



The U.S. Nuclear Energy Enterprise: A Key National Security Enabler

A Special Report by the Energy Futures Initiative



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A Special Report from

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List of Acronyms and Abbreviations

AEA	Atomic Energy Act
ANS	American Nuclear Society
ASEE	American Society for Engineering Education
BLS	Bureau of Labor Statistics
BWXT	BWXT Technologies, Inc.
CCUS	carbon capture utilization and storage
CSIS	Center for Strategic and International Studies
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EPACT2005	Energy Policy Act of 2005
EU	European Union
FERC	Federal Energy Regulatory Commission

GW	gigawatt
G-7	Group of Seven (Canada, France, Germany, Italy, Japan, United Kingdom, U.S.)
HEU	highly enriched uranium
IEA	International Energy Agency
IEAE	International Atomic Energy Agency
IGA	intergovernmental agreement
INL	Idaho National Laboratory
JCPOA	Joint Comprehensive Plan of Action
LEU	low-enriched uranium
LWR	light-water reactor
MW	megawatt
MWe	megawatts electrical
MWh	megawatt hour
NNSA	National Nuclear Security Administration
NPCIL	Nuclear Power Corporation of India Ltd.
NPT	Nuclear Nonproliferation Treaty
NRC	U.S. Nuclear Regulatory Commission
OECD	Organization for Economic Cooperation and Development
PPA	power purchase agreement
PTC	Production Tax Credit
SEAB	Secretary of Energy Advisory Board
SMR	small modular reactor
R&D	research and development
RD&D	research, development and demonstration
UAE	United Arab Emirates
UNFQP	U.S.-Ukraine Nuclear Fuel Qualification Project
VVER	water-water energetic reactor
ZEC	Zero Emission Credit

Introduction

This report discusses the underpinnings for policies that would internalize the national security benefits of a robust nuclear enterprise, including generation from existing and new nuclear power plants and the associated and extensive supply chain. Both elements are under considerable stress and call for Federal response.

Specifically, this report analyzes the key role played by the U.S. nuclear energy enterprise in meeting three national security imperatives:

- maintaining U.S. leadership in ensuring nuclear non-proliferation;
- supporting the U.S. nuclear Navy; and
- supporting the global strategic stability and deterrence value of nuclear weapons.

The report's focus is the role of the nuclear energy enterprise as a key enabler of these objectives; it is not about the nuclear enterprise per se. The report includes an appendix that details the current state of the domestic nuclear energy enterprise for readers who want more information on this topic.

Report Summary

The U.S. electricity system is a lifeline network on which all other lifeline networks depend, including many that directly and indirectly support key components of our national security infrastructure. While most of the electricity system has been developed and is operated by the private sector, significant public obligations come into play for electricity service providers, such as the requirement to provide universal access to affordable and reliable electricity. These obligations necessarily come with significant public regulation that determines allowable cost recovery through customer rate setting.

Nuclear power has additional drivers for public support because of “externalities” to the prevailing methods for setting rates:

- *Climate change risk mitigation:* Nuclear power and renewables (hydro, wind, solar, geothermal,...) are “zero” greenhouse gas emissions technologies, with wind and solar significantly outpacing other renewable fuel sources for power generation capacity additions. Nuclear power has, by far, the highest capacity factor among all currently deployed generation technologies, while wind and solar have relatively low capacity factors and are highly variable; these features suggest different roles for grid operations.
- *Risk management:* Nuclear and renewables generation is characterized by relatively high capital costs when weighted by capacity factor and low to zero fuel cost; natural gas historically has been the opposite, with low capital cost and high and varying fuel costs. In recent years, low natural gas fuel prices have led to significant deployment of combined cycle gas capacity; last year, for the first time, natural gas surpassed coal as the most used fuel for power generation. While natural gas prices are projected to remain moderate for several years, the history of gas price volatility suggests that sound risk management would argue for a portfolio of generation technologies with fuel diversity in order to mitigate fuel price exposure in the long run.
- *National security:* Nuclear power and a robust associated supply chain (equipment, services, people) are intimately connected with U.S. leadership in global nuclear nonproliferation policy and norms and with the nation’s nuclear security capabilities.

The first two externalities – climate change risk mitigation and risk management through fuel diversity – are, in some locations, being taken into account, although policies and approaches are highly uneven and inadequate. Many states recognize the climate change benefits of existing nuclear power plants, although most states have renewable portfolio standards that credit the zero emissions characteristics of renewables only. There is considerable regulatory activity in developing rate structures that value grid services (capacity, storage...), but little activity for valuing fuel diversity and “baseload” services.

The national security imperatives of nuclear energy, however, are not addressed in state rate-making. This is understandable: national security policy is inherently Federal in nature. As such, the fundamental role of a robust nuclear energy sector in meeting national security imperatives must, in reality, be addressed by the Federal government.

This report discusses the underpinnings for policies that would internalize the national security benefits of a robust nuclear enterprise, both generation from existing and new nuclear power plants and the associated and extensive supply chain. Each of these dimensions are under considerable stress and call for Federal response.

In October 2016, then-Secretary Moniz delivered a presentation at the CSIS workshop “Nuclear Energy at a Crossroads.” He listed eight areas with important decisions to be taken within approximately five years that would play a crucial role in determining the trajectory of the American nuclear enterprise in the

long run. The first two were the fate of existing nuclear power plants and final resolution of cost, schedule and cost recovery performance for the four AP-1000 units under construction at two sites in the Southeast.

In just the ten months since that workshop, two nuclear utilities have announced the closure of three more units before the end of their current operating license period, state programs to provide Zero Emission Credits for existing nuclear plants in New York and Illinois moved ahead but are in litigation, and perhaps most significant, in the wake of significant cost and schedule overruns and Toshiba/Westinghouse financial travails, construction termination of two of the four new units was announced and the fate of the other two remains unresolved at the moment.

Meeting National Security Priorities Requires a Robust Nuclear Energy Industry. These trends, issues and developments provide the backdrop for our discussion of a robust U.S. nuclear energy sector as a key enabler of national security. This sector helps the U.S. military meet specific defense priorities, supports the implementation of U.S. nonproliferation policy, and is essential to the global projection of U.S. military capability. The flip side is that an eroding nuclear enterprise will compromise important nuclear security capabilities or make them more costly.

The Role of Nuclear Fuel Cycle Development Standards in Nuclear Nonproliferation. The U.S. initiated the era of nuclear energy. Since President Eisenhower's *Atoms for Peace* speech (1953), the subsequent establishment (1957) of the International Atomic Energy Agency (IAEA) and the entry into force (1970) of the Nuclear Nonproliferation Treaty (NPT), the United States has been the leader in setting the global standard for nuclear fuel cycle development consistent with nuclear nonproliferation objectives.

A pillar for this leadership role has been the Atomic Energy Act Section 123 requirements for bilateral agreements with countries that receive nuclear technology, services and/or know-how, supplemented by export licensing programs at the Nuclear Regulatory Commission (Part 110) and at the Department of Energy (Part 810) that regulate individual transactions within the 123 framework. The 123 agreements in many cases established nonproliferation benchmarks beyond the NPT requirements; U.S. leverage to do so was rooted in the historically unique capabilities in U.S. technology, services and know-how. While this supply chain remains strong, other countries with less stringent requirements have advanced their capabilities dramatically and are capturing significant global market share for new reactor construction.

