPR: Hinkley C) • **France** (1) • **Finland** (1) • **China** (Taishan 1 & 2)	• **Romania** (2) (Chinese construction and financing for Candu units at Cernovoda 3 & 4) • **Argentina** (Chinese financing for Candu canceled)
Total	8	33	13	6	5	2

*Vendor Westinghouse, as a subsidiary of Japan's Toshiba, was involved in the China and Vogtle AP-1000 projects, and GE and Hitachi are partnering in Japanese units.

Sources: World Nuclear Association Country Profiles, World Nuclear News, Reuters, and the *Financial Times*.

7 It is expected to fall short by 5 GW, achieving 53 GW by 2020. See David Stanway, "China to Fall Short of 2020 Nuclear Capacity Target," Reuters, April 1, 2019, https://www.reuters.com/article/us-china-nuclearpower/china-to-fall-short-of-2020-nuclear-capacity-target-idUSKCN1RE04S.

Construction including one of two 'nuclear islands' is seen at the Hinkley Point C nuclear power station near Cannington in southwest England, January 17, 2018. Source: REUTERS/Toby Melville.

The Russian nuclear monopoly Rosatom claims to have a construction portfolio of thirty-six NPP units in twelve countries and US$133 billion in foreign orders.[8] Although agreements may have been reached for these projects, there are questions about the financial and resource capability of Rosatom to execute all these projects. However, Rosatom has been moving ahead with the construction of its latest generation reactor, the VVER-1200, which is in operation at Novovoronezh 6, and the first unit at Leningrad II, which is the prime design that is being offered internationally.[9] Russia has focused on the Middle East (Turkey, Egypt, Saudi Arabia, and Jordan); South Asia (India and Bangladesh); as well as former Soviet satellite and now-European Union states (Hungary, Romania, Czech Republic, Slovakia, and Bulgaria). Russia's strategic approach has sometimes been indirectly linked with Russian sales of military equipment, e.g., surface-to-air missiles in Turkey, undermining US foreign policy and NATO defense interests. The *Washington Post* reported on January 30, 2019, that Russia has sought to influence the negotiations with North Korea by offering to provide a nuclear power plant, supply fuel, and take back used fuel.[10] Russian President Vladimir Putin also emphasized nuclear power cooperation in his January 2019 visit to Serbia, during which he criticized the West for "destabilizing" the Balkans. In addition to South Asia, the Middle East, and Eastern Europe, Russia has been concluding nu-

8 "Rosenergoatom: Initial Fuel Loading Began Right on Schedule at Unit No. 2, Novovoronezh-2," Rosatom, last updated February 19, 2019, https://www.rosatom.ru/en/press-centre/news/rosenergoatom-initial-fuel-loading-began-right-on-schedule-at-unit-no-2-novovoronezh-2-/.

9 Charles Digges, "Nuclear Reactor Near St. Petersburg Russia Back Online after Weekend Hiccup," Bellona Foundation, February 18, 2019, https://bellona.org/news/nuclear-issues/2019-02-nuclear-reactor-near-st-petersburg-russia-back-online-after-weekend-hiccup.

10 John Hudson and Ellen Nakashima, "Russia Secretly Offered North Korea a Nuclear Power Plant, Officials Say," *Washington Post*, January 29, 2019, https://www.washingtonpost.com/world/national-security/russia-secretly-offered-north-korea-a-nuclear-power-plant-officials-say/2019/01/29/d1872588-a99b-4b68-ba34-9ce1bc95b573_story.html?utm_term=.162b3e2df5d5.

clear cooperation agreements with African countries including Nigeria, Morocco, Ghana, and Kenya. Putin had hoped for a significant deal with South Africa, but a court ruling declaring the illegality of the agreement—made before former South African President Jacob Zuma left office—has led to a policy change to defer further investment in nuclear power.

China has entered the international market more recently—with the exception of its early nuclear involvement in Pakistan—and is exploring opportunities with a number of countries. China has focused on Pakistan, the UK, Romania, Argentina, Turkey, Saudi Arabia, and Bulgaria, and has also announced its intention to pursue expanded nuclear projects under the Belt and Road Initiative. However, at present, China appears to have an active reactor supply agreement with Pakistan for two Hualong 1 (ACP-1000) units outside Karachi, as as well as "at least one nuclear agreement" with Saudi Arabia that allows the kingdom "to put certain building blocks in place."[11] To get a foothold in key markets, China has agreed to finance—together with Electricité de France SA—the Hinkley Point C plant in the UK (with the possible condition that China will be allowed to build its Hualong 1 systems at the Sizewell and Bradwell-on-Essex sites), and construct and partially finance the completion of the Candu 6 units at Cernavoda 3 and 4 in Romania. The cancellation by Argentina's government of the planned Chinese-financed Candu unit at Atucha II, apparently due to financial debt pressures, was a temporary setback to China's export efforts, but in April it was reported that discussions are still underway with China on the Atucha III Hualong One unit, with China offering a combined soft loan and substantial cash proposal.[12] Even if China is unable to realize all of its ambitions, it is positioning itself to be a major player in the future nuclear export market.

While US nuclear reactor technology has enhanced safety features, US companies have not been able to compete with the large, long-term, low-interest funding from the Russian government and, more recently, the Chinese government for large reactors producing 1000 to 1200 megawatts (MW), which appear to cost in the range of US$4 billion to US$6 billion each, depending on the country and the number of reactors at the site. Russia supplies its large reactors with fuel and, in some cases, operating services and lower-cost construction. Chinese companies have adapted US and European technology to develop indigenous designs that they are deploying in domestic and foreign markets. Through their nuclear export programs, Russia and China are establishing long-term relationships and strengthening their political and economic presence in countries of strategic importance to the United States.

In both Russia and China, domestic factors may become increasingly important to the nuclear export drives of these countries. In Russia, flat electricity demand and budgetary constraints have led to delays in construction and postponements of some units. In China, slower electricity demand growth, the huge expansion of renewables, and large excess capacity in the coal-generation sector, seem to be leading to a slowdown in domestic nuclear start-ups and investment interest. Given these factors, the politically powerful nuclear industry in both countries may further push their governments to pursue export markets.

11 Mercy A. Kuo, "China and Saudi Arabia: the Global Ambitions of Mohammad bin Salman," *The Diplomat*, March 20, 2019, https://thediplomat.com/2019/03/china-and-saudi-arabia-the-global-ambitions-of-mohammad-bin-salman/.

12 Tom Daly, "Argentina, China still discussing nuclear power project: undersecretary," Reuters, April 2, 2019, https://www.reuters.com/article/us-china-nuclearpower-argentina/argentina-china-still-discussing-nuclear-power-project-undersecretary-idUSKCN1RE0O5

Differing Viewpoints on Uranium Imports

In July 2018, the US Department of Commerce initiated an investigation under Section 232 of the Trade Expansion Act of 1962 on the national security implications of US uranium imports following a petition from US uranium-mining companies Energy Fuels and Ur-Energy. Members of the Task Force hold a variety of views on the extent to which uranium should be imported as opposed to mined domestically.

Supporters of the domestic uranium industry argue that the global uranium and nuclear fuel business is increasingly monopolized by Russia and China, since Russia—through Rosatom—has expanded its control of the uranium-mining industry in Kazakhstan and Uzbekistan, while Chinese nuclear companies have moved into both Kazakhstan and Namibia. In 2017, Russia, Kazakhstan, and Uzbekistan supplied almost 40 percent of US uranium, and in 2019, domestic US uranium production may fall to 1 percent of US nuclear utility demand. Market dominance by Russia and China could pose an energy security risk to the United States. Further, pursuant to long-standing policy and US treaty obligations, US military needs for enriched uranium must be met from US-mined uranium that is converted and enriched with US technology. While public reporting indicates this is not a concern until at least 2038, private conversations suggest current defense stocks of enriched uranium could be drawn down at a rate that may potentially pose problems as early as the late 2020s. This serious condition of the US mining industry is compounded by limitations and problems with US uranium conversion, fuel fabrication, and enrichment processes, a situation that gives Russia a comparative advantage by offering a full package of fuel services in contracts with US companies.

In contrast, other supporters of US nuclear power have opposed this limitation, expressing concern given the nuclear power industry's difficult financial position and the higher costs of domestic uranium supplies. Furthermore, the international uranium supply market is functioning adequately, with the majority of US external supplies coming from allies Canada and Australia. There is no evidence that dependence on imported uranium is a problem. For example, Kazakhstan, a major foreign supplier, has been a strong supporter and partner of the United States on nuclear nonproliferation matters, and there is no indication that dependence on Kazakhstan's uranium exports is a national security issue. Additionally, opponents of the petition argue that any trade abuse be addressed with allies, including Australia and Canada, two large uranium producers, as well as other allied nuclear-power countries.

The Commerce Department submitted their findings to the White House in April 2019 and the President is expected to choose a course of action, if any, in July 2019.

3 WHY THE UNITED STATES MUST LEAD IN CIVILIAN NUCLEAR POWER

NUCLEAR SAFETY AND SECURITY

The United States has been the central architect of international nuclear nonproliferation, nuclear safety, and materials-safeguard institutions and norms, especially the IAEA, the Nuclear Suppliers Group, the World Association of Nuclear Operators, and the G7 Nuclear Safety Group. This ecosystem of institutions and standards has played a critical role in the safety of nuclear power and nonproliferation and has been undergirded by the United States. However, if the US nuclear industry continues to erode and foreign state-owned enterprises increase their domination of the global nuclear scene, the US capacity to protect and influence the international nuclear regulatory and export-control system will most likely decline. China has been consistently "building its nuclear capacity," and it is now "the biggest platform in the world for nuclear power, making up more than half of new global nuclear investment and slated to overtake the [United States] in nuclear power production sometime before 2030."[13]

This change will come at a time when several newcomer countries that have weak institutions, nontransparent governance, and are in unstable and potentially conflict-prone regions seek to build new reactors. The involvement of US companies—and the US standards and oversight that would accompany such involvement—would provide much stronger assurances against the risks of diversion of nuclear materials for military or terrorist purposes.

There are both national and international efforts at the IAEA and elsewhere addressing the appropriate safety standards for new Generation III+ and IV reactors, with their different designs, materials, and fuels. With current Generation III reactors, the US and European systems have developed advanced safety features, but some countries view US and European reactors as too expensive, complex, and unable to offer material operating-safety advantages. Hence, international cooperation with US leadership on development of standards for advanced reactors is extremely important for safety and security and for setting a level playing field where all parties can compete. Early steps on this effort could be undertaken on a bilateral basis between the US Nuclear Regulatory Commission (NRC) and the Canadian Safety Commission, given the commonality of advanced reactor designs that are seeking licensing in both countries. In this process, the United States should not weaken its standards but expand them in a way that effectively takes into account the characteristics and requirements of the new fuels and designs.

DEFENSE: CIVILIAN AND MILITARY INTERDEPENDENCES

The civilian nuclear power sector plays a crucial role in supporting US national security goals. The connectivity of the civilian and military nuclear value chain—including shared equipment, services, and human capital—has created a mutually reinforcing feedback loop, wherein a robust civilian nuclear industry supports the nuclear elements of the national security establishment. The ability of veterans of the naval nuclear program to find career opportunities in the civilian nuclear industry is essential to naval recruitment and helps sustain the talent pool required by both the US Navy and the fleet of ninety-eight commercial nuclear reactors. Maintaining a civilian fleet of nuclear reactors is critical for preserving these capabilities.

However, the atrophy of the US civilian nuclear industry has left gaps in the commercial nuclear supply chain, which introduces considerable risks into this ecosystem. The closure of existing plants is reducing demands for domestic parts and services, while the lack of new construction threatens the industry's human capital base and eventual ability to support the introduction of a future generation of reactors. The decline of the civilian nuclear industry has damaged the human capital pipeline, reducing the incentive for military personnel to pursue nuclear engineering as a postmilitary career path. Taken together, these challenges jeopardize a key pillar of US national security, especially as global rivals increase their own nuclear development.

Admiral Hyman Rickover's pioneering role in developing the Naval Reactors Program and deploying small nuclear reactors in US submarines has left a military

13 "Is China Powering the Future of Nuclear?," Power Technology, October 10, 2018, https://www.power-technology.com/features/future-of-nuclear-china/.

Russian Arktika-class nuclear-powered icebreaker Yamal, during the removal of manned drifting station North Pole-36, August 2009. Source: Wikimedia Commons/Hohum.

legacy—nuclear reactors currently power all US Navy aircraft carriers (ten Nimitz-class and one Gerald Ford-class) and submarines (about seventy)—and shaped the technology of the commercial reactor fleet. This model may well be appropriate for the development of new technologies including small, advanced nuclear systems with the potential for important stationary and mobile applications. Though nuclear systems were not selected for new cruisers due to cost considerations, current plans to expand the US naval fleet, including building new icebreakers to address the expanding Arctic presence of the Russian fleet (which has nuclear-powered icebreakers), provide an opportunity to further develop and implement new nuclear systems.