The most obvious case in point is in the Middle East, where recent U.S. 123 negotiations with Egypt, Jordan and Saudi Arabia have been unsuccessful; all three countries have signed agreements with Russia for reactor construction and fuel supply. In addition, Russia has finished construction of Iran's operating reactor, is committed to additional reactor construction, and supplies Iran with nuclear fuel. Russia also has an agreement with Turkey.

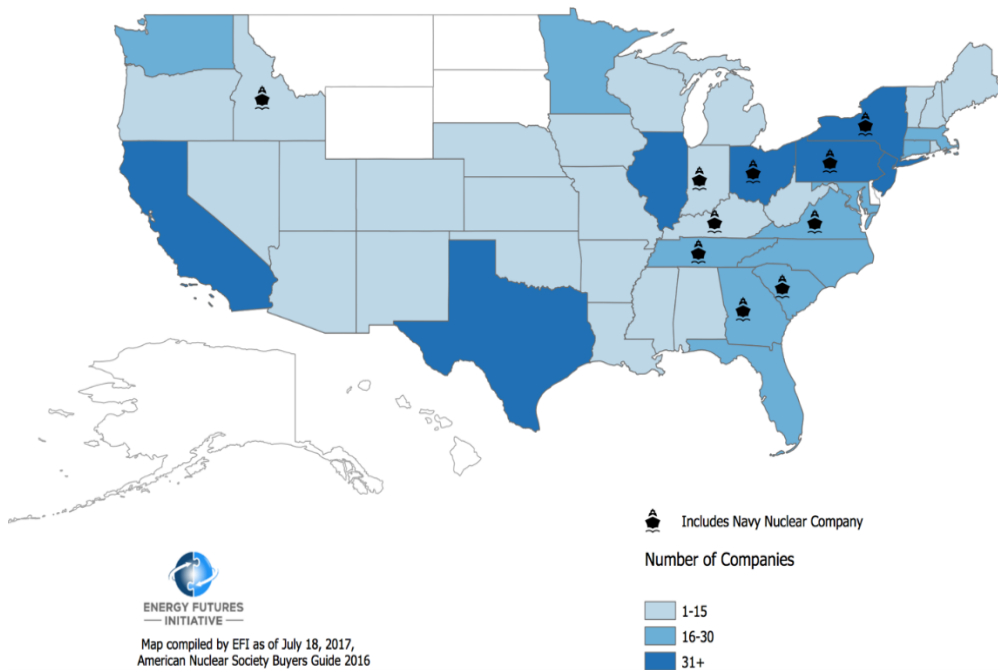
Even the UAE, with which the United States has a "gold standard" 123 agreement, chose South Korea as the developer of its first nuclear reactors. The dominant Russian presence in the Mideast nuclear power market does not augur well for U.S. national security objectives in the long term. A strong domestic nuclear enterprise will be necessary, perhaps not sufficient, to protect and advance U.S. national security equities as nuclear fuel cycles develop internationally in regions that historically have had little or no nuclear energy.

The U.S. Nuclear Navy Relies on a Robust Domestic Nuclear Energy Supply Chain. The Naval Nuclear Propulsion Program is comprised of military and civilian personnel who design, build, operate, maintain and manage the nearly one hundred reactors that power U.S. aircraft carriers and submarines and provide training and research services. The program is operated jointly by the Department of Energy and

the U.S. Navy. Nuclear reactors provide the Navy with the mobility, flexibility and endurance required to carry out its global mission. More powerful reactors are beginning to be employed on the new Ford class aircraft carriers and will enable the new Columbia class of submarines in the next decades.

Two important points must be made in this context. First, a strong domestic supply chain is needed to provide for nuclear Navy requirements. This supply chain has an inherent and very strong overlap with the commercial nuclear energy sector and has a strong presence in states with commercial nuclear power plants (see Figure S1, supply chain states including the Navy's). This supply chain for meeting the critical national security need for design and operation of Navy reactors includes a workforce trained in science and engineering, comprised of U.S. citizens who qualify for security clearances.

Figure S1. Commercial and U.S. Navy Supply Chain Companies by State



Second, the Navy will eventually need additional highly enriched uranium (HEU) to fuel its reactors for long intervals between refueling. Because of the national security use and the sensitivity of HEU production, the entire supply chain from uranium feed to the enrichment technology must be U.S. origin. There is currently no such domestic capability in the supply chain. The relatively lengthy time period required to stand up such a capability raises serious, near-term concerns about the U.S. capacity to meet this critical national security need.

Supporting the Global Strategic Stability and Deterrence Value of Nuclear Weapons. Even as we aspire to the eventual elimination of nuclear weapons, they are and will remain at the core of the United States' defense posture for the foreseeable future as a deterrent to the use of nuclear weapons against the U.S. and its allies. Simple arithmetic identifies the large Russian stockpile of nuclear weapons and their delivery systems as the dominant existential threat to the United States, underscoring the importance of nuclear weapons to global strategic stability and deterrence. The nuclear weapons stockpile requires a constant source of tritium (half life about 12.5 years), provided by irradiating special fuel rods in one or two commercial power reactors. As with the Navy HEU requirements, the tritium must be supplied from U.S. origin reactors using domestically produced LEU reactor fuel. Once again, we do not have the long-term capability to meet this need because of the absence of an enrichment facility using U.S.-origin technology. This is a glaring hole in the domestic nuclear supply chain, since the only enrichment facility in the United States today uses Urenco (European) technology to supply power reactor fuel.

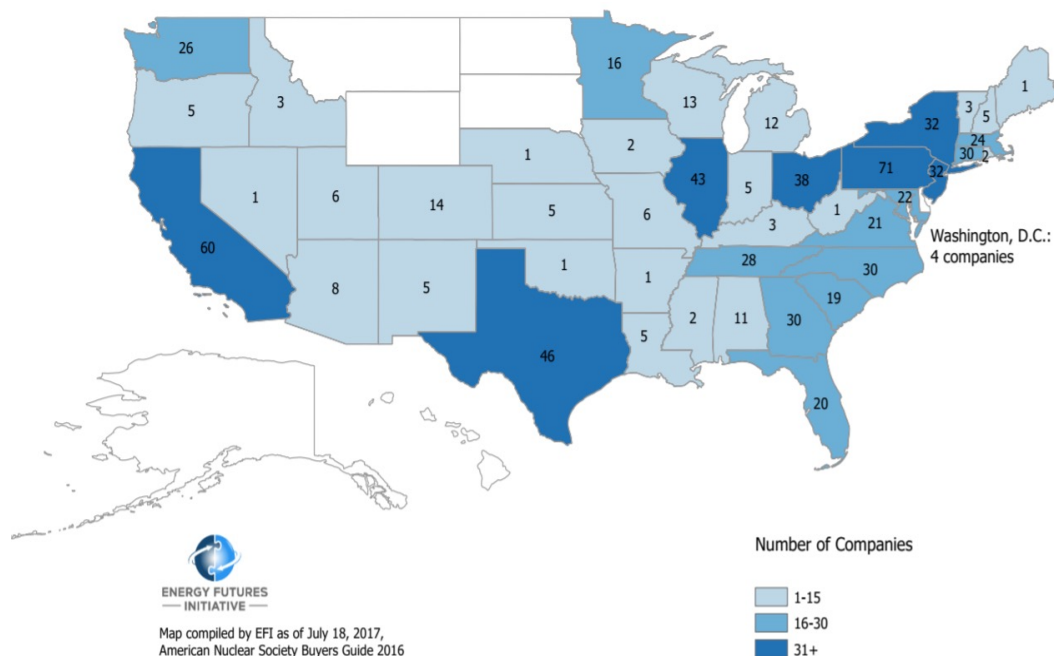
The U.S. Nuclear Energy Supply Chain. As noted, the nuclear supply chain plays a critical role in supporting U.S. nonproliferation and defense priorities. The United States has been a leader in "all things

nuclear” – nuclear energy, nuclear technology for medical and industrial uses, nuclear security – and this leadership is a continuing national security imperative, as discussed above.