The US Department of Defense is also considering nuclear reactors for bases and installations that increasingly require reliable, high-quality power for their digital electronics and for energy-based weapons systems. Multiple studies—including one conducted by the US Army—have found that 52 percent of US casualties from Operation Iraqi Freedom and Operation Enduring Freedom "occurred from hostile attacks during land transport missions, mainly associated with resupplying fuel and water."[14] In response, a study by DOD's Defense Science Board concluded that micro modular nuclear reactors "would be optimal" in providing power to the US military in a theater of war.[15] According to the US Government Accountability Office (GAO), DOD is the single largest consumer of energy in the federal government.[16]

DOD is also interested in mobile nuclear units, and the Army's deputy chief of staff commissioned a study in 2018 that found that nuclear power applications were consistent with the National Defense Strategy and "can

14 James Conca, "U.S. Military Eyes Mini Nuclear Reactors To Reduce Convoy Casualties," *Forbes*, March 12, 2019, https://www.forbes.com/sites/jamesconca/2019/03/12/our-military-wants-small-nukes-to-reduce-convoy-casualties/#76f41297ba2b.

15 Ibid.

16 "Energy Management in DOD Facilities," US Government Accountability Office, https://www.gao.gov/key_issues/energy_management_dod_facilities/issue_summary.

reduce supply vulnerabilities and operating costs while providing a sustainable option for reducing petroleum demand and focusing fuel forward to support Combatant Commander (CCDR) priorities and maneuver in multi-domain operations (MDO)."[17] On January 18, 2019, the DOD Strategic Capabilities Office issued a request for information asking for proposals for small, mobile nuclear reactors. The criteria sought for these systems include: a size of 1 to 10 MW, the ability to be transported by truck or C-17 aircraft, a three-year refueling cycle, and short set-up and pack-up times.[18]

Russia and China are actively developing nuclear power for military applications, which will bolster their civilian nuclear power capabilities—posing a threat to US primacy in the realm of civilian nuclear power. Both countries are expanding their nuclear-powered submarine fleets. Russia has an estimated thirteen nuclear submarines and will soon deploy a Severodvinsk-class submarine K-561 Kazan, which is a nuclear-powered, guided-missile submarine.[19] China has nine nuclear-powered submarines: five nuclear-powered attack submarines (SSN), and four nuclear-powered ballistic missile submarines (SSBN).[20] Russia has the only nuclear-powered icebreaker fleet and is looking to expand the fleet for the escort of Russia's Arctic liquefied natural gas (LNG) tankers from the Yamal LNG plant. Russia is also looking at building small reactors for cities and military bases in the Arctic. A floating barge installation with twin 35 megawatts electric (MWe) KLT-40S nuclear reactors (the same reactor design used to power the Russian nuclear icebreaker fleet) has been launched and is being fueled in Murmansk, with operation planned for 2019.[21] Russia is also in the process of designing a single reactor design to replace the KLT-40S. China, meanwhile, is developing reactors for offshore platforms and islands in the critical global transport route through the South China Sea. The recent Worldwide Threat Assessment from the US Office of the Director of National Intelligence notes: "We assess that China will continue increasing its maritime presence in the South China Sea and building military and dual-use infrastructure in the Spratly Islands to improve its ability to control access, project power, and undermine US influence in the area."[22]

GLOBAL ELECTRICITY MARKET OPPORTUNITIES

The world is moving toward greater electrification of energy systems, and projections show that while electricity growth is slowing or flat in most industrial countries, energy and electricity growth will be concentrated in countries that are not members of the Organisation for Economic Co-operation and Development (OECD), especially in Asia. These are the power markets of the future and US companies will face strong competition in these markets. The International Energy Agency (IEA) *2018 World Energy Outlook* forecasts electricity demand may increase by 60 percent to over 35,500 TWh by 2040,[23] and that developing countries will account for almost 90 percent of future electricity demand growth. More specifically, China and India will account for as much as half of that growth. The IEA report notes that "increasing digitalization of the global economy is going hand in hand with electrification, making the need for electricity for daily living more essential than ever. Electricity is increasingly the 'fuel' of choice for meeting the energy needs of households and companies."[24]

17 Juan A. Vitali, Joseph G. Lamothe, Charles J. Toomey Jr., Virgil O. Peoples, and Kerry A. Mccabe, *Study on the Use of Mobile Nuclear Power Plants for Ground Operations*, US Army Deputy Chief of Staff, G-4, October 26, 2018, https://apps.dtic.mil/dtic/tr/fulltext/u2/1064604.pdf.

18 "RFI Small Mobile Nuclear Reactor," GovTribe Inc., last updated January 22, 2019, https://govtribe.com/opportunity/federal-contract-opportunity/rfi-small-mobile-nuclear-reactor-rfi01182019rdwhs019.

19 David Majambar, "Russia's Most Advanced (and Stealthy) Nuclear Submarine Ever Just Went to Sea," *National Interest*, September 29, 2018, https://nationalinterest.org/blog/buzz/russias-most-advanced-and-stealthly-nuclear-submarine-ever-just-went-sea-32217.

20 David Majambar, "China's Advanced Submarines are Breaking Record," *National Interest*, July 26, 2018, https://nationalinterest.org/blog/buzz/chinas-advanced-submarines-are-breaking-records-26811.

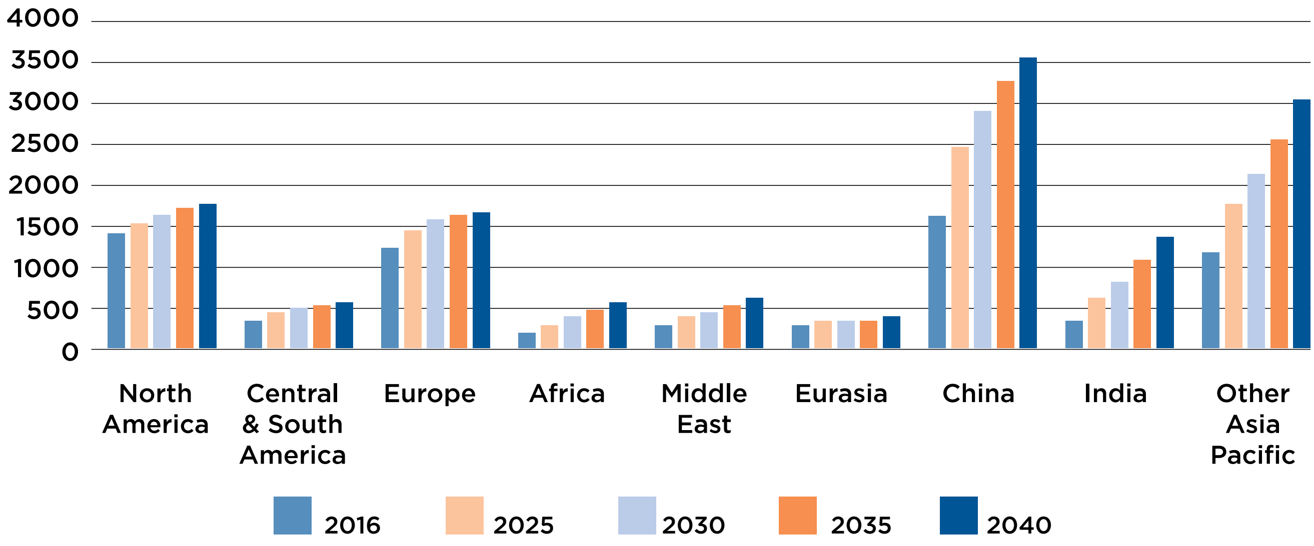
21 Joseph Trevithick, "Here's What We Know About Russia's New Floating Nuclear Power Plant Heading to the Arctic," TheDrive.com's The War Zone newsletter, May 1, 2018, https://www.thedrive.com/the-war-zone/20564/heres-what-we-know-about-russias-new-floating-nuclear-power-plant-heading-to-the-arctic.

22 Daniel R. Coats, *Worldwide Threat Assessment of the US Intelligence Community*, Statement to the Senate Select Committee on Intelligence, January 29, 2019, https://www.dni.gov/index.php/newsroom/congressional-testimonies/item/1947-statement-for-the-record-worldwide-threat-assessment-of-the-us-intelligence-community.

23 *World Energy Outlook 2018*, International Energy Agency, 2018, page 325, https://www.iea.org/weo2018/.

24 *World Energy Outlook 2018*, page 283.

Figure 3: Growth in Installed Electricity Capacity by Region 2016 - 2040 (GWs)



Source: Data drawn from IEA's *World Energy Outlook 2018*, New Policies Scenario, Appendix tables.

Nuclear power currently accounts for about 10 percent of global electricity generation and 35 percent of carbon-free generation.[25] With concerns over the environment and climate change, there is increased interest in renewables and low-carbon power technologies, and power markets are in a period of change. A recent report from the Intergovernmental Panel on Climate Change (IPCC) warns that the world may be as little as a dozen years away from crossing a critical threshold of seeing a global temperature rise of 1.5°C above preindustrial levels, increasing the risk of dangerous climate change. The IEA New Policies Scenario foresees nuclear capacity additions of 270 GW from 2017 to 2040, especially in China, Russia, and India.[26] While renewables are expected to dominate new power-generation investments and account for more than 41 percent of total global generation as early as 2035, the report assumes that nuclear power will become more competitive with coal and gas. Given the current and projected cost of alternatives, it will be critical to develop nuclear systems that can provide a levelized cost of energy of between US$30 and US$50 per MWh, which would, using Lazard Ltd.'s data,[27] allow them to beat new coal units and compete with current unsubsidized wind, solar, and gas units.

Policy and tax incentives that introduce a price for carbon could give nuclear energy a competitive boost, relative to gas and coal. For instance, the US Energy Information Administration has modeled two scenarios in the United States: one with a carbon fee of US$15 per ton of carbon dioxide and one using US$25 per ton of CO2 (in 2017 dollars), increasing by 5 percent (in real dollar terms) each year. The results suggest that if either of these policies were introduced in the United States starting in 2020, "much of the existing nuclear fleet [would remain] competitive," and "additional nuclear plants [would be] constructed so that capacity in 2050 [would be] higher than current levels," with significantly more new capacity in the latter scenario.[28]

25 *Global Energy & CO^2 Status Report*, IEA, March 26, 2019, https://www.iea.org/geco/emissions/.

26 At the time of writing, the United States and the Indian Government announced on March 13, 2019, the signing of a nuclear cooperation agreement that envisions development of six nuclear reactors. See "US, India Document Their Commitment to New Build," World Nuclear News, March 14, 2019, https://www.world-nuclear-news.org/Articles/India-USA-document-their-commitment-to-new-build.

27 *Lazard's Levelized Cost of Energy Analysis—Version 12.0*, Lazard Ltd. study, November 2018, https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf.

28 Michael Scott, "Future of U.S. Nuclear Power Fleet Depends Mostly on Natural Gas Prices, Carbon Policies," US Energy Information Administration, May 8, 2018, https://www.eia.gov/todayinenergy/detail.php?id=36112#.

The investments needed to meet a projected global electricity-capacity increase from 6961 GW in 2017 to 12,466 GW in 2040 will be significant. The IEA calculates an investment requirement of US$20 trillion over that period, of which 60 percent would be for generation. Even if nuclear power remains at about 10 percent of global generation, this is a sizable potential market, which the US Commerce Department in its *2017 Civil Nuclear Top Markets Report* estimates to be valued between US$500 billion and US$740 billion over the next ten years, with the potential to generate more than US$100 billion in US exports and thousands of new jobs.[29]

Large upfront capital costs and the small size of electricity grids in the developing world have been significant obstacles to adoption of large-size, nuclear power technology, causing several countries to abandon plans for nuclear units (e.g., Vietnam and Malaysia). Most current nuclear plants are located in countries with electricity systems larger than 20 GWs in size. But in 2016, there were an estimated fifteen countries with grids between 10 and 20 GWs and seventy-two countries with systems between 1 and 10 GWs.[30] The advent of small modular reactors (SMRs) in the size range of 50 to 300 MWs, like the ones NuScale, GE, and Holtec International are developing, together with an increasing policy focus on decarbonization and reducing air pollution in coal-intensive countries, may significantly change these market dynamics. In addition to their potential for grid-connected applications and as a reliable and flexible complement to intermittent renewables, these SMRs may be important in supplying process heat and steam, as well as electricity, to industrial complexes, district heating systems, decentralized mining and remote communities, military installations, and the growing desalination market. Packaged micro reactors (25 kilowatt hour electrical to 25 MW) like the ones that Oklo Inc., HolosGen LLC, and Westinghouse are developing may also be well-suited to new markets in the developing world and offer an alternative to expensive diesel generation and decentralized renewable systems.

ENVIRONMENT: GLOBAL LEADERSHIP IN ADDRESSING CLIMATE CHANGE AND ENVIRONMENTAL POLLUTION

An increasing number of scientific analyses, such as a recent Massachusetts Institute of Technology (MIT) report titled, *The Future of Nuclear Power in a Carbon-Constrained World*, conclude that nuclear is an essential part of a global effort to reduce CO_2 emissions.[31] But as the MIT report concludes, it is becoming clear that the current policy trajectory will not lead to the reduction in emissions that is necessary to come close to the IPCC report's target of 2° Celsius. Under the IEA *World Energy Outlook 2018*'s New Policies Scenario—which assumes that nuclear power retains its current share of between 9 percent and 10 percent of world electricity generation in 2040[32]—carbon dioxide emissions continue to rise at a 0.4 percent annual average rate to 2040, despite a significant improvement in carbon intensity.[33] By 2040, roughly half of world CO_2 emissions are expected to come from Asia, with emissions more than doubling in Southeast Asia and India, given continued growth in coal generation, while slightly declining in China.[34] With the plans to close nuclear plants permanently in the United States, Germany, Japan, and Belgium, as well as potential closures in France, Taiwan, South Korea, and several other countries, emissions could rise even more if they are replaced by fossil fuels. The report estimates that if US nuclear-power generation drops 14 percent by 2040 (as is assumed in the New Policies Scenario) this could lead to an additional 170 to 180 million tons of annual CO_2 emissions.[35] In its Sustainable Development Scenario, which assumes an increase in nuclear energy's share to 13 percent of generation in 2040 as well as a substantial increase in renewables, the IEA calculated that global energy CO_2 emissions could drop by half and for the power sector by a factor of four.[36] A recent report by Rhodium Group, an independent research provider, projects that without policy actions the United States is likely to have a rebound in emissions after 2025 and fall well short of the US's Paris Agreement target of between 26 and 28

29 Jonathan Chesebro and Devin Horne, *2017 Top Markets Report: Civil Nuclear*, US Department of Commerce, International Trade Administration, August 2017, https://www.trade.gov/topmarkets/civil-nuclear.asp.

30 "International Energy Statistics: Installed Electricity Generation Capacity, Beta," Energy Information Administration, https://www.eia.gov/beta/international/data/browser.

31 *The Future of Nuclear Energy in a Carbon-Constrained World: An Interdisciplinary MIT Study*, MIT Energy Initiative, 2018, http://energy.mit.edu/wp-content/uploads/2018/09/The-Future-of-Nuclear-Energy-in-a-Carbon-Constrained-World.pdf.

32 *World Energy Outlook 2018*, p. 528.

33 Ibid, p. 528.

34 Ibid, pp. 592, 584, 580.

35 Ibid, p. 349

36 Ibid, pp. 528-9.

Nuclear officials stand near the entrance to a reactor at the Browns Ferry nuclear facility in Alabama, in this photo taken March 25, 2011. The Browns Ferry nuclear plant, similar in design to the earthquake-hit Fukushima facility in Japan, has multiple defenses installed after 2011 to prevent and tackle the same kind of emergency, its operator said. Picture taken March 25, 2011. Source: REUTERS/Matthew Bigg.

percent below the 2005 level for overall CO_2 emissions by 2025.[37]

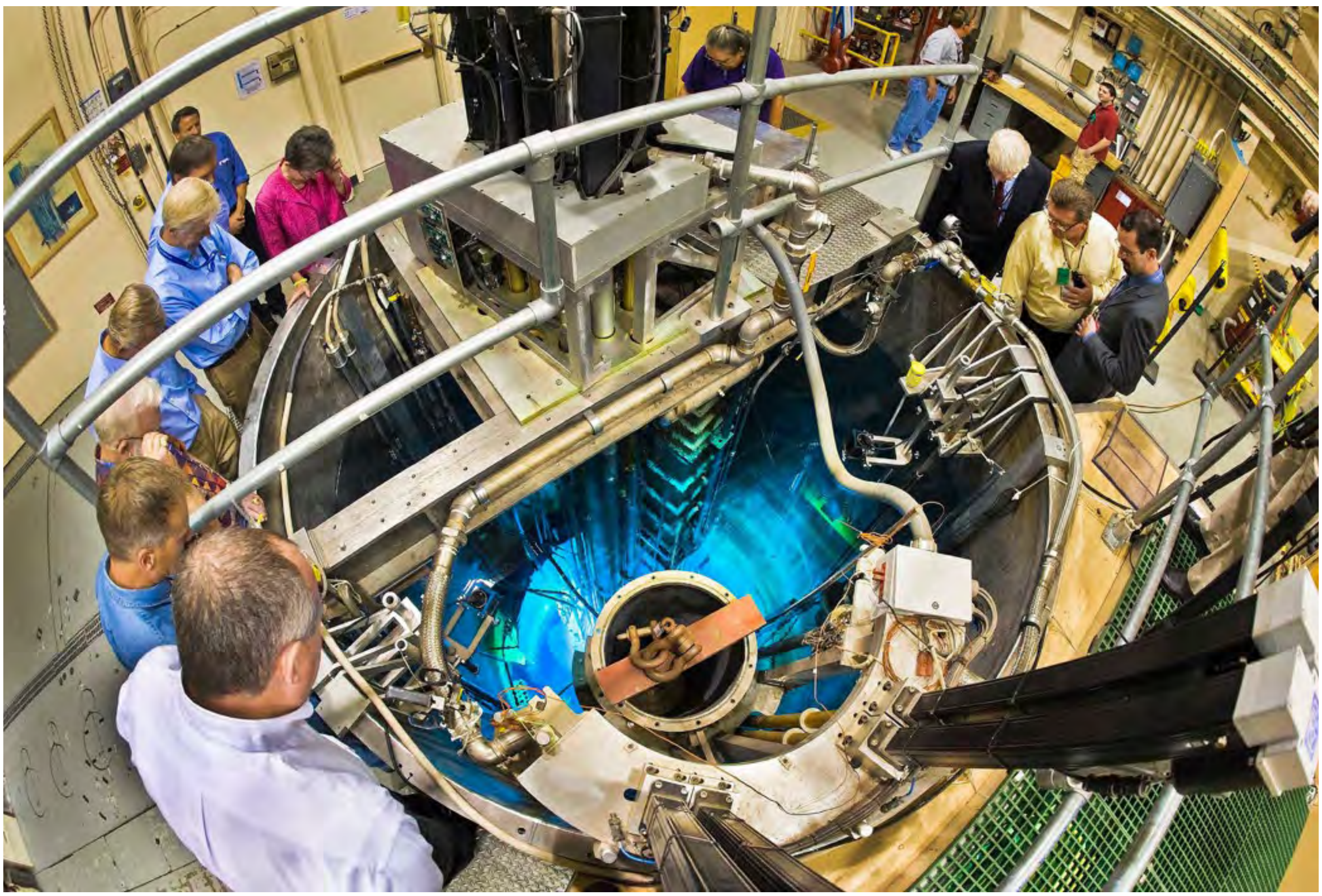
Under the Paris Agreement on Climate Change, reached in December 2015 and since ratified by 118 countries, parties agreed to cooperate in addressing global climate change and developing the mitigation and adaptation measures to cope with rising greenhouse gas emissions and the consequences of a warming planet. Following the Trump Administration's announcement of its plans to withdraw from the Paris Agreement, China has sought to stake out its position as the global leader on climate change and "green growth," with its ambitious domestic and international efforts to develop and finance renewables, nuclear power, electric vehicles, and energy efficiency, and to limit new domestic coal plants.

Despite these efforts, Chinese emissions have continued to increase—and are 70 percent higher than US CO_2 emissions; meanwhile, the United States has achieved the largest global reduction in energy-related CO_2 emissions of any country (about 800 million tons

37 John Larsen, Kate Larsen, Whitney Herndon, Peter Marsters, Hannah Pitt, and Shashank Mohan, "Taking Stock 2018," Rhodium Group, June 28, 2019, https://rhg.com/research/taking-stock-2018/.

of energy-related reductions since 2007).[38] Reduced US emissions are due to improvements in nuclear capacity factors, increased displacement of coal by natural gas, and growing renewable energy generation and energy efficiency improvements. Besides its high reliability, resilience, and contribution to US energy diversity, nuclear power provided 55.2 percent of the US carbon-free electricity in 2018 and helped avoid 528 million tons of carbon emissions, which together with decreases in nitrogen oxide and sulfur dioxide (SO_2) emissions, were estimated by the Nuclear Energy Institute (NEI) to have a social cost of US$28.1 billion.[39] But further closures of US nuclear plants are likely without the types of interventions seen in Illinois, New York, New Jersey, and Connecticut, which all have approved zero-emission credits for nuclear power, delaying utility-company closure decisions.

The economic as well as environmental impact of future closures would be significant and would hasten the decline in the human and industrial base for US nuclear power. However, the United States can further its leadership in reducing emissions by stemming premature plant closures and investing in carbon-free nuclear technologies. The recent United Nations Environmental *Emissions Gap Report* concludes that "accelerating innovation is a key component of any attempt to bridge the emissions gap."[40]



A group of spectators gathers at the Annular Core Research Reactor for its 10,000th operation. The reactor has been in operation since 1979 at Sandia National Laboratories in New Mexico. September 2011. Photo courtesy of Randy Montoya/Nuclear Regulatory Commission/Flickr.

38 *BP Statistical Review of World Energy*; and Joanne Zulinski, "US Leads in Greenhouse Gas Reductions but Some States Are Falling Behind," Environmental and Energy Study Institute, March 27, 2018, https://www.eesi.org/articles/view/u.s.-leads-in-greenhouse-gas-reductions-but-some-states-are-falling-behind.

39 *Nuclear by the Numbers*.

40 *Emissions Gap Report 2018*, United Nations Environment Programme, November 27, 2018, https://www.unenvironment.org/resources/emissions-gap-report-2018.

4 MEETING THE NUCLEAR POWER INNOVATION CHALLENGE

Given the global clean-energy market potential, there is a race to develop and commercialize small modular reactors and advanced (Generation IV) reactors. The key competitors in this race are the United States, Canada, Japan, South Korea, France, the UK, China, Russia, India, and Argentina. Although the development costs and commercial risks for these units are high, the potential benefits of future large-scale deployment suggest that the United States, with its design expertise and previous experience with some of these reactor types, has the capability to be a leader in this area and needs to accelerate its efforts to compete in this area of technological innovation. Advanced reactors employ different fuels and technologies that have the potential to: (1) reduce waste via more efficient fuel use; (2) trim costs through coolants that require less material for containment; (3) shorten construction times with smaller, segmented reactors built offsite and shipped to destination; (4) decrease the risk of weapons proliferation due to their longer refueling cycles and, in some cases, spent fuels that are more difficult to reprocess; and (5) improve safety via inherent features that allow safe operation with fewer safety systems, reduced emergency-evacuation requirements, and without requiring operator action.[41] With the growing problem of the buildup of spent fuel in the United States, Japan, South Korea, and other countries, the potential for some of these technologies to burn modified spent fuel is another important consideration that may ameliorate some public concerns about safety. Although long-term efforts will be needed, short-term actions on consolidated waste-storage approaches should also be pursued.

The previously-mentioned MIT study, referring to light water reactors (LWRs) and other advancements, concludes: "We judge that advanced reactors like LWR-based SMRs (e.g., NuScale) and mature Generation-IV reactor concepts (e.g., high-temperature gas reactors and sodium-cooled fast reactors) . . . possess such features and are now ready for commercial deployment. Further, our assessment of the US and international regulatory environments suggests that the current regulatory system is flexible enough to accommodate licensing of these advanced reactor designs. Certain modifications to the current regulatory framework could improve the efficiency and efficacy of licensing reviews."[42]

The competition will be intense as governments step up to provide strong support to their industries. One example is the Canadian government's well-coordinated efforts to refurbish its fleet of Candu reactors—and support its nuclear industry supply chain through a C$26 billion effort—and develop SMRs for a range of centralized and decentralized applications as part of its overall program to reduce carbon emissions and phase out coal plants by 2030. In November 2018, the Canadian government launched an initiative, "A Call to Action: A Canadian Roadmap for Small Modular Reactors."[43] Several US and international companies are pursuing the Canadian market and working with its flexible regulator on vendor design reviews. Companies involved in these reviews are pursuing a variety of designs, i.e., integral pressurized water reactors (PWR), liquid sodium, molten salt, and several high temperature gas-cooled reactors (HTGR). (See Appendix 1 for an overview of advanced reactor types.)

There is significant innovation focused on the development of a variety of small modular reactors (25 to 300 MW) and micro reactors (up to 25 MW), as shown in Appendix 1. US company examples include: NuScale Power LLC's work on an integral PWR; work on fast neutron reactors (FNRs) by GEH, Advanced Reactor Concepts (ARC), and TerraPower, which is focused on

41 *Fourth National Climate Assessment—Volume II*, US Global Change Research Program, November 2018, https://www.globalchange.gov/nca4.

42 *The Future of Nuclear Energy in a Carbon-Constrained World: An Interdisciplinary MIT Study*.

43 *A Call to Action: A Canadian Roadmap for Small Modular Reactors*, Canadian Small Modular Reactor (SMR) Roadmap Steering Committee, 2018, https://smrroadmap.ca/wp-content/uploads/2018/11/SMRroadmap_EN_nov6_Web-1.pdf.

a sodium FNR and a Molten Chloride FNR; X-Energy's HTGR, Terrestrial Energy USA's Molten Salt Reactor; and the micro reactor work of Westinghouse, Holos-Gen, and Oklo. DOE has recently awarded a contract to GEH to develop the design of the planned Versatile Test Reactor (VTR) Program, which is likely to incorporate features from its PRISM design as well as other designs and provide a state-of-art system for testing of materials, fuels, and reactor components. Although some Generation IV systems do not require a fast neutron test reactor,[44] VTR would facilitate the development of some types of advanced reactors and represent an important step in ultimately competing with Russia and China in the global market. All these companies seek to develop initial units by 2030. Most of these advanced reactors require different types of fuels, and urgent efforts are needed to increase the availability of and fuel-fabrication technologies for high-assay low-enriched uranium (HALEU), in which uranium-235 accounts for up to 20 percent of the fuel. DOE recently announced a pilot project to support Centrus Energy's efforts to utilize centrifuges to produce a small amount of HALEU for new reactor development. Idaho National Labs has a parallel effort to process used fuel from the US Navy to provide an additional source of HALEU. In addition, Urenco, in February 2019, announced it was proceeding with plans to expand its gas centrifuge enrichment facilities in New Mexico to produce HALEU (this US activity by an international company would not be considered US origin and would be acceptable for commercial but not military applications).[45] NEI has provided to US Secretary of Energy Rick Perry a chart estimating industry requirements of 110 metric tons of uranium (MTU) by 2026 and 589 MTU by 2030 (see Appendix 3). Even if this analysis turned out to be a bit optimistic, a long-term plan for HALEU is a necessary element in ensuring the development of advanced reactors.