However, the reality is that the supply chain, while extensive, has been sustained by the large deployed fleet (still by far the world’s largest). The dramatic reduction in new plant construction following the Three Mile Island incident in 1979 has taken its toll in a scaled back domestic manufacturing capability. The new builds in the Southeast promised a reversal, but as already discussed this advance has already been compromised and is at risk in its entirety. Further the early retirement of existing plants, with as much as another twenty gigawatts considered at risk by 2020, will also impact the supply chain, which already has significant gaps. Without a strong nuclear energy program, which is by far the largest nuclear activity in the United States, sustaining the supply chain for both civilian and national security objectives will be challenging.

Figure S2. Number of Nuclear Supply Chain Companies by State

A snapshot of the current domestic supply chain (Figure S2) shows more than 700 companies located in 44 states providing products or services in direct support of the U.S. nuclear energy industry. The top five states for nuclear supply chain companies are Pennsylvania, California, Texas, Illinois and Ohio. The geographic distribution of these companies tends to follow the location of operating commercial reactors, reinforcing the point about needing a strong nuclear power



sector. However, discussions with several U.S. companies point to the eroding supply chain, since many key components are no longer supplied domestically or have limited domestic fabrication capability; among them are: reactor pressure vessels; steam generators; pressurizers; main condensers and turbine generators; specialized valves; and passive residual heat removal.

Beyond these commercial supply chain gaps is another concern: the specialized national security requirements, such as domestic origin enrichment capability, that cannot be met with today’s supply chain. As noted, Figure S1 also includes the supply chain for the nuclear Navy; all of the companies in this chain also supply the commercial sector. BWXT, for example, provides materials and services to the commercial nuclear industry, owns four facilities that specialize in the design and manufacturing of large, heavy components for Navy reactors, and is one of two private firms licensed to possess and process HEU. There is obviously synergy among these various activities. A shrinking commercial enterprise will have long term spillover effects on the Navy supply chain, including by lessened enthusiasm among American citizens to pursue nuclear technology careers.

The picture is clear: a stabilized existing reactor fleet and new builds, perhaps incentivized by the favorable emissions characteristics of nuclear power, will be needed to rebuild a supply chain that will underpin both clean energy and national security success.

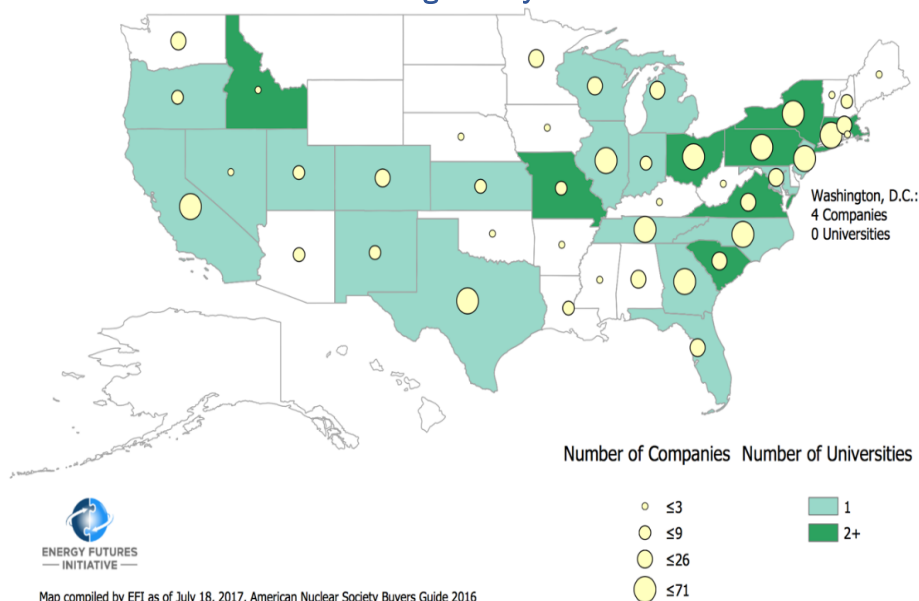
Nuclear Engineering Human Resource Pipeline. Following the Three Mile Island accident in 1979, new orders for nuclear reactors evaporated, although a number of reactors finished construction in the 1980's and 1990's. Not surprisingly, this had a dramatic impact on the human resource supply chain. The number of nuclear engineering graduates in the United States fell from 1408 to 345 students between 1979 and 2001.

Early in this century, the promise of a “nuclear renaissance” was embodied in the Energy Policy Act of 2005 that included the authorization of loan guarantees and of nuclear energy research and education program expansion, standby insurance and production tax credits for new plant construction. Announcements of planned new commercial nuclear power plant builds, combined with procurement

actions for next generation Navy nuclear submarines and aircraft carriers, gave a boost to educational programs. Several universities reestablished nuclear engineering educational programs and total enrollments and graduates steadily increased over the decade. These actions demonstrated that colleges and universities and students are quite responsive (with relatively short time delays) to changes in the nuclear energy marketplace. This progress is now at risk.

Also, there is a clear correlation between the location of nuclear engineering educational programs and nuclear supply chain companies (Figure S3). For

Figure S3. Nuclear Supply Chain Companies and Nuclear Engineering Programs by State



example, New York and Ohio have the most higher education nuclear engineering programs; each state also has more than thirty supply chain companies.

If, however, the future of nuclear power is not robust and the nuclear enterprise further weakens, nuclear engineering and other related disciplines are likely to constrict once again. At a minimum, high quality U.S university programs are likely to tip more towards international students coming from countries with expanding nuclear prospects, which will further dilute the pool of American nationals who can fill national security roles. Retirements are also a significant concern. The Nuclear Energy Institute reports that the nuclear power sector will soon lose 25,000 skilled workers to retirement.

Clearly, without a vibrant nuclear enterprise, it will be difficult to attract the talented scientists and engineers needed to support both commercial and national security needs for decades to come.

The U.S. Nuclear Energy Enterprise as A Key National Security Enabler: Considerations for Policymakers

The analysis suggests that the imperatives of global climate change, collective energy security, balance of trade and U.S. national security require a viable domestic commercial nuclear power industry, including a robust supply chain of technology, services and human resources. Recent events and future trends point in the opposite direction: commercial reactors are shutting down, new builds are struggling, the supply chain is at risk, and it is likely that the educational pipeline will negatively respond to these challenges.

National security is an inherently Federal responsibility. Externalities such as climate change and fuel diversity, although not yet adequately accounted for, may be partly taken into account in state level policy and regulatory actions. It is unrealistic, however, to anticipate state or regional level internalization of the national security benefits of a strong nuclear enterprise. In this context, we close with a summary of issues that need to be taken up at the Federal policy and regulatory level, including through possible statutory changes or fixes that would require Congressional action.