Russia and China are major competitors, and their governments have made development of advanced reactors a high priority. Unlike the United States, they continue to be committed to a closed fuel cycle and fast breeder reactor, which pose heightened proliferation risks. Both countries have invested heavily in research reactors and capabilities to test various advanced fuels. Russia has the most experience with fast neutron reactors, including with their old, sodium-cooled BN-600 unit and a newer and larger BN-800 mixed oxide-fueled (MOX) unit. Under its breakthrough project for large fast-breeders, Russia is developing a BN-1220 MWe system, with the goal of installing 11 GW by 2030.[46] Small fast neutron reactors are also being developed by the Russian NIKIET (N.A. Dollezhal Scientific Research and Design Institute of Energy Technologies), i.e., the lead-cooled BREST300 planned for testing in Seversk.

China is also scaling up a fast neutron reactor program that has been operating a 65 MW experimental unit. A December 2017 announcement indicates that the Chinese National Nuclear Corporation (CNNC) began construction of a 600 MW sodium-cooled, MOX-fueled fast reactor at Xiapu, with larger 1000 MW commercial reactors planned in the future.[47] China is also well along in the development of HTGRs that can meet industrial and other heat requirements as well as produce electricity, and has signed several international cooperation agreements on this technology including with Indonesia and Saudi Arabia. Two pebble-bed 250 MW helium-cooled HTGR units are in the process of being installed by the Chinese State Nuclear Power Technology Corporation in Sandong Province, but they do not yet appear to be in operation.

Russia and China are also working on SMRs and have several under construction. All three of the Chinese state nuclear enterprises are pursuing their own designs. A key project in China's 12th Five-Year Plan is CNNC's multipurpose small modular reactor, the ACP100, or LingLong One. State-owned CNNC is building the first unit at Changjiang, in the province of Hainan, with construction set to commence in December 2019. Commercial operation is planned for May 2025.[48] China General Nuclear (CGN) has been developing its ACPR50S design and has begun construction on the first unit. CGN has been working with China National Offshore Oil Corporation and the China Shipbuilding Industry Cor-

44 *The Future of Nuclear Energy in a Carbon-Constrained World: An Interdisciplinary MIT Study*.

45 "Urenco USA Announces HALEU Activities," World Nuclear News, World Nuclear Association, February 6, 2019, http://world-nuclear-news.org/Articles/Urenco-USA-announces-HALEU-activities.

46 "Advanced Nuclear Power Reactors," World Nuclear Association, October 2018, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx.

47 "China Begins Building Pilot Fast Reactor," World Nuclear News, World Nuclear Assocation, December 29, 2017, https://www.world-nuclear-news.org/NN-China-begins-building-pilot-fast-reactor-2912174.html.

48 "December Construction Start for Chinese SMR," World Nuclear News, World Nuclear Association, March 25, 2019, http://world-nuclear-news.org/Articles/December-construction-start-for-Chinese-SMR.

poration to demonstrate a nuclear power installation on an offshore platform. Russia has been upgrading its small, submarine-design reactors including for floating installations (FNPP), as discussed below. Several years ago, China began working with Russia to use Russian FNPP technology for barge installations but has since been developing its own designs.[49]

The full implications of the myriad of international development efforts underway are not entirely clear. What is evident is that the costs of new-system development are high, and there are considerable resources being put into this development. US government support in the research and design process will be critical to the eventual commercial application, especially given the large state-funded programs in most other countries. Nuclear energy research is one of the priorities in China's 13th Five-Year Plan and is part of the estimated US$291 billion of Chinese state financing for science and research in 2018.[50] US companies are making decisions about the costs and benefits of international collaboration in developing, licensing, and commercializing their systems. The US government position on international company-to-company partnerships in this technological development is an important policy issue, and international collaborations may prove to be an effective way to control weapons risks. However, the Trump Administration has recently moved to block advanced reactor exports to China because of concerns about Chinese theft of US technology and military applications, which has resulted in a direct impact on TerraPower and its efforts to deploy its Traveling Wave Nuclear Reactor technology in China.

Nuclear energy research at Idaho National Laboratory's Hot Fuel Examination Facility. January 2011.
Source: Idaho National Laboratory/Flickr.

49 "Advanced Nuclear Power Reactors."

50 Teddy Ng and Jane Cai, "China's Funding for Science and Research to Reach 2.5% of GDP in 2019," *South China Morning Post*, March 10, 2019, https://www.scmp.com/news/china/science/article/2189427/chinas-funding-science-and-research-reach-25-cent-gdp-2019.

5 EXECUTIVE BRANCH AND CONGRESSIONAL POLICIES AND ACTIONS

Both the US president and Congress are seeking to support domestic nuclear power and the development of new advanced nuclear reactors. This support includes greater congressional funding for advanced reactors and regulatory review costs, promoting greater cooperation between industry and the DOE national laboratories, improving the framework for financing initial commercial demonstrations, investing in new test facilities needed for new reactor designs and fuels, and supporting human-resource development in critical nuclear fields.

However, further action is needed given the importance of nuclear power to a stable and resilient US electrical grid, the importance of having an industry that is able to support the nuclear components of our long-term national security requirements, and the role that nuclear exports can serve as a counterbalance to aggressive competition from Russia, China, and others. After nearly four years without a quorum, recent Congressional action restored the Export-Import Bank to its full potential. However, its charter must be renewed by September 30, 2019, or industry will be unable to have a competitive financing option. Additionally, the newly created US International Development Finance Corporation (USDFC) has the opportunity to modify the policies of its predecessor, the Overseas Private Investment Corporation (OPIC), to allow nuclear technologies to qualify for its funding capabilities.

DECEMBER 2017 NATIONAL SECURITY STRATEGY (NSS) AND NATIONAL DEFENSE STRATEGY 2018: A NEW RUSSIA/CHINA PARADIGM

The 2017 White House National Security Strategy (NSS) prominently presented the national security challenge which China and Russia pose to the United States. It states: "China and Russia challenge American power, influence and interests, attempting to erode American security and prosperity." In response, the NSS embraces "energy dominance" as an important element of the US international approach and lays out five main strategic goals that promote energy security and development and bolster US exports of energy, technology, and services.[51]

The NSS specifically mentions the development of advanced nuclear reactors in conjunction with its fifth goal, which is furthering the US technological edge in the energy sector. However, nuclear energy is also relevant to goals such as energy security, increasing US exports, and energy access for the billion people in the developing world without adequate access to electricity. While the administration has given priority to fossil-fuel development and expanding US LNG exports, nuclear power has also factored into US international engagements and presidential meetings with several key countries, including India, Japan, South Korea, Saudi Arabia, and Poland.

FREE AND OPEN INDO-PACIFIC STRATEGY

Within the NSS framework, President Trump in his trip to Vietnam in December 2017 launched the US "Free and Open Indo-Pacific Strategy," which calls for increased collaboration with US allies and partners, including boosting cooperation with Japan, Australia, and India.[52] US Secretary of State Mike Pompeo elaborated the concept in his July 30, 2018, speech to the US business community on "America's Indo-Pacific Economic Vision,"[53] which outlined three specific initiatives: (1) the Digital Connectivity and Cybersecurity Partnership; (2) Asia EDGE (Enhancing Development and Growth through Energy); and (3) infrastructure and a new Indo-Pacific Transaction Advisory Fund. US Secretary of Energy Perry has further defined the goals of Asia EDGE as:

- "Expanding energy commerce by growing foreign

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

52 The White House, remarks by President Trump at APEC CEO Summit, Da Nang, Vietnam, November 10, 2017, https://www.whitehouse.gov/briefings-statements/remarks-president-trump-apec-ceo-summit-da-nang-vietnam/.

53 US Department of State, remarks by Secretary of State Pompeo on "America's Indo-Pacific Economic Vision," at the Indo-Pacific Business Forum, July 30, 2018, https://www.state.gov/secretary/remarks/2018/07/284722.htm.

A cut-away model of the Chinese Gen-III nuclear power technology Hualong 1 by China General Nuclear Power Corporation (CGN) is displayed at the World Nuclear Exhibition (WNE), the trade fair event for the global nuclear community in Villepinte near Paris, France, June 26, 2018. Source: REUTERS/Benoit Tessier.

Debate Over Controls on Nuclear Exports to China

As military and trade tensions have grown with China, the DOE in October 2018 instituted controls on nuclear technology, equipment, and component exports to China and specifically to CGN and its subsidiaries, establishing a "framework for the disposition of current requests for Part 810 authorizations concerning transfers to China" (See Appendix 2).[1] Although it does not prohibit technology exports prior to January 1, 2018, or equipment and component exports for the Westinghouse AP-1000 and similar CAP-1400 reactors in China, it does deny technology exports for light water SMRs and nonlight water advanced reactors.

Advocates for nuclear power in the United States disagree about this policy. Some have argued that the policy cuts off access to the largest future nuclear power market in the world, effectively hamstringing US industry and stymieing innovation without providing concurrent support in the United States to make up for the loss. Others note China's documented attempts to steal US nuclear technology and argue that in the competition for future nuclear technological leadership, working with China is not a winning strategy.

The US nuclear industry is already feeling the impact of the new policy. TerraPower, which previously received authorization from DOE to collaborate with a Chinese state-owned enterprise on a traveling wave reactor, recently announced it may not be able to pursue its advanced reactor project in China due to the October 2018 policy shift.

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

energy markets, expanding public-private partnerships, and fostering business-to-business connections.

- Advancing market-based energy policies and market reforms by helping partner governments set transparent, market-based, best-value energy policies.

- Catalyzing private capital for the financing of export and investment projects by partnering with international financial institutions and firms on pooled finance, insurance, and risk mitigation.

- Promoting universal access to affordable, secure, and reliable energy supplies by tapping America's vast natural resources and technical expertise."[54]

DOE has indicated that international nuclear cooperation will be an important component of the Asia EDGE program, and on November 13, 2018, DOE signed a memorandum of cooperation with Japan to promote the global leadership role of the two countries in civilian nuclear power. Secretary of Energy Perry has also promoted nuclear power, along with counterparts from Japan and Canada, as part of the Mission Innovation Initiative, originally launched at the Paris Conference in 2015 to further clean energy. The NICE Future (Nuclear Innovation: Clean Energy Future) group met in 2018 at the COP 24 United Nations Climate Change Conference in Poland and is expanding its membership and engagement.[55]

US INTERNATIONAL DEVELOPMENT FINANCE AND THE BUILD ACT

Although the Trump Administration initially proposed the elimination of OPIC and the Trade and Development Agency, this position changed following President Trump's trip to Asia. Since then, the administration has supported the creation of the USDFC. On October 5, 2018, the president signed into law the BUILD Act (Better Utilization of Investments Leading to Development), which authorizes an expanded US capacity to support trade and investment and expands its investment limitation from US$39 billion to US$60 billion. This effort reflects the strong administration and congressional view that the United States needs to boost its capacity to offer a market-based alternative to Chinese Belt and Road infrastructure financing, which officials have called "predatory" and a "debt trap."[56] The USDFC, scheduled to open on October 1, 2019, will incorporate functions of OPIC, for which energy has been an important sector for both loans and loan guarantees. In order to facilitate nuclear exports, the USDFC will need to modify the OPIC Environment and Social Policy Statement that prohibits funds from being used for new nuclear projects.

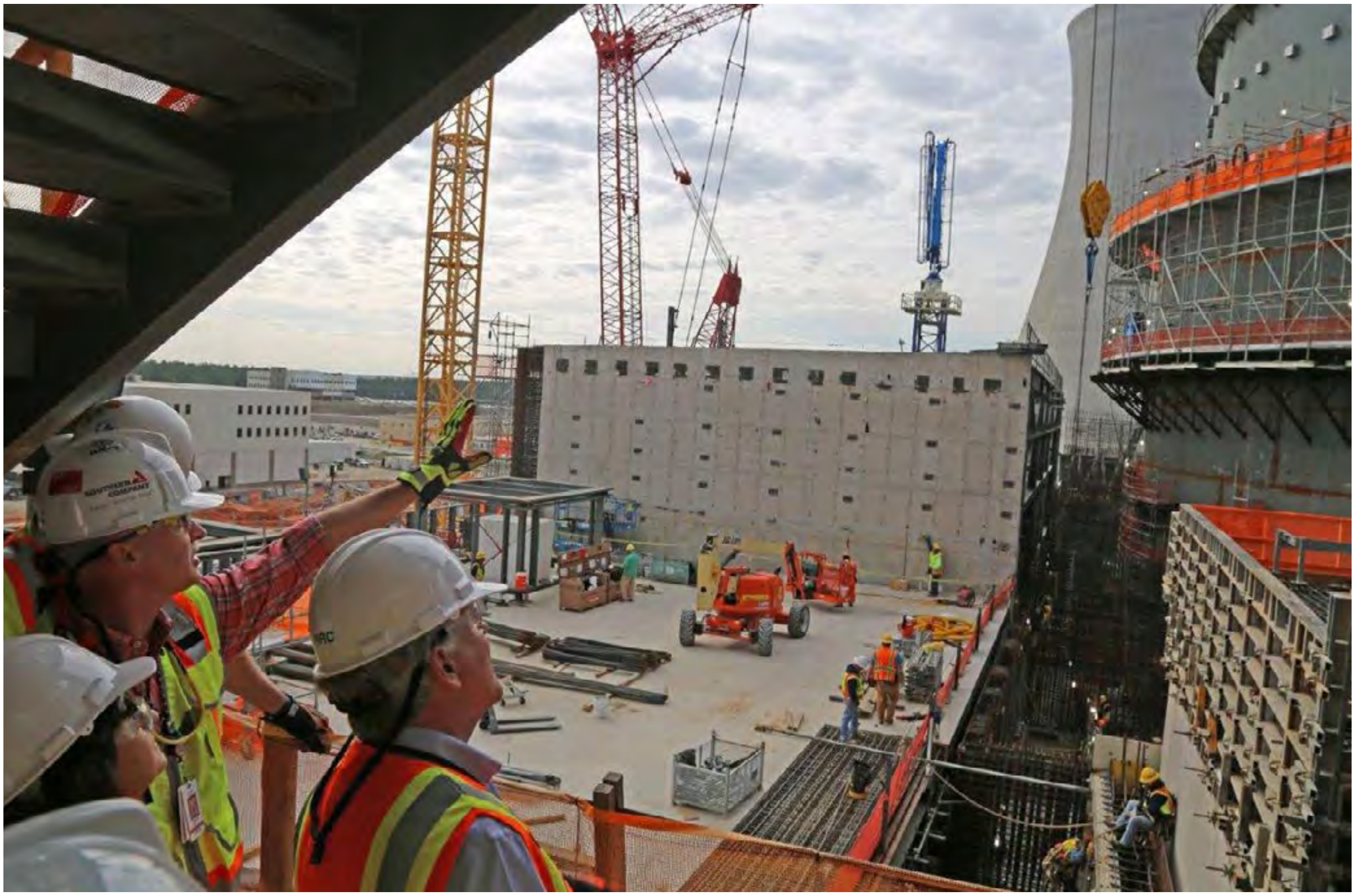
ASIA REASSURANCE INITIATIVE ACT

The significant congressional interest in expanding US focus and engagement in Asia was also reflected in the enactment of the Asia Reassurance Initiative Act, which was signed by the president on December 31, 2018. This act (S. 2736, P.L. 115-409) stresses the importance of continued US leadership in the Indo-Pacific to further peace and stability, foster economic prosperity, and promote respect for fundamental human rights. It authorizes US$1.5 billion per year from FY2019-2023 to the US Department of State, US Agency for International Development (USAID), and, where appropriate, the Department of Defense, for a range of diplomatic, economic and democracy promotion, and defense activities. It directs the president to "establish a comprehensive, integrated, multiyear strategy to encourage the efforts of Indo-Pacific countries to implement national power strategies and cooperation with US energy companies and the Department of Energy national laboratories to develop an appropriate mix of power solutions to provide access to sufficient, reliable, and affordable power in order to reduce pov-

54 US Department of Energy, "Five Ways the United States Is Partnering with the Indo-Pacific Region on Energy," July 30, 2018, https://www.energy.gov/articles/5-ways-us-partnering-indo-pacific-region-energy.

55 US Department of Energy, "Five Ways the United States Is Partnering with the Indo-Pacific Region on Energy," July 30, 2018, https://www.energy.gov/articles/5-ways-us-partnering-indo-pacific-region-energy.

56 Anthony B. Kim, "Will Pakistan Get Caught in China's 'Debt-Trap Diplomacy'?," commentary on CNSNew.com, Media Research Center, August 9, 2018, https://www.cnsnews.com/commentary/anthony-b-kim/will-pakistan-get-caught-chinas-debt-trap-diplomacy; and U.S.' Pompeo Warns Against IMF Bailout for Pakistan That Aids China," Reuters, July 30, 2018, https://www.reuters.com/article/us-imf-pakistan/us-pompeo-warns-against-imf-bailout-for-pakistan-that-aids-china-idUSKBN1KK2G5.



Alvin Ward Vogtle Nuclear Power Plant, Waynesboro, Georgia. Source: Wikimedia Commons/ChNPP.

erty, drive economic growth and job creation, and to increase energy security in the Indo-Pacific region."[57] This energy strategy-development requirement offers an opportunity to integrate nuclear into an overall approach to electric power in the region.

CONGRESSIONAL ACTION TO SPUR NUCLEAR TECHNOLOGY INNOVATION

In addition to these initiatives in the foreign policy arena, Congress has taken significant actions to support nuclear research, design, and development and strengthen DOE's nuclear programs. Senators Crapo and Whitehouse introduced S. 97, the Nuclear Energy Innovation Capabilities Act of 2017 (Pub. L. No. 115-248), or NEICA, which passed the Senate on January 7, 2018, with strong bipartisan support, and passed the House on September 13, 2018. The bill was signed by the president on September 28, 2018, and it authorizes testing and demonstration of advanced reactors with private and public funding through a Nuclear Reactor Innovation Center. NEICA also establishes requirements for DOE to develop a versatile neutron source—a fast-spectrum test facility at a national laboratory (known as the Versatile Advanced Test Reactor)—planned to be operational by December 31, 2025, to carry out testing and demonstration. The legislation also seeks to ensure that the NRC "has sufficient technical expertise to support the evaluation of applications for licenses, permits, and design certifications and other requests for regulatory approval for advanced nuclear reactors." It requests a report within one year on the ten-year budget requirements for advanced reactor R&D and authorizes a grant program, to be known as the "Advanced Nuclear Energy Cost-Share Grant Program," under which the DOE secretary shall make cost-share grants to applicants for the purpose of funding a portion of the commission fees of the applicant for preapplication and application review activities.

57 Asia Reassurance Initiative Act of 2018, S. 2736, Section 306, P.L. 115-409, https://www.congress.gov/115/bills/s2736/BILLS-115s2736enr.pdf.

In the final days of the 115th Congress, another important piece of US legislation was passed by the Senate and House: the Nuclear Energy Innovation and Modernization Act (NEIMA). The president signed the act on January 14, 2019 (Pub. L. No. 115-439). NEIMA seeks to improve and implement an efficient and predictable NRC review and licensing process for advanced reactors, reform the licensing-fee structure, train staff needed to review advanced reactor submissions, and authorize annual appropriations (US$14.4 million per year) to carry out these measures. It requires development of both a shorter-term staged review and licensing process and a longer-term, technology-inclusive regulatory framework as an optional pathway for licensing commercial advanced nuclear reactors.

Another significant action in 2018 was the extension of the nuclear production tax credit (PTC) as part of the overall tax reform bill. This legislation contained several provisions of support for new plants planned or under construction, notably allowing for new nuclear reactors placed in service after December 31, 2020, to qualify for the nuclear PTC; permitting the secretary of energy to allocate credits up to a 6,000 MW capacity limit for the first "new nuclear" reactors placed in service after December 31, 2020; and allowing public-entity partners to transfer their credits to other private partners. The deadline change will ensure the two reactors being built at the Vogtle power plant in Georgia will benefit from the PTC. The 6,000 MW capacity limit indicates that the PTC will also benefit NuScale and its partners' plans to build its first commercial power plant at the Idaho National Laboratory by 2026.[58] Additionally, other advanced reactor technology developers could benefit from the 6,000 MW PTC provisions; however, it should be noted that the PTC for nuclear energy is not indexed for inflation.

While 2018 saw a flurry of bipartisan nuclear-related activity in Congress, 2019 will likely be full of new initiatives as well. The Nuclear Energy Leadership Act, S. 3422, first introduced in the 115th Congress on September 6, 2018, by Senator Murkowski with cosponsors Senators Crapo, Whitehouse, and others, was reintroduced in March 2019 as S. 903.

This bill contains several provisions to support reactor development and deployment, including allowing the US government to enter into long-term power purchase agreements (up to forty years) with all energy fuel types and separately authorizing pilot power purchase agreements with new nuclear power plants under this broader provision; the completion of two advanced-reactor demonstration projects by December 31, 2025, and two or three more by December 31, 2035; the submission by DOE of a strategic plan for a ten-year program; the construction of a versatile, fast neutron source facility; the leasing (or sale) by DOE of HALEU fuels for advanced reactor use; and the establishment of a University Nuclear Leadership Program to create the workforce needed to maintain, develop, and secure nuclear facilities. This last provision could address a concern raised by a number of industry executives and former government officials that DOE has significantly cut support for nuclear engineering programs.[59] Task Force members also stressed, given the experience with the Vogtle and Summer new plant construction, the importance of workforce development in the craft and construction fields if it is clear that new plants will be built.

DOE NUCLEAR AND NATIONAL LABORATORY PROGRAMS

Although the Trump Administration has proclaimed its intention to reactivate nuclear energy programs and President Trump signed both NEICA and NEIMA, the administration's fiscal-year (FY) budgets in 2018 and 2019 proposed cuts in DOE's nuclear programs and the elimination of the DOE Loan Guarantee Program. The budgets also sought to limit DOE's nuclear programs to early-stage research and development. However, Congress increased the DOE budget for these programs over the requested amount in both years, from a US$703 million budget request to US$1.01 billion appropriated in FY 2018 and from a US$757 million budget request in FY2019 to US$1.34 billion in enacted appropriations, and continued support for the DOE Loan Guarantee Program, Advanced Research Projects Agency-Energy (ARPA-E), and its new program on advanced reactor concepts, MEITNER. The

58 Nuclear Energy Institute, "Congress Passes Nuclear Tax Credit in Big Boost to New Nuclear Construction," February 9, 2018, https://www.nei.org/news/2018/congress-passes-nuclear-production-tax-credit.

59 Bipartisan Policy Center Action letter to US Senators Thad Cochran and Patrick Leahy and US Representatives Rodney Frelinghuysen and Nita Lowey, June 7, 2017, https://www.eenews.net/assets/2017/06/08/document_gw_01.pdf.

recently submitted FY 2020 budget requested a lower level than the FY 2019 appropriations, at US$824 million for DOE nuclear energy programs, and again proposed the elimination of ARPA-E and the DOE Loan Guarantee Program. The FY 2020 request for the naval reactors program to support DOD was US$1.6 billion,[60] lower than the US$1.8 billion requested in FY 2019.

These DOE nuclear program funds have allowed DOE to increase its support to private industry for the development of new reactors. Although awards to NuScale have received substantial press coverage, many other awards have been made (e.g., to Southern Company/ TerraPower, and X-Energy LLC). Support for NuScale's 60 MWe (200 megawatts thermal) modular technology has helped the company pursue a twelve-module demonstration plant at the Idaho National Laboratory, which will be owned by Utah Associated Municipal Power Systems, a nonprofit wholesale supplier throughout the Intermountain West. Continuation of these successful public-private partnerships through first deployment is critical to maintaining the US technology advantage over Russian and Chinese state-owned companies' competing designs.

In 2018, DOE made the first awards under its "US Industry Opportunities for Advanced Nuclear Technology Development" funding opportunity. The US$60 million in awards are all in public-private cost-shared advanced nuclear research and development (R&D) partnership projects, with industry contributing up to 50 percent of the costs of thirteen projects, starting in FY 2018. The awards further three major areas of development: (1) first-of-a-kind nuclear demonstration readiness projects; (2) advanced reactor development projects; and (3) regulatory assistance grants.

DOE is also providing support to a variety of US small modular and advanced reactor designers for collaborative research and development projects with the Argonne, Idaho, and Oak Ridge national laboratories under the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative.[61]

DEPARTMENT OF STATE MEMORANDUMS OF UNDERSTANDING

In February, Christopher Ford, assistant secretary for international security and nonproliferation at the State Department, outlined a new policy to make nuclear power part of the US energy diplomacy toolkit with the specific intention of helping US companies compete with China and Russia. The new policy includes better coordination across agencies and signing nuclear cooperation memorandums of understanding (MOUs) with potential partner countries to help them become "fully prepared to take advantage of the emerging technologies and coming innovations in reactor design and other areas that are being pioneered in the United States."[62] These MOUs, each of which would precede a 123 agreement (the name for a formal cooperation agreement under Section 123 of the US Atomic Energy Act of 1954), would help the United States play a role in shaping nascent nuclear power programs well in advance of formal decisions to start building reactors. US participation in early discussions with potential purchasing countries could offer US companies a competitive advantage over other countries seeking to export nuclear technologies.

In sum, the Trump Administration (with the exception of proposed budget cuts) and congressional actions over the past year show a higher level of commitment to nuclear power and a recognition of the serious challenge the United States faces in maintaining a global leadership position. Although the private sector will provide the innovative designs for next-generation systems, US government action and support from DOE and its national laboratory system and DOD are critically important given the magnitude of the costs involved, the difficulty of competing with the large government-funded programs in Russia and China, and the need for an initial market for the first units given the reluctance of US investor-owned utilities to assume these risks.