The U.S. Nuclear Energy Enterprise: Considerations for Policymakers

It is essential that policymakers recognize that a robust nuclear energy enterprise is a key enabler of the Nation's nonproliferation goals, and that it supports both the fleet modernization plans of the U.S. Navy, as well as the global strategic stability and deterrence value of nuclear weapons. To ensure that these issues and concerns are addressed going forward, the Federal government could:

- ✓ make maximum flexible use of its existing resources and capabilities, including credit support, tax incentives and federal siting and/or purchase power agreements, to bolster support for current new builds and to encourage additional new builds. This could include legislative action where necessary, to extend the availability of the current PTC and the DOE Title XVII loan guarantee program.
- ✓ work with states to harmonize federal and state policies affecting the design of organized electricity markets to appropriately value attributes of nuclear electricity including supply diversity.
- ✓ direct FERC to place greater emphasis on the national security importance of nuclear power and its associated supply chain.
- ✓ foster the organization of a broad-based consortium of nuclear supply chain companies, power generation companies, financing institutions and other appropriate entities to share the risk and benefits of additional new builds domestically, and a competitive offering internationally of new commercial nuclear power plants. The federal government should make maximum flexible use of existing resources and capabilities, including export financing assistance, as an inducement for formation of the consortium.
- ✓ expand and accelerate support for RD&D for a new generation of advanced nuclear reactor technologies. The program should be fully competitive, stage-gated and cost-shared. The 2016 SEAB Task Force report provides a good template. The initial phase of technology development, engineering and systems analysis and conceptual design should be funded at a level of about \$2 billion over the next 5 years.
- ✓ maintain and expand current programs to provide support for nuclear engineering education, including fellowships as well as training grants targeted to key occupational needs.
- ✓ regain U.S. leverage in using 123 Agreements to advance nuclear nonproliferation objectives by developing more flexible approaches for negotiating future agreements.

The U.S. Nuclear Energy Enterprise: A Key National Security Enabler

Full Report

In 2013, the Center for Strategic and International Studies (CSIS) convened a special task force that articulated the rationale on the linkage of the U.S. commercial nuclear industry and national security. That report, *Ensuring Leadership in Nuclear Energy: A National Security Imperative*¹, provided an initial articulation of the national security rationale for a robust domestic commercial nuclear industry sector.

This study elaborates, updates and amplifies that discussion. Specifically, this report highlights the key role that a robust nuclear energy sector and supply chain plays in meeting U.S. national security imperatives. It addresses the geopolitical concern of diminishing global market share for U.S. companies and the impact on nonproliferation objectives.

In addition, it takes a more detailed snapshot of the current domestic nuclear market supply chain, the erosion of capability to supply the domestic commercial nuclear power market, and the relationship between commercial supply chain and support of the U.S. nuclear Navy program. Finally, the report looks at the issue of the educational pipeline providing the next generation of nuclear scientists and engineers to serve both domestic commercial industry and U.S. government nuclear programs.

U.S. Nuclear Energy Policy Framework and National Security Issues

On October 26, 2016, then Secretary of Energy Ernest Moniz addressed a workshop at CSIS entitled “Nuclear Energy at a Crossroads.” His presentation outlined eight issues, trends, or developments that will shape the future of nuclear energy, each requiring that important decisions be taken over the next five years:

1. The prospects for *existing* nuclear power plants and the associated implications for carbon emissions;
2. Final resolution of cost, schedule, performance and cost recovery for the four new nuclear power units under construction at two plant sites in the Southeast;
3. The schedule of capital planning decisions for many utilities that reflect a second round of nuclear plant license extensions from 60 to 80 years, absent which there will be a large wave of retirements after 2030 and a concomitant need for clean replacement power;
4. Valuation of various grid services (fuel diversity, capacity, storage and others) with major implications for the need for additional new nuclear power generation as part of a portfolio for a future reliable, resilient, decarbonized electricity system;

¹ www.csis.org/

5. The ongoing need to address spent fuel management (including moving ahead with consolidated storage), which continues to pose headwinds for many decisions in the nuclear space;
6. The need to maintain and strengthen the U.S. commercial nuclear enterprise as an essential pillar of U.S. nonproliferation and national security policy;
7. Development and deployment of small modular reactors (SMRs), and specifically, the need for a better understanding of the cost and performance parameters in the real world; and
8. Establishment of a robust RD&D program for advanced reactor technologies in the context of an expanded “all of the above” commitment to clean energy innovation.

In the ten months since this workshop, the “crossroads” metaphor has taken on even more meaning. In the intervening period:

- Two nuclear utilities have announced closures of three more nuclear power plant units before the end of their current operating license period;
- State programs to provide Zero Emission Credits (ZECs) for existing nuclear plants in Illinois and in New York moved ahead but are in litigation;
- There has been virtually no progress on resolution of the spent fuel issue, while the Government has made payments from the Judgment Fund in the range of \$600-700 million in just this past 10-month period;
- Funding support for the next generation of light water reactor based small modular reactors (SMRs) and for other key elements of the nuclear energy innovation agenda, including development of accident tolerant fuels, life extension and non-LWR advanced reactor R&D, is in question;
- The DOE Title XVII loan guarantee program authority for innovative nuclear energy technologies is targeted for rescission;
- Delays in the construction of new nuclear power plants has endangered the production tax credit program. The House of Representatives has passed legislation to extend the nuclear production tax credit beyond the sunset date authorized in the Energy Policy Act of 2005, but corresponding Senate action is unclear;
- The FERC held a technical workshop on electricity capacity market issues, including how to reconcile federal and state requirements affecting electricity supply mix in organized markets, but any federal action has been held up due to lack of a quorum at the Commission; and
- In the wake of Toshiba/Westinghouse financial difficulties, construction termination of two of the four new GW-scale reactor builds was announced last week by their owners, Santee Cooper and SCANA. The Vogtle project is the sole reactor build carrying the flag of the “nuclear renaissance,” and its future is being evaluated.

These setbacks notwithstanding, the existing nuclear fleet remains the Nation’s largest source of carbon-free electricity; meeting key mid-century greenhouse gas emission targets will be significantly more challenging without existing and new nuclear power plants. All indications suggest that the world is committed to a low carbon economy.

Decarbonizing the electricity system is necessary to meet economy-wide low carbon goals. This means that growing electrification of other sectors will take on even greater significance in the years and decades ahead. In this context, the trajectory for nuclear power is central to the discussion.

The importance of this critical contribution of the nuclear fleet has been further elevated by the Administration’s announced intention to withdraw the United States from the Paris Climate Agreement and the subsequent announcement by cities, states, universities and businesses that they will strive to

meet climate goals absent federal leadership. These subnational efforts will require all available tools to meet mid-century targets.

While the public policy debate has been principally focused on the environmental attributes of commercial nuclear energy, Secretary Moniz advanced two other bases for public support of nuclear power in his 2016 remarks. One stems from fuel diversity. While nuclear and renewables are essentially “high capital cost, low operating cost” (weighted for capacity factor) technologies, natural gas combined cycle generation is a low capital cost technology with significant fuel cost exposure. The recent history of low natural gas prices (contrasted with very high prices at the turn of the century) has been the principal driver in the expanded use of natural gas in electricity generation, last year surpassing coal as the largest fuel source for power generation; this fuel switching has made a significant contribution to carbon dioxide emissions reductions. While further growth in natural gas market share is expected and welcomed if natural gas prices remain low, an elementary and robust risk management strategy suggests that a fuel-diverse generation portfolio that includes nuclear and renewables is in the public interest, especially in a low carbon environment.

The third driver of public support for nuclear energy and a strong nuclear enterprise is its role in collective energy security and national security. The critical role played by a robust nuclear power sector in both our energy and national security policy frameworks has received inadequate attention in the public debates on electricity, fuel diversity, and energy innovation. This essential role is the focus of this paper.

Energy security has been defined by the International Energy Agency as “the uninterrupted availability of energy sources at an affordable price.”² Long-term energy security deals with long term investments in energy assets consistent with economic developments and sustainable environmental needs. The concept of energy security has evolved from this simple statement, with the most recent formulation consisting of seven principles put forward by the G-7 Energy Ministers in Rome in May 2014 and subsequently adopted by the Leaders at the G-7 Summit.³ Three of these principles are directly relevant to nuclear energy:

- Diversification of energy fuels, sources and routes, and encouragement of indigenous sources of supply;
- Reducing our greenhouse gas emissions, and accelerating the transition to a low carbon economy, as a key contributor to enduring energy security; and
- Promoting deployment of clean and sustainable energy technologies and investment in research and innovation.

The G-7 Energy Security principles follow from an overarching statement that energy security is a collective responsibility among allies and friends, since the energy insecurity of any single partner can influence geopolitical considerations for all. This is especially true for the United States given its special responsibilities in many parts of the world.

The IEA provided further elaboration on the concept of electricity security, stating that the overarching principle of electricity security is to “...ensure enough power system flexibility to cope with variations of demand and generation availability while still reliably delivering power.”⁴ There are many analyses of the potential for further expansion of variable renewable electricity generation, either at utility scale or as distributed generation sources. All credible analyses however, especially in the context of the three G7

² <https://www.iea.org/topics/energysecurity/subtopics/whatisenergysecurity/>

³ http://eurpoa.eu/rapid/press-release_IP-14-530_en.htm

⁴ IEA Note on Electricity Security for the G7, March 2, 2016.

principles highlighted above, also include some level of bulk electricity generation capable of operating at high capacity factors – i.e. nuclear power, coal with CCUS, utility scale storage for significant time periods. Of these, only nuclear is deployed at large scale today.

The National Security imperative should be another key dimension of domestic nuclear energy policy. A vibrant domestic nuclear energy industry, including a healthy supply chain and sustained pipeline of highly trained nuclear scientists and engineers, is essential for the achievement of U.S. national security objectives.

Nuclear Fuel Cycle Development and Nuclear Nonproliferation. The United States initiated the era of nuclear energy and, since President Eisenhower’s Atoms for Peace speech (1953) and the subsequent establishment (1957) of the International Atomic Energy Agency (IAEA) and entry into force (1970) of the Nuclear Nonproliferation Treaty (NPT), has been the leader in setting the global standard for nuclear fuel cycle development consistent with nonproliferation objectives.

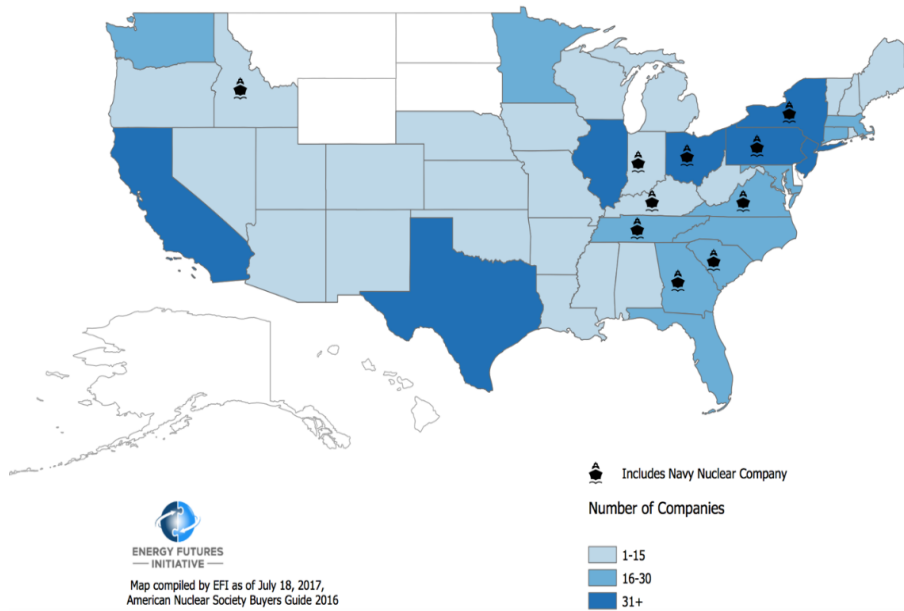
A pillar for doing so lies with Atomic Energy Act Section 123 requirements for bilateral agreements with countries that receive nuclear technology, services and/or know-how, supplemented by export licensing programs at the Nuclear Regulatory Commission (Part 110) and at the Department of Energy (Part 810) that regulate individual transactions within the 123 framework. The 123 agreements in many cases established nonproliferation benchmarks beyond the NPT requirements, and U.S. leverage to do so was rooted in the historically unique capabilities in U.S. technology, services and know-how.

While this supply chain remains strong, the reality is that other countries with less stringent requirements have advanced their capabilities dramatically and are capturing significant market share for new reactor construction globally. The most obvious case in point is in the Middle East, where recent U.S. 123 negotiations with Egypt, Jordan and Saudi Arabia have been unsuccessful. All three countries have signed agreements with Russia for reactor construction and fuel supply. In addition, Russia has finished construction of Iran’s operating reactor, is committed to further construction, and supplies fuel. Russia also has an agreement with Turkey.

Even the UAE, with which the U.S. has a “gold standard” 123 agreement, chose South Korea as the developer of its first nuclear reactors. The dominant Russian presence in the Middle East nuclear power market does not augur well for U.S. national security objectives in the long term. A strong domestic nuclear enterprise will be necessary, perhaps not sufficient, to protect and advance U.S. national security equities as nuclear fuel cycles develop internationally in regions that historically have had little or no nuclear energy.

Supporting The U.S. Nuclear Navy. The Naval Nuclear Propulsion Program is comprised of military and civilian personnel who design, build, operate, maintain and manage the nearly one hundred reactors that power U.S. aircraft carriers and submarines and provide training and research services. The program is operated jointly by the Department of Energy and the U.S. Navy. Nuclear reactors provide the Navy with the mobility, flexibility and endurance required to carry out its global mission. New more powerful reactors are beginning to be employed on the new Ford class aircraft carriers and will enable the new Columbia class of submarines in the next decades. Two important points must be made in this context.

Figure 1. Commercial and U.S. Navy Supply Chain Companies by State



First, a strong domestic supply chain is needed to provide for nuclear Navy requirements. This supply chain has an inherent and very strong overlap with the commercial nuclear energy sector and has a strong presence in states with commercial nuclear power plants (Figure 1). This supply chain for meeting the critical national security need for design and operation of Navy reactors includes a workforce trained in science and engineering, comprised of U.S. citizens who qualify for security clearances.

Second, the Navy will eventually need additional highly enriched

uranium (HEU) to fuel its reactors for long intervals between refueling. Because of the national security use and the sensitivity of HEU production, the entire supply chain from uranium feed to the enrichment technology must be U.S. origin. There is currently no such domestic capability in the supply chain. The relatively lengthy time period required to stand up such a capability raises serious, near-term concerns about the U.S. capacity to meet this critical national security need. Serious consideration is being given to transitioning Navy fuel from HEU to LEU, but this will certainly take many decades for submarines and in any case the same enrichment technology requirements would apply to LEU used for this purpose.

Supporting the Global Strategic Stability and Deterrence Value of Nuclear Weapons. Even as we aspire to the eventual elimination of nuclear weapons, they are and will remain at the core of the U.S. defense posture for the foreseeable future as a deterrent to the use of nuclear weapons against the U.S. and its allies. Simple arithmetic identifies the large Russian stockpile of nuclear weapons and their delivery systems as the dominant existential threat to the U.S., underscoring the importance of nuclear weapons to global strategic stability and deterrence.