60 "President Trump Releases FY 2020 Budget Request," US Department of Energy news release, March 11, 2019, https://www.energy.gov/articles/president-trump-releases-fy-2020-budget-request

61 "How to do Business through GAIN," Gateway for Accelerated Innovation in Nuclear (GAIN), last updated March 11, 2019, https://gain.inl.gov/SiteAssets/Teresa/HowToDoBusinessThroughGAIN_11Mar19.pdf; and "NE Vouchers," Gateway for Accelerated Innovation in Nuclear (GAIN), 2019, https://gain.inl.gov/SitePages/Nuclear%20Energy%20Vouchers.aspx.

62 Tom DiChristopher, "The U.S. is Losing the Nuclear Energy Export Race to China and Russia. Here's the Trump Team's Plan to Turn the Tide," CNBC, March 21, 2019, https://www.cnbc.com/2019/03/21/trump-aims-to-beat-china-and-russia-in-nuclear-energy-export-race.html.

6 RECOMMENDATIONS FOR AN ENHANCED US GOVERNMENT - INDUSTRY PARTNERSHIP

The administration and congressional actions discussed above are beginning to advance domestic R&D and leverage the potential US government power market. However, there is an urgent need to enhance the government-industry partnership to return the United States to an international leadership position, while addressing the global nuclear power challenge of Russia and China. Strengthening the US domestic nuclear power industry—as well as related research and educational capabilities—is directly tied to the nation's international credibility and influence, and both are of critical importance. For the new generation of advanced nuclear technologies, the United States must show that it can successfully design, manufacture, construct, and operate these systems at competitive prices. Government cofinancing of the initial demonstrations will be essential, as will other efforts to reduce the investor risks with these first units. Despite the minimal projected growth of electricity demand in the United States, there are likely to be opportunities over the next several decades for US utilities to replace baseload generation capacity as coal and older gas and nuclear units retire. Although the electricity growth markets in emerging and developing countries offer tremendous opportunity, the United States cannot realistically establish a future industry based on the export market alone: the United States must build and operate new domestic reactors.

To achieve this goal, the United States should pursue a concerted strategy within the following three categories: (1) maintaining and expanding the current nuclear fleet; (2) creating a conducive environment for new technologies; and (3) encouraging and facilitating nuclear energy exports.

1: MAINTAIN AND EXPAND THE CURRENT NUCLEAR FLEET

Preserve and strengthen the US civilian nuclear power industry and its supply chain and research base

ACTIONS:

- The executive branch should take concrete steps to ensure that the benefits (including reliability, diversity, and zero emissions) of US nuclear power plants are valued in US electricity markets and that existing nuclear plants are not forced to close prematurely. Key interests of both electricity markets and national security stakeholders include grid resiliency and the international soft power that accompanies energy exports. In particular, DOE and the Federal Energy Regulatory Commission (FERC) should build on previous efforts to investigate opportunities to revise the framework for organized markets to better capture the full range of value provided by nuclear electricity.[63]

RATIONALE:

- Additional closures of nuclear plants will further erode the US supply chain and technical and human-resource capabilities needed for commercializing new civilian reactors and serving US military needs—as well as providing civilian jobs for veterans, as has been pointed out by the Energy Futures Initiative.[64] Policies that prohibit or disfavor new nuclear builds have already resulted in the offshoring of the portion of the nuclear supply chain dependent on new projects, such as heavy forgings and large component machining. Additionally, the current market approach does not fully value the attributes of a thoughtfully-designed future electricity system that includes reliability, resilience, and zero emissions.

63 See, for example, the 2017 *Staff Report to the Secretary on Electricity Markets and Reliability*, US Department of Energy, August 2017, https://www.energy.gov/sites/prod/files/2017/08/f36/Staff%20Report%20on%20Electricity%20Markets%20and%20Reliability_0.pdf.

64 *The US Nuclear Energy Enterprise: A Key National Security Enabler*, Energy Futures Initiative, August 2017, https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/59947949f43b55af66b0684b/1502902604749/EFI+nuclear+paper+17+Aug+2017.pdf.

Nuclear reactor operators man the control room as they await the arrival of US President George W. Bush at Browns Ferry Nuclear Plant in Athens, Alabama, June 21, 2007. Source: REUTERS/Kevin Lamarque.

DISCUSSION:

- The Task Force advocates action at both the federal and state level to avoid premature closure of nuclear plants while ensuring strong safety standards are met. Measures to create a more level playing field should be considered as to their costs and benefits. These measures include adoption of broad clean-energy standards that add nuclear energy to state renewable portfolio standards; carbon fees or dividends; and reform of regional transmission organization and independent system operator (RTO/ISO) markets to value long-term, reliable, baseload power. The reform of electricity markets is especially important and was supported in the DOE *Quadrennial Energy Review* and the 2016 DOE *Secretary of Energy Advisory Board Report*. The Task Force suggests the delinking of coal and nuclear in the administration's domestic electric-power approach given their very different operating characteristics and environmental and social impacts. Actions to support nuclear should be carefully crafted so as to avoid a repetition of the failed DOE Notice of Proposed Rulemaking to FERC in 2017.

CREATE A CONDUCIVE ENVIRONMENT FOR NEW TECHNOLOGIES

Improve and streamline the review and licensing process for new advanced reactors

ACTIONS:

- The executive branch should quickly implement the provisions of the recently approved Nuclear Energy Innovation and Modernization Act that directs the improvement in the NRC's capacities and licensing framework for advanced nuclear reactors and provides direct budgetary funding, including support for hiring and training staff to facilitate reviews and licensing of advanced reactor submissions.

- Congress and the NRC should consider further efforts to change the 90/10 fee structure for reviews to reduce these costs to developers.

- In adapting regulatory processes to the requirements of the new generation of reactors, the NRC should collaborate more closely with the Canadian, UK, Japanese, and South Korean nuclear regulators and work toward harmonization of regulatory processes.

- In order to invest in new reactor types, the federal government should support deployment of first-of-a-kind reactors in order to help drive down costs, as has been done with other technologies. An immediate opportunity is with micro reactors, where a joint DOD-DOE program is merited given the clear and direct government-use case.

RATIONALE:

- Regulatory review is a critical-path item in the achievement of early commercial demonstration goals. Although the NuScale review is proceeding on schedule, the process is lengthy and NuScale is estimated to have already invested between US$50 million and US$100 million thus far on regulatory issues, before even beginning commercial demonstration-unit construction. Although the NRC can rely on the national labs for technical support, it needs to enhance the expertise of its staff with specific knowledge of advanced and fast spectrum reactors. NRC and Canadian regulators do meet frequently and, given the strong commitments of the Canadian government and Ontario and New Brunswick utilities to nuclear power and SMR deployment, the harmonization of standards could help advance prospects for deployment in both countries.

DISCUSSION:

- Congress enacted NEIMA at the end of the last Congress, and President Trump approved it in mid-January. This action is an important milestone in authorizing funding for the NRC to address the challenge posed by the new reactor designs. With declining fees from utilities and their current limited interest in advanced nuclear technologies, this budgetary support is critical. The Task Force also concluded that the NRC should streamline its processes and learn from the Canadian stepwise licensing approach, which provides guidance to developers at early stages as to the general acceptability of a design and then input along the way as engineering design proceeds.

Increase US government support and private financing for advanced nuclear technology research, development, and commercial demonstration, as well as advanced manufacturing and construction

ACTIONS:

- DOE should formulate, as the industry has suggested, an initiative focused on reducing the costs of new nuclear reactors by adopting advanced manufacturing and construction methods, similar to the SunShot Initiative for solar energy.

- Congress and the administration should continue to support the Versatile Test Reactor (VTR) while industry develops a better business case for this huge investment.

- The administration and Congress should also implement new authorities for extended, long-term federal power purchase agreements for new nuclear reactors, as is proposed under the reintroduced Nuclear Energy Leadership Act.

- The administration should develop an estimate of the government cofinancing requirements to meet the goal of demonstrating two advanced reactors by 2025 and two or three more by 2035 as contemplated in the bill and develop a standardized loan guarantee framework for advanced reactor projects. Congress should plan for appropriate cofinancing to realize these early demonstration units.

- Continue and increase funding opportunties such as the recent iFOA (integrated form of agreement) to accelerate development of new and advanced nuclear technologies.

RATIONALE:

- Given the basic need for new reactors to compete successfully with energy technologies that are less costly, special attention needs to be given to the manufacturing and construction phase as well as to the basic reactor components, as the MIT study found. In addition, if the United States is to develop new fast spectrum reactors and compete with Russia and China (which already have such fast-spectrum test units), a facility is needed to allow testing of materials, fuels, reactor components under high temperatures, and different operating regimes. Experimental data from such testing are essential to validate performance and safety and for the NRC to license the new reactor systems. For promising systems, substantial government support for pioneering efforts will be critical. A well-designed loan-guarantee program, together with long-term PPAs, will accelerate the demonstration and overall commercialization process.

VTR DISCUSSION:

- Companies developing advanced reactors are already in discussion with manufacturers about requirements for modular production. DOE can do more to further the study of promising technologies. For the VTR, GEH was awarded a DOE contract to begin design work, which will incorporate design elements from the PRISM sodium-cooled system. The results of the project will help inform a DOE decision about whether to construct a sodium-cooled fast test reactor that could become operational as early as 2026. GEH and Bechtel National Inc., a unit of Bechtel Corp., will advance the design and cost estimates. The cost of a full VTR will be very expensive—as much as US$3.5 billion—but Russia and China have established and are continuing to develop a fast neutron reactor R&D capacity that may further advance their technological position in the future. The proposed Nuclear Energy Leadership Act would direct DOE to construct the VTR, but full funding would be a challenge and the business case and the budgetary trade-offs need to be carefully reviewed.

FEDERAL PURCHASING AGREEMENT DISCUSSION:

- Current law limits federal power purchase agreements to ten years. Nuclear projects require longer-term agreements to recover costs, and the proposed legislation extends the maximum length of federal power purchase agreements to up to forty years. In addition, DOE, as it has done in other energy fields, should work with industry to develop a loan-guarantee approach that would provide greater certainty to developers and investors.

Further the development of HALEU fuel production and fabrication capacity

ACTIONS:

- The United States should expand on its initial efforts to develop a US origin HALEU production and fuel-fabrication capacity and increase DOE funding.
- DOE and the NRC should mount an effort to develop the technology and regulatory framework for the transportation of HALEU fuels.

RATIONALE:

- The United States does not currently have a US origin enrichment capacity to produce HALEU fuels. Most fast spectrum reactors and HTGRs will require HALEU fuels. It is therefore critical to develop both a HALEU production and fuel-fabrication capacity. Restoring US origin conversion and enrichment capability would not only support the development of advanced reactors but also would meet critical US national security requirements to have a US origin source of enriched uranium needed to meet long-term needs for tritium utilized in the US nuclear arsenal and for highly enriched uranium required to fuel the nuclear fleet of the US Navy. It would also help reclaim lost US influence on nonproliferation matters. Since these domestic conversion and enrichment capabilities will be needed for national security independent of the need for HALEU, investing in domestic HALEU production with US technologies could solve two problems at once.

DISCUSSION:

- DOE has been pursuing a variety of efforts to develop HALEU capacity to support the development of advanced nuclear reactors that require fuels with a higher level of enriched uranium (up to 20 percent U-235). DOE's Idaho National Laboratory could quickly move to produce some suitable HALEU fuel, and DOE has received US$20 million in FY 2019 to begin processing naval waste into fuel. DOE also recently announced plans to award a contract to American Centrifuge Operating LLC (ACO), a subsidiary of Centrus Energy, for the construction by 2020 of a sixteen-centrifuge cascade machine that would produce a small amount of HALEU for use in research and development efforts. DOE has also been conducting an environmental assessment on the impact of using DOE-owned HALEU at the Idaho National Laboratory for fabricating fuel for use by companies developing new advanced reactors. While this is a helpful action, the proposed process in Idaho may result in HALEU that contains residual radionuclide components that may not be acceptable for some advanced reactor designs. Hence, the pursuit of multiple sources of HALEU is vital in ensuring a sufficient supply of this material for the developing advanced reactor community. On a related note, X-Energy and Centrus, which are collaborating on the design of a TRISO-X Fuel Fabrication Facility, are developing a HALEU fuel-fabrication capacity. The proposed Nuclear Energy Leadership Act includes a provision that would make a minimum account of HALEU available to US advanced-reactor development from DOE stockpiles.

ENCOURAGE AND FACILITATE EXPORTS

Provide competitive US government financial support for US nuclear technology exports

ACTIONS:

- Congress should reauthorize the Export-Import Bank before its charter expires in September 2019.
- In the reauthorization, the Export-Import Bank lending authority should be increased, terms should be reformed to compete better with Russian and Chinese funding, and approval processes should be streamlined.
- The new US International Development Finance Corporation should give strong support for energy and power projects and not discriminate against any specific energy technology.
- The administration should work with G7 and G20 countries to change the lending policies of international financial institutions such as the World Bank and permit consideration of nuclear power projects under certain circumstances.

RATIONALE:

- Competitive financing is vitally important to the US ability to pursue international nuclear power projects. The combination of expanded Export-Import Bank and USDFC funding could at least keep the United States in the running against the large state-funding efforts from Russia and China.