The nuclear weapons stockpile requires a constant source of tritium (half life about 12.5 years), provided by irradiating special fuel rods in one or two power reactors. As with the Navy HEU requirements, the tritium must be supplied from U.S. origin reactors using domestically produced LEU reactor fuel. Once again, we do not have the long-term capability to meet this need because of the absence of an enrichment facility using U.S.-origin technology. This is a glaring hole in the domestic nuclear supply chain, since the only enrichment facility in the U.S. today uses Urenco (European) technology to supply power reactor fuel.

Global Nuclear Power Developments and Nonproliferation Considerations

A robust U.S. nuclear technology and services supply chain is clearly very important for American national security, and ultimately the scope and health of that supply chain depends on the operating reactor fleet and the new reactor builds as the biggest driver of commercial activity. It is undeniable that the domestic nuclear energy sector is in a precarious state, with numerous units shut down before the end of their operating licenses, another 20 GW considered at risk for premature closure by 2020, and the new builds in South Carolina and Georgia facing existential challenges because of cost and schedule overruns and

the Toshiba/Westinghouse financial situation (see Appendix A for an overview of the domestic nuclear energy situation).

Given this, the engagement of American companies in the global nuclear energy market takes on even greater significance. Such participation is linked both to the competitiveness of U.S. companies and to the conditions attached to commercial transactions by nonproliferation norms. Consequently we provide an extensive overview of the global nuclear energy market and the associated nonproliferation issues. The bottom line is that, while there is considerably more nuclear energy growth in some parts of the world, American company market share is not what it once was.

World electricity demand is projected to increase by nearly 70% between now and 2040. As more countries seek reliable and clean sources of electricity, forecasts suggest almost a doubling of worldwide electricity generation from nuclear fuel in that timeframe.⁵ Countries outside of the Organization for Economic Cooperation and Development (non-OECD) are expected to account for 86% of this increase in nuclear generation, led by China, Russia, and India.⁶

As of April 2017, there were 449 nuclear reactors generating electricity in 30 countries.⁷ Last year, with a combined capacity of 390 GW, the global nuclear fleet generated roughly 15% of the world's electricity. Five countries generated more than half of their electricity from nuclear, including France (72.3%), Slovakia (54.1%), Ukraine (52.3%), Belgium (51.7%), and Hungary (51.3%), while another eight relied on nuclear for at least one-quarter of their total power supply.⁸ Because nuclear power generation facilities are at the gigawatt-scale, new nuclear power development can account for a significant share of electricity generation in many smaller countries. The scale factor can pose issues for energy security if a country becomes overly dependent on nuclear generation, especially if there is only a single source providing operation and maintenance assistance and fuel cycle services.

Demand for nuclear power is growing in many regions of the world (Figure 2).⁹ Most of demand growth for nuclear energy is expected to come from developing countries, as populations grow, trends toward urbanization continue, and demand for clean energy resources increases. The growth of the global civilian nuclear market is valued between \$500 and \$740 billion over the next 10 years alone.¹⁰ By 2040, worldwide generation from nuclear sources is projected to nearly double to 4.5 trillion kilowatt-hours (kWh).¹¹ In 2016, worldwide reactor construction reached a 25-year high with an estimated 64 reactors—and a combined capacity of 61.5 GW—under construction in 15 countries (Figure 3).¹² More than half of the new reactors are being built in China, India, and Russia. In China alone, 21 GW of new capacity is expected by 2021—roughly the capacity of South Korea's current nuclear fleet.¹³ Of the 4.5 trillion kWh expected from nuclear sources worldwide in 2040, China is projected to produce more than 1.2 trillion kWh, which would make China the world's largest producer of nuclear power.¹⁴

⁵ <https://www.eia.gov/todayinenergy/detail.php?id=28132>

⁶ <https://www.eia.gov/todayinenergy/detail.php?id=28132>

⁷ <https://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx>

⁸ <https://www.nei.org/Knowledge-Center/Nuclear-Statistics/World-Statistics>

⁹ <https://www.iaea.org/pris/>

¹⁰ <https://energy.gov/sites/prod/files/2017/01/f34/Global%20Nuclear%20Markets--Market%20Arrangements%20and%20Service%20Agreements.pdf>

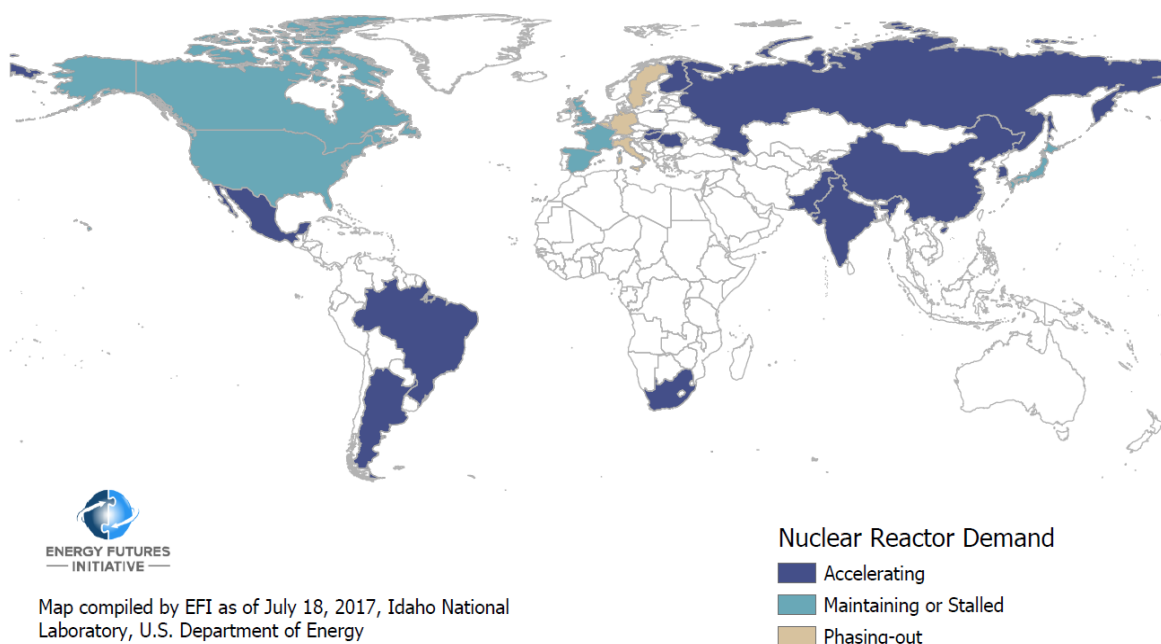
¹¹ <https://www.eia.gov/todayinenergy/detail.php?id=28132>

¹² <https://www.iaea.org/pris/>

¹³ <http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx>

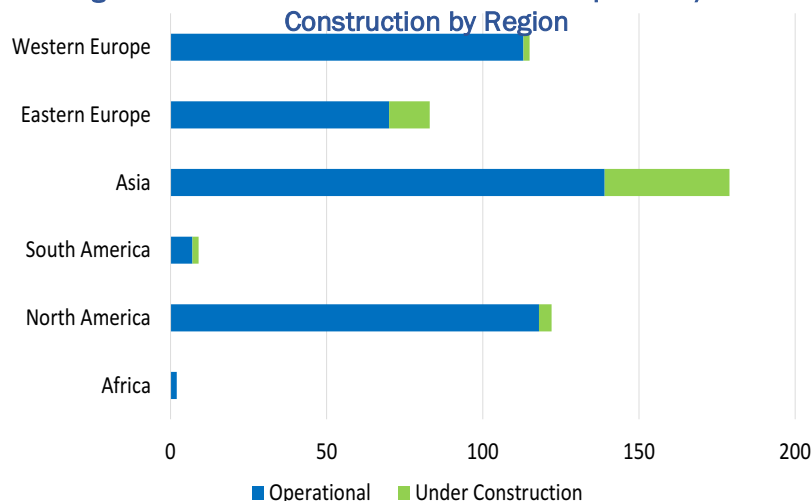
¹⁴ <https://www.eia.gov/todayinenergy/detail.php?id=28132>