DISCUSSION:

- Since 2015, the Export-Import Bank has been limited to loans of only US$10 million due to the lack of a quorum on the Board of Directors. Although the Senate approved the full slate of Trump nominees on May 8, 2019, the Bank's charter expires, and must be renewed, by September 30, 2019. In contrast, Congress, with strong bipartisan support, approved the BUILD Act establishing the USDFC with expanded investment authority. It is scheduled to go into operation in September 2019. It incorporates OPIC, which in the past has given emphasis to energy-sector projects, but has tended to concentrate on renewable energy investments while specifically prohibiting nuclear projects in its Environmental and Social Policy. The World Bank and other international financial institutions, except the European Bank for Reconstruction and Development, have not permitted lending for nuclear projects, even though they have been strong advocates for low-carbon economies and emissions mitigation. These institutions could start considering nuclear projects and developing staff capabilities to help countries objectively consider the future role of nuclear power, especially SMRs. Developing countries are showing increased interest in SMR technology as part of their energy diversification and low-carbon transitions.

Maintain strong Section 123 agreements while streamlining the export-control process under 10 CFR part 810

ACTIONS:

The executive branch should:

- Implement the new approach in Section 3116 of the 2019 National Defense Authorization Act (Pub. L. No. 115-232) reforming the procedure for secretarial delegation of approval authority and establishing a process for expedited approvals of delegated exports of low significance.
- Expand existing "fast-track general authorization" to technologies of low proliferation risk.
- Revise the approach to information technology and publish written guidance on these issues, incorporating US Commerce Department approaches under the Export Administration Regulations (EAR).

- Clarify the applicability of 10 CFR 810.6(c) to any civilian nuclear-power facility in a country that has a voluntary offer safeguards agreement with the IAEA.

- Adopt rules for reexports and dual/multiple citizenship that conform with those adopted by the Commerce Department under the EAR.

- Formulate an approach that both maintains the stringent requirements of Section 123 agreements, which ensure adherence to effective materials control, monitoring, and nonproliferation standards pursuant to the Nuclear Non-Proliferation Act of 1978, but does not necessarily require prior agreement by the cooperating countries to refrain from developing enrichment or reprocessing technology.

- Test the approach recently advocated by Assistant Secretary of State Christopher Ford to pursue nuclear cooperation MOUs, in addition to and in advance of 123 agreements, with countries considering nuclear power to establish a framework for "making partner countries fully prepared to take advantage of the emerging technologies and coming innovations in reactor design and other areas that are being pioneered in the United States, and to do so under the highest standards of safety, security, and nonproliferation."[65]

RATIONALE:

- The US system of export controls is highly complex, inefficient, and time-consuming. The United States already has the most stringent export controls and nonproliferation conditions in the world; suggestions to make it still more restrictive than other supplier countries' conditions places US firms at an unfair and unnecessary disadvantage in pursuing foreign contracts.[66] Although the goal of preventing enrichment and reprocessing is important to US nonproliferation goals, the insistence that countries renounce these as a condition of cooperation may be counterproductive and drive countries into the hands of competitors who are willing to provide technology without making such demands. Current Section 123 agreements already uniquely require consent for the disposition of used fuel.[67] Most countries that are newly adopting nuclear power do not have the resources or needs for expensive enrichment and reprocessing technologies. Long-term, on-the-ground US engagement with such countries provides a more effective means of preventing misuse and diversion of sensitive fissile material than insisting on conditions that will simply be rejected and drive buyers to competitors with less-rigorous nonproliferation standards.

DISCUSSION:

- The export-control process is too lengthy and burdensome. The process and strict requirements of Section 123 put US industry at a competitive disadvantage. Proposed new conditions for US nuclear cooperation under Section 123, such as a requirement to forswear nuclear fuel-cycle activities, would likely prevent the conclusion of new agreements or renewal of expiring ones, and could isolate the United States from the future of nuclear commerce. In the case of the United Arab Emirates agreement, the United States took advantage of a prior UAE decision to forswear indigenous enrichment and reprocessing based on its own assessment of its national interests. All twenty-four of the United States' Section 123 agreements that are in force—with fifty-one governments or organizations—require US consent for enrichment and reprocessing of material subject to the agreements, but only two agreements require the partner to forswear enrichment and reprocessing altogether.

65 Dr. Christopher Ashley Ford, "A New Approach to Civil Nuclear Cooperation Policy," speech at the Hudson Institute, Washington, DC, February 26, 2019, https://www.state.gov/t/isn/rls/rm/2019/289727.htm.

66 See James A. Glasgow, Elina Teplinsky, and Stephen L. Markus, *Nuclear Export Controls: A Comparative Analysis of National Regimes for the Control of Nuclear Materials, Components and Technology*, Pillsbury, Winthrop, Shaw, and Pittman LLP and the Nuclear Energy Institute, October 2012, https://www.pillsburylaw.com/images/content/3/3/v2/332/NuclearExportControls.pdf.

67 Fred McGoldrick, *Nuclear Trade Controls: Minding the Gaps*, Center for Strategic and International Studies, January 2013, https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/130122_McGoldrick_NuclearTradeControls_Web.pdf.

Build an effective and adequately funded US government program for international nuclear cooperation and market development

ACTIONS:
Congress should authorize and increase funding for DOE, NRC, the State Department, USAID, and the Commerce Department for international nuclear energy cooperation and assistance programs that would:

- Develop new international standards for SMRs and advanced nuclear systems.
- Help build competent regulatory organizations and legal frameworks in countries looking to develop nuclear power.
- Assist countries in considering the role of nuclear power in their future electricity system development and investment plans and strategies.
- Conduct market assessments and feasibility studies.
- Carry out training and exchange programs to improve human and institutional knowledge of US technologies and companies.
- Collaborate with US allies in R&D areas and support the international efforts of US companies where feasible.

RATIONALE:
- If the United States is to compete in the future global nuclear market, it needs to develop a coordinated interagency program with adequate resources to expand US presence, target key countries for nuclear cooperation, and provide an effective package of energy technologies and financing to meet their energy-sector requirements.

DISCUSSION:
- Current US government international nuclear program funding is extremely limited, except in the nuclear materials safeguards area. At less than US$10 million per year (i.e., the DOE international nuclear budget was US$3 million in FY 2019 while the NRC international budget for both new reactors and operating reactors was US$4.6 million in FY 2019), it is miniscule compared with the estimated US$2.5 billion in US international energy cooperation and assistance programmed in FY 2016 (including the State Department, USAID, DOE, the Millennium Challenge Corporation, OPIC, and the Trade and Development Agency, but excluding the Export-Import Bank).[68] Existing DOE and NRC international programs should be evaluated as to their effectiveness and options for expansion formulated. Nuclear energy must be better integrated into the overall US foreign energy approach and engagement with foreign governments through US State Department economic commission and strategic partnerships and DOE dialogues on energy and cooperative mechanisms. The energy strategy requested by Congress under the Asia Reassurance Initiative Act should indicate funding levels required for an effective international nuclear program. The concept of nuclear cooperation memorandums of understanding mentioned above could also be incorporated into this new engagement.

Finally, the Task Force believes a strong commitment from President Trump and Congress to a whole-of-government approach is essential to implementing the above recommendations. The United States must bring together both domestic and foreign affairs agencies in this effort. Increasing White House capacity to both coordinate this initiative and integrate it with other energy and other strategic foreign policy initiatives, such as the Indo-Pacific Strategy, will be critically important. To elevate and better define this new effort, the Task Force suggests that the White House build and revitalize the interagency group convened following the June 2017 launch of the civilian nuclear review, with the strengthening of its capacity to address international nuclear leadership issues such as those raised in this report.

68 Robert F. Ichord Jr., "US International Energy Assistance and Cooperation: Has the Title V Objective Been Realized?," March 2018, Non-Proliferation Education Center, http://npolicy.org/Articles/Ichord_Final.pdf.

7 CONCLUSION

The United States stands at a critical junction in its approach to civilian nuclear power. Will the domestic nuclear industry be allowed to decline, or will the United States take up the challenge of developing a new generation of nuclear reactors that can restore its historical international leadership and serve to solve pressing global economic and environmental problems? The national security imperative is strong for ambitious action, and an enhanced, high-level government-private partnership is needed to respond to the challenge of Russian and Chinese investment in nuclear power and to maintain a technological edge. With the first US domestic commercial advanced reactors forecast to be completed around 2026, international commercial deployment should occur no later than 2030. Although Russia, China, South Korea, or others may deploy sooner, it is important from a long-term market perspective that the United States succeed in the early projects and develop market-leading technology in order to demonstrate that the nation can construct and operate these new systems in a safe, secure, timely, and affordable manner. The United States thus needs to build a new domestic nuclear base from which to pursue the promising future global market. US national and economic security depends on it.

Enrico Fermi Nuclear Power plant on Lake Erie, Rockwood, Michigan. May 2008. Source: James Marvin Phelps/Flickr.

APPENDIX 1

STATUS OF ADVANCED NUCLEAR REACTOR TECHNOLOGIES

There are different types of advanced nuclear reactors under development with different characteristics. This appendix draws heavily from the recent MIT Study and its Chapter 3 on Advanced Reactor Technology Evaluation.

DIFFERENT COOLANTS AND NEUTRON SPECTRUMS:

Advanced reactors can be characterized by their coolants and neutron spectrum:

- Water-cooled, thermal neutron reactors are termed SMRs, such as the light water reactor in NuScale's system;
- Helium-cooled thermal reactors are either high temperature (HTGR) or very high temperature systems (VHTR);
- Helium-cooled fast spectrum reactors are gas-cooled fast reactors (GFR);
- Liquid metal coolant reactors are all fast spectrum systems: sodium-cooled or lead-cooled fast reactors; and
- Molten salt-cooled reactors can be thermal spectrum fluoride-cooled high temperature reactors (FHR) or molten salt reactor—fluoride (MSR—fluoride); fast spectrum molten salt chloride reactors (MSR); or molten salt-fueled.

TEMPERATURE AND EFFICIENCY:

Helium, liquid metal, and molten salt reactors (HTGR, GFR, LFR, FHR, and MSR) reach higher temperatures (between 700°C and 950°C) and therefore can achieve higher thermal conversion efficiencies in the range of 40 percent to 50 percent, compared with 33 percent for water-cooled SMRs.

SAFETY FEATURES OF DIFFERENT DESIGNS:

The advanced fuel systems, as well as the new LWR SMRs, all embody "inherent and passive safety systems." The MIT evaluation analyzes these passive safety features for helium-cooled, liquid metal-cooled, and molten salt-cooled reactors as well as the extent these features have been demonstrated.

RESEARCH ON SAFETY AND OPERATIONAL ISSUES NEEDED:

Although some of the safety attributes of advanced reactors have been confirmed in test and demonstration plants, there remain a number of issues that need to be addressed in relation to the behavior and interaction of coolants, fuels, and materials. The operational aspects of these reactors are also critical, including: (a) refueling operations; (b) preventative and corrective maintenance of mechanical and electrical equipment, instrumentation and control, and chemical systems; (c) cleanup/recovery from minor spills and leaks; (d) inspection of key components/systems as required to meet regulatory requirements and standards; and (e) coolant sampling and routine radiological surveys around plant equipment.

Due to the many issues that need to be addressed and the question of whether sufficient public and private resources will be available, the time frame for commercial demonstration is hard to predict. The MIT evaluation estimates the following level of maturity of the non-LWR technologies:

- Lowest maturity: LFRs (nitride fuel), GFRs, MSR (fast) and MSR (thermal using salt other than FLiBe, a molten salt made from a mixture of lithium fluoride (LiF) and beryllium fluoride (BeF_2)
- Low to moderate maturity: Advanced SFRs, FHRs, MSRs (thermal using FLiBe), LFRs (oxide fuel), VHTRs (900°C outlet)
- Moderate to high maturity: Small conventional SMRs and modular HTGRs (750°C outlet)

It is possible that the first commercial deployment of the NuScale and other LWR SMR systems could occur before 2030, while HTGR and SFRs are more likely to be deployed around 2030; the remainder are expected after 2030.

Likely costs are also difficult to estimate at this point. The MIT study provides a highly qualified estimated overnight cost in the range of US$4,600 to US$5,400 per installed kW for initial units, which is somewhat above the costs of renewables in favorable locations but lower than third-generation Western nuclear units. Economic comparisons can be misleading, and a full life-cycle approach is needed since the new nuclear systems are designed for at least sixty-year lives, with operating efficiencies and capacity factors that are so much higher than renewables or gas.

The following table from the World Nuclear Association lists SMRs that are operating, under construction, and at various stages of development.

Small reactors operating

Name	Capacity	Type	Developer
CNP-300	300 MWe	PWR	SNERDI/CNNC, Pakistan & China
PHWR-220	PHWR-220	PHWR	NPCIL, India
EGP-6	11 MWe	LWGR	at Bilibino, Serbia (cogen, soon to retire)

Small reactor designs under construction

Name	Capacity	Type	Developer
KLT-40S	35 MWe	PWR	OKBM, Russia
RITM-200	50 MWe	integral PWR	OKBM, Russia
CAREM-25	27 MWe	integral PWR	CNEA & INVAP, Argentina
HTR-PM	2x250 MWt	HTR	INET, CNEC &Huaneng, China
ACPR50S	60 MWe	PWR	CGN, China

Small reactors for near-term deployment—development well advanced

Name	Capacity	Type	Developer
VBER-300	300 MWe	PWR	OKBM, Russia
NuScale	60 MWe	integral PWR	NuScale Power + Fluor, USA
SMR-160	160 MWe	PWR	Holtec, USA + SNC-Lavalin, Canada
ACP100	125 MWe	integral PWR	NPIC/CNPE/CNNC, China
SMART	100 MWe	integral PWR	KAERI, South Korea
PRISM	165 & 311 MWe	sodium FNR	GE Hitachi, USA
ARC-100	100 MWe	sodium FNR	ARC, USA
Integral MSR	192 MWe	MSR	Terrestrial Energy, Canada
BREST	300 MWt	lead FNR	RDIPE, Russia
SVBR-100	100 MWe	lead-Bi FNR	AKME-engineering, Russia
Xe-10	75 MWe	HTR	X-ENERGY, USA
TWR	400+ MWt	sodium FNR	TerraPower USA
BWRX-300	300 MWe	BWR	GE Hitachi, USA

Small reactor designs at earlier stages (or shelved)

Name	Capacity	Type	Developer
EM2	240 MWe	HTR, FNR	GENERAL ATOMICS (USA)
VK-300	300 MWe	BWR	NIKIET, Russia
AHWR-300 LEU	300 MWe	PHWR	BARC, India
CAP200	220 MWe	PWR	SNERDI, China
SNP350	350 MWe	PWR	SNERDI, China
ACPR100	140 MWe	integral PWR	CGN, China
IMR	350 MWe	integral PWR	Mitsubishi Heavy Ind, Japan
Westinghouse SMR	225 MWe	integral PWR	Westinghouse, USA
mPower	195 MWt	integral PWR	BWXT, USA
Rolls Royce SMR	220+ MWe	PWR	Rolls-Royce, UK
PBMR	165 MWe	HTR	PBMR, South Africa
HTMR-100	35 MW	HTR	HTMR Ltd, South Africa
MCFR	200+ MWt	MSR/FNR	TerraPower USA
TMSR-SF	100 MWe	MSR	SINAP, China
PB-FHR	100 MWt	MSR	UC Berkeley, USA
Moltex SSR	300 MWe	MSR/FNR	Moltex, Uk
Moltex SSR global	40 MWe	MSR	Moltex, UK
Thorcon MSR	250 MWe	MSR	Martingale, USA
Leadir-PS100	36 MWe	lead-cooled	Northern Nuclear, Canada

Very small reactor designs being developed (up to 25 MWe)

Name	Capacity	Type	Developer
U-battery	4 MWe	HTR	Urenco-led consortium, UK
Starcore	10-20 MWe	HTR	Starcore, Quebec
USNC MMR-5 & 10	5 MWe	HTR	UltraSafe Nuclear, USA
Gen4 module	25 MWe	Lead-bismuth FNR	Gen4 (Hyperion), USA
Sealer	3-10 MWe	Lead FNR	LeadCold, Sweden
eVinci	A few MWe		Westinghouse, USA
Holos Titan	13 MWe	Fuel Cartridges	Holos USA
Oklo			Oklo, USA

Abbreviations: **FNR** — Fast Neutron Reactor **PWR** — Pressurized Water Reactor
HTR — High Temperature Gas-Cooled Reactor **MSR** — Molten Salt Reactor

Chart source: World Nuclear Association, "Small Nuclear Power Reactors," last updated April 2019, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx.

APPENDIX 2

US EXPORT-CONTROL REGULATION FOR CHINA

(Issued October 11, 2018)

U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

U.S. Policy Framework on Civil Nuclear Cooperation with China

The licensing policy for ***technology exports*** under 10 CFR part 810 will be the following:

- Presumption of approval, contingent on non-derogatory end-user checks, for:
  - Amendments or extensions for existing authorizations for technology transferred prior to January 1, 2018. This presumption does not apply to light water SMRs and non-light water advanced reactors;
  - New technology transfers for operational safety contingent on satisfactory technical analysis on applicability to and benefit of operational safety and assessment of the end user; and,
  - New technology transfers required to support sale of an item that is commercially available.
- Presumption of denial for:
  - Exports related to light water SMRs;
  - Non-light water advanced reactors;
  - New technology transfers after January 1, 2018; and
  - Any transfer to China General Nuclear (CGN) and/or CGN subsidiaries or related entities.

For exports to CGN, subsidiaries and CGN-related entities there is a presumption of denial for new license applications and amendments or extensions to existing authorizations for exports of technology, equipment and components, and material.

The presumption of denial will be in place until the U.S. Government is satisfied with CGN engagement on its indictment with the U.S. legal system. If there are changes to this policy, we will communicate that to industry.

For exports to Non-CGN intermediaries and end users there will be a case-by-case review that will assess the risk of diversion to the military, the risk to U.S. national and economic security, and the risk inherent in the parties to the transaction.

This will be balanced against the economic and strategic benefits the export might provide, and, if approved, impose conditions to mitigate the risks.

Additionally, the export of source codes (that includes for computer programs, systems, or components), and certain engineering and manufacturing techniques will not be approved.

The licensing policy for exports of ***equipment and components*** will be the following.

- Presumption of approval, contingent on non-derogatory end-user checks, for requests:
  - Supporting continued projects such as construction of AP-1000, CAP-1000, and major identical components supporting CAP-1400 reactors (i.e., those that are similar in type and technology level to those commonly available); and,
  - For only pressurized light water SMR or non-light water advanced reactors with no technology transfer above and beyond installation and operation.
- Presumption of denial for requests:
  - Related to direct economic competition with the United States such as the Hualong One and unique U.S. components supporting CAP-1400 reactors; and
  - Any transfer to CGN and/or CGN subsidiaries or related entities.

The licensing policy for exports of ***material*** will be a presumption of approval for new license applications and amendments or extensions to existing authorizations, but a resumption of denial for any transfer to CGN and/or CGN subsidiaries or related entities.

Source: US Department of Energy, "PF 2019-03 U.S. Policy Framework on Civil Nuclear Cooperation with China," October 11, 2018, https://www.energy.gov/sites/prod/files/2018/10/f56/US_Policy_Framework_on_Civil_Nuclear_Cooperation_with_China.pdf.

APPENDIX 3

NUCLEAR ENERGY INSTITUTE TABLE ON ESTIMATED HALEU REQUIREMENTS

(Released July 5, 2018)

Estimated Annual Requirements for High-Assay Low-Enriched Uranium to 2030 (MTU/yr)

Company	A	B	C	D	E	F	G	H	Total	Cumulative
Enrichment Range	13-19.75%	19-19.75%	10-19.75%	15.5%	19.75% and 12.6%	19.75%	17.5%	14.4%		
Year										
2018	0.001			0.025					0.026	0.026
2019	0.006	1.5							1.506	1.532
2020	0.7	1.5	0.01						2.21	3.7
2021	0.7	2.5				1.0			4.2	7.9
2022	0.7	3.0							3.7	11.6
2023	0.7	3.5	1.1		13.5				18.8	30.4
2024	0.7	5.0	1.1			3.0		0.5	10.3	40.7
2025	0.7	6.0	1.8	0.4		3.0		0.5	12.4	53.1
2026	23.3	7.0	1.8	0.4		3.0	21.4	0.5	57.4	110.5
2027	35.0	9.0	1.8	0.9		5.0	21.4	0.5	73.6	184.1
2028	46.6	11.0	1.8	1.8		25.0	21.4	0.5	108.1	292.2
2029	58.3	13.0	1.8	1.8		15.0	21.4	0.5	111.8	404.0
2030	70.0	13.5	1.8	1.8	61.0	15.0	21.4	1.0	185.5	589.5

NOTES:

The material needs listed above are inmetric tons of uranium per year and are a fraction of the approximately 2000 MTU used annually by the existing fleet of reactors.

The year the material is needed is for fuel fabrication. Insertion in the reactoe and reactor operations will occur ina later year.

The material needs that are less than 1 MTU/year are for irradiation samples, lead test rods and lead fuel assemblies.

The material needs represent a few scenarios.

The deployment of advanced fuel in the existing fleet of light-water reactors.

The deployment of multiple reactors of the same design that will not rquire refueling before 2030.

The deployment of reactors that have annual refueling requirements.

These reactors include a range of sizes from a few Megawatt electric to 100s of Megawatt electric.

Source: Nuclear Energy Institute letter to US Secretary of Energy Rick Perry, “Need for High-Assay Low-Enriched Uranium,” July 5, 2018, https://www.nei.org/resources/letters-filings-comments/nei-letter-perry-need-haleu.

BIOGRAPHIES

Senator Mike Crapo, the senior United States senator for Idaho, was first elected to the Senate in 1998 and is currently serving his fourth term as US Senator. He became a member of the Senate Banking, Housing, and Urban Affairs Committee at the beginning of his service in 1999. In addition to serving as the chairman of the Banking Committee, Senator Crapo serves on the Finance Committee, Judiciary Committee and Budget Committee, and he has been selected to serve in various other leadership roles. Prior to his Senate service, Senator Crapo served three terms in the US House of Representatives and eight years in the Idaho State Senate, including as Senate president *pro tempore* from 1988-1992. A native of Idaho Falls, Idaho, and lifelong Idahoan, Senator Crapo graduated cum laude from Harvard Law School after receiving his undergraduate degree from Brigham Young University.

Senator Sheldon Whitehouse, a graduate of Yale University and the University of Virginia School of Law, served as Rhode Island's director of business regulation under Governor Sundlun before being recommended by Senator Pell and nominated by President Bill Clinton to be Rhode Island's United States attorney in 1994. Senator Whitehouse was elected attorney general of Rhode Island in 1998, a position in which he served until 2003. On November 7, 2006, he was elected to the United States Senate, where he is a member of the Budget Committee; the Environment and Public Works Committee (EPW); the Judiciary Committee; and the Finance Committee.

Dr. Robert F. Ichord, Jr. is a senior fellow with the Atlantic Council Global Energy Center and is CEO of Ichord Ventures LLC, a consulting company providing energy advisory services to both the private and public sectors. He has a distinguished forty-year career in the US government working on international energy security, development, and climate change issues. Dr. Ichord served from 2011 to 2015 as deputy assistant secretary for energy transformation in the State Department's Energy Resources Bureau, where he advanced US interests in sustainable energy development, electricity sector and market reform, nuclear safety, and renewable energy and energy efficiency.

Prior to State, Dr. Ichord managed and supported large energy assistance programs in Asia, Near East, Europe, and Eurasia for the US Agency for International Development, pioneering many innovative regulatory reform, utility and energy industry partnerships, and energy efficiency activities. He also served at the Energy Research and Development Administration and the Department of Energy from 1976 to 1979 as point person for energy and developing countries, representing the Department on several initiatives with the International Energy Agency. Dr. Ichord holds a BA from Denison University, an MALD from the Fletcher School of Law and Diplomacy at Tufts University, and a PhD in Political Science from the University of Hawaii, under a fellowship from the East-West Center Technology and Development Institute.

Randolph Bell is the director of the Atlantic Council's Global Energy Center (GEC), where he oversees the Center's research and programs in Washington and elsewhere, including the annual Atlantic Council Global Energy Forum in Abu Dhabi. He also serves as a co-director of the Atlantic Council's Task Force on US Nuclear Energy Leadership. He joined the Global Energy Center in 2017 as its director of business strategies. From 2014–2016, Mr. Bell led the launch of the Center in his capacity as director of business development and new ventures for the Atlantic Council.

From 2011–2014, Mr. Bell was managing director at the International Institute for Strategic Studies (IISS)–US, where in addition to holding overall responsibility for the operations and programming of the IISS's Washington, DC office he published extensively on African, South Asian, and cyber security issues. From 2010–2011, he was manager of national security at the Markle Foundation, where he worked on cyber security, intelligence community information sharing, and technology policy issues.

Mr. Bell has an MPP from the John F. Kennedy School of Government at Harvard University, where he was a Public Service and Belfer International and Global Affairs Fellow, and graduated *magna cum laude* from Harvard College.

Dr. Jennifer T. Gordon is the deputy director of the Atlantic Council Global Energy Center (GEC), where she has oversight of the Center's research and publications, including its reports, issue briefs, and EnergySource blog. From 2016-2018, Jennifer was a senior energy policy analyst at National Journal's Network Science Initiative, where she focused on clean energy policy and the intersection of energy with food and agricultural policy. Jennifer has served as a CIA political analyst and has also worked as a freelance writer and TV commentator.

Jennifer earned her PhD in 2014 from Harvard's History Department and Center for Middle Eastern Studies, after completing a dissertation on early Shia political thought. In 2004, Jennifer graduated *magna cum laude* from Wellesley College, with a major in Middle Eastern Studies and a minor in English.

Ellen Scholl is a senior fellow with, and formerly deputy director at, the Atlantic Council Global Energy Center (GEC). Ellen has worked on a range of energy issues throughout her career, most recently as Robert Bosch fellow at the German Institute for International and Security Affairs (SWP) and the Federation of German Industries (BDI). She also has over five years of energy-related legislative experience, having handled an energy portfolio as committee staff for the US Congress and Texas Senate. Her work on energy and geopolitics and energy governance has been published by SWP, and other work has appeared in the Berlin Policy Journal, Foreign Policy, and Lawfare, among others.

Ellen also worked on energy issues as a student fellow with the Robert S. Strauss Center on International Security and Law, and as a member of the inaugural cohort of the US Foreign Service Internship Program, during which she worked in the Bureau of European and Eurasian Affairs and at US Embassy Ankara. Ellen received her master's degree in global policy studies, with a certificate in Russian, East European, and Eurasian Studies, from the LBJ School of Public Affairs, where she was a Powers fellow. She earned a BA in humanities and government from the University of Texas at Austin, where she graduated with highest honors.

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