Figure 2. Current Trends in Nuclear Energy Programs by Country



In many growth markets, including China, India, and Russia, domestic demand for nuclear power is increasingly met from indigenous supply chains that are expanding their capacity to design, build, and operate nuclear technologies and facilities. A common trend is to buy the initial reactor designs from foreign vendors, and as more units are constructed and the local content of sourced components increases, there is an effort to develop domestic designs.¹⁵

Figure 3. Number of Nuclear Reactors in Operation/Under Construction by Region



Countries actively building larger fleets of reactors have the most to gain through innovation of advanced designs. Multiple “fast reactors” are being developed in Russia (BN-800), China (CEFR), and India (Kalpakkam-1),¹⁶ which are a technological step beyond conventional light water power reactors. Fast reactors are designed to use fuel more effectively and efficiently. Meanwhile, research and development of small modular reactors (SMRs) is also proceeding. SMRs range in size up to 300 megawatts electrical (MWe), employ modular construction

techniques, ship major components from the factory to the plant site by rail or truck, and include designs

¹⁵ <https://energy.gov/sites/prod/files/2017/01/f34/Global%20Nuclear%20Markets--Market%20Arrangements%20and%20Service%20Agreements.pdf>

¹⁶ <https://energy.gov/sites/prod/files/2017/01/f34/Global%20Nuclear%20Markets--Market%20Arrangements%20and%20Service%20Agreements.pdf>

that simplify plant assembly.¹⁷ Argentina's CAREM prototype and the floating reactors in Russia that are under construction are recent developments, as well as demonstration projects planned in several countries, including the United States.¹⁸ U.S. efforts include an early site permit for an SMR at the Department of Energy's (DOE) Idaho National Laboratory (INL).¹⁹

The U.S. Role in the Global Nuclear Energy Market: Growing Challenges

The global nuclear energy market still relies on U.S. technologies and designs but our domestic nuclear sector is increasingly foreign-owned.²⁰ Many nuclear technologies can no longer be fabricated in the United States²¹, and as more reactors are expected to retire early in the coming decades this trend could accelerate.²²

To advance its collective energy security agenda and maintain its national security posture, the United States must continue to influence global nuclear priorities. This requires a robust domestic nuclear supply chain that can effectively compete in the global nuclear energy market, not only to capture a share of the benefits, but also to provide the leadership to ensure that nonproliferation and energy security objectives are not eroded.

History of U.S. Leadership in Global Nuclear Nonproliferation. Since building the world's first reactor, the global nuclear industry and the international regimes for safe, secure and proliferation-resistant peaceful uses of nuclear rested in U.S. leadership. The loss of domestic capacity is, however, likely to weaken the U.S. ability to influence international nuclear programs. As other countries strengthen their nuclear capabilities and market positions, they are more likely to successfully exert influence over global nuclear priorities and norms.

The United States established the framework for global commercial nuclear power development and led its early evolution. President Eisenhower's "Atoms for Peace" address to the United Nations in 1953 was the genesis for the creation of the International Atomic Energy Agency (IAEA), formed in response to the deep fears and expectations generated by the discoveries and diverse uses of nuclear technology. The Agency was established by unanimous resolution to provide assurance to the international community that countries are honoring their commitments to use nuclear materials and facilities exclusively for peaceful purposes.²³

The United States helped design and build a global framework to promote the development of the nuclear fuel cycle, as well as its safe and secure operation. The Treaty on the Nonproliferation of Nuclear Weapons (NPT), which entered into force in 1970, provided the foundation for current nonproliferation efforts.²⁴ The elements of the NPT constitute a bargain between the five declared nuclear weapons states—the United States, Russia, China, France, and the United Kingdom—and the non-nuclear weapons

¹⁷ <https://www.energy.gov/ne/nuclear-reactor-technologies/small-modular-nuclear-reactors>

¹⁸ <https://energy.gov/sites/prod/files/2017/01/f34/Global%20Nuclear%20Markets--Market%20Arrangements%20and%20Service%20Agreements.pdf>

¹⁹ <https://www.energy.gov/ne/articles/department-energy-continues-commitment-development-innovative-small-modular-reactors>

²⁰ https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/130719_Wallace_RestoringUSLeadershipNuclearEnergy_WEB.pdf

²¹ Southern Company, private communication

²² A further description of recent trends in the U.S. nuclear industry is provided in the Appendix

²³ <http://www.world-nuclear.org/information-library/safety-and-security/non-proliferation/safeguards-to-prevent-nuclear-proliferation.aspx>

²⁴ <https://www.un.org/disarmament/wmd/nuclear/npt/>

states. Countries without these weapons agreed to not acquire them; states with them agreed to pursue disarmament over time; and all states were permitted to access nuclear technology for peaceful purposes, under safeguards.²⁵ A total of 191 States have joined the NPT, more countries than any other arms agreement in history.

As noted by the Congressional Research Service,²⁶ the NPT itself was silent on how to assess compliance, how to resolve compliance disputes, and what procedures to follow in the event of non-compliance. There is no language on verification of the obligations in Articles I or II of the Treaty.²⁷ However, Article III does require states to accept nuclear safeguards, and with U.S. leadership, IAEA has developed and implemented a comprehensive program of safeguards that provides insight into NPT compliance. IAEA Safeguards, for example, are now embedded in legally binding agreements with partner countries, and provide the IAEA with the right and obligation to verify the status and safety of each country's nuclear material.²⁸ To date, the IAEA has concluded comprehensive safeguards agreements with 174 countries.

The United States historically has set the standard for strengthening verification and compliance with the NPT. The Nuclear Nonproliferation Act of 1978 amended the Atomic Energy Act (AEA) to put in place stringent requirements for the export of U.S. nuclear technology. Section 123 of the Act required that bilateral agreements, subject to Congressional review, be put in place prior to the export of nuclear materials, components or other technology know-how. Section 123 lists nine criteria that must be part of any such agreement.

The United States has Section 123 agreements in place with 24 countries, Euratom (which includes 27-member countries), the IAEA and Taiwan.²⁹ However, some nations that are accelerating nuclear programs, such as Mexico, do not have a Section 123 agreement with the United States, which closes the market to American businesses.³⁰ Mexico already has two reactors in operation, and multiple proposals for power uprates, as well as plans for new nuclear plants under consideration by the government.³¹

Further, the AEA established export licensing programs at the Nuclear Regulatory Commission (Part 110) and at the Department of Energy (Part 810) to regulate individual transactions within the 123 framework.

- DOE's responsibilities are administered through the DOE National Nuclear Security Administration (NNSA), which is responsible for maintaining a safe, secure, and effective nuclear deterrent; preventing, countering, and responding to the threats of nuclear proliferation and terrorism worldwide; and providing the U.S. Navy with nuclear propulsion.³² NNSA is engaged in over 130 countries worldwide to collaborate and build the capacity of foreign partners to prevent and respond to nuclear dangers. DOE/NNSA administers the Part 810 licensing program for authorizing the transfer of unclassified nuclear technology and assistance to foreign atomic energy activities within the United States and abroad. In 2015, DOE issued a comprehensive update to the final rule (Part 810) to clarify the activities and technologies that are within the scope, and to

²⁵ <http://www.nti.org/learn/treaties-and-regimes/treaty-on-the-non-proliferation-of-nuclear-weapons/>

²⁶ Congressional Research Service, "NPT Compliance: Issues and Views," April 26, 2005.

²⁷ Mason Willrich, *Non-Proliferation Treaty: Framework for Nuclear Arms Control*, The Michie Company, 1969.

²⁸ <https://www.iaea.org/topics/safeguards-agreements>

²⁹ <https://www.nei.org/Issues-Policy/Exports-Trade/Nuclear-Export-Agreements>

³⁰ <https://www.nei.org/Issues-Policy/Exports-Trade/Nuclear-Export-Agreements>

³¹ <https://cnpp.iaea.org/countryprofiles/Mexico/Mexico.htm>

³² https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/Final_Strategic_Vision_2015_9-3_screen%20quality.pdf

provide an affirmative list of destinations that are generally authorized to receive these transfers, among other enhancements.³³

- The Nuclear Regulatory Commission (NRC) is another key U.S. agency that engages multiple international organizations on nuclear safety and security. As a global leader in nuclear regulatory issues, the NRC works to develop codes and standards worldwide to ensure that regulatory environments are based on sound approaches.³⁴

Global Proliferation Concerns are Increasing. Over the last two decades, the global nuclear security environment has changed significantly. The global proliferation of technology continues to enhance the capacity of both state and non-state actors in many aspects of nuclear security. Several countries outside of the five declared nuclear weapons states have demonstrated growing and more-diverse capabilities that could support a nuclear weapons program and continue to produce fissile material. The importance of strong nonproliferation regimes and verification is increasingly clear. These trends will continue to challenge international capabilities.³⁵

The shift in the global nuclear energy market away from the United States and toward other regions of the world is exemplified by Saudi Arabia's actions in 2015. The failure to reach a 123 agreement, with the disagreement rooted in nonproliferation constraints on permitted nuclear activities, has (among several factors) led the Kingdom to turn to Russia. Saudi Arabia and Russia signed a cooperation agreement in 2015 without the restrictions of a U.S. "gold standard" 123 agreement and then agreed in principle to the construction of sixteen Russian reactors in Saudi Arabia over the next quarter century.

The UAE is already well along in the construction of four South Korean reactors. Iran is operating a reactor finished and fueled by Russia. Of course, Iran's nuclear program is moving ahead with significant constraints imposed by the JCPOA³⁶ over a fifteen-year period and with stringent verification requirements. If the U.S. nuclear enterprise is weakened over the next decade and beyond, the risk of a weakened nonproliferation regime is substantial and would pose a challenge for U.S. national security.

Weakening of the U.S. enterprise is not merely a possibility. Despite the fact that much of the global nuclear industry is based on designs and technologies developed in the United States, a significant number of firms in the U.S. nuclear supply chain are foreign-owned while important nuclear components are no longer fabricated domestically, including reactor pressure vessels, steam generators, and pressurizers, among many others.³⁷ The loss of these capabilities may have spillover effects in the U.S. ability to support global nuclear security and meet domestic national security requirements.

The Growing Influence of China, India, and Russia. China is one of the largest contributors to the shift in global nuclear energy markets. Rapid electricity demand and heavy reliance on fossil fuels has led to China's interest in increasing its clean energy sector.³⁸ China's 13th Five-Year Plan (2016-2020) expects an additional 770 GW of non-fossil generation by 2020 from renewable, hydro, natural gas, and nuclear sources, while coal production capacity will be limited to 1100 GW. Over that time period, nuclear generation capacity will increase by 70%.

³³ <https://nnsa.energy.gov/aboutus/ourprograms/nonproliferation-0/npac/policy/10cfr810>

³⁴ <https://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1614/v6/>

³⁵ https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/Final_Strategic_Vision_2015_9-3_screen%20quality.pdf

³⁶ Joint Comprehensive Action Plan. <https://www.state.gov/e/eb/tfs/spi/iran/jcpoa/>

³⁷ Southern Company, private communication

³⁸ <http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx>

Since 2010, China's nuclear reactor additions have accounted for more than 80% of new nuclear capacity across all non-OECD countries.³⁹ At China's current construction rate, one reactor is expected to come online every five months through 2025. Last year alone, China added 5 of the 10 new reactors that came online globally. As of 2016, China had 37 operating reactors, with a total capacity of 32.4 GW. Despite this sizable sector, nuclear generation accounted for only 3.56% of the total electricity supply. China has the youngest nuclear fleet compared to other major markets, with nearly all reactors entering into service since 2000. Of China's current nuclear fleet, the majority of reactors were designed and built in China.⁴⁰ In addition, there are two Canadian and two Russian reactors in operation. The majority of reactors under construction are the Chinese CPR-1000 model. Other models under construction include Westinghouse's AP-1000 and Russia's VVER. According to the most recent Five-Year Plan, China aims to become a reactor design exporter and compete alongside established companies for reactor tenders worldwide. Already there are two reactors being developed for export, the ACC1000 and the CAP1400, which is based on the Westinghouse AP1000.⁴¹

Another major player in the growth global nuclear power is India, where electricity demand has more than tripled in the last two decades.⁴² According to International Energy Agency (IEA) forecasts, to support its growing domestic electric power sector, India will need approximately \$1.6 trillion in investment in generation, transmission, and distribution by 2035. With 22 reactors in operation, India ranks seventh in the world in terms of the number of reactors and 13th in the world for electricity generated from nuclear. Another 6 reactors, totaling 3.9 GW of capacity, are currently under construction. By 2050, India plans for nuclear generation to represent 25% of the total electricity supply, up from the current level of near 3.4%.⁴³ Nearly all reactors in operation were designed and constructed by the Nuclear Power Corporation of India Ltd (NPCIL).

Russia is one of the world's largest producers of nuclear generation, as well as one of the largest suppliers of nuclear energy technology. Last year, Russia had 35 reactors with a combined capacity of over 26 GW.⁴⁴ Russia also has the second most reactors under construction (7) after China, representing an additional 5.52 GW of capacity. The significant growth in capacity—roughly one new large reactor per year through 2028—is due in part to capacity retirements over that time period.

Due to improvements in the nuclear supply chain and technology in Russia, reactor utilization capacity has increased drastically from around 60% in the 1990s to around 90% in recent years.⁴⁵ Its state-owned nuclear supplier, Rosatom, plans to boost the share of nuclear in electricity generating capacity from 17.1% to around 50% by 2050. As part of this long-term strategy, Russia hopes to move its nuclear fleet to fast reactors with a closed fuel cycle. According to Rosatom, the ultimate aim is to eliminate the production of very long-lived radioactive waste and to become the world's leaders in both fast reactor and closed fuel cycle technologies.⁴⁶

Russia exerts significant influence in global nuclear energy markets as a key supplier of nuclear equipment and services. Rosatom provides reactor design, construction, operation and maintenance services, as well as nuclear fuel sales and support. Since the end of 2013, foreign orders for Russian nuclear reactors have nearly doubled, from \$74 billion to \$133 billion. Much of this growth is attributed

³⁹ <https://www.eia.gov/todayinenergy/detail.php?id=28132>

⁴⁰ http://trade.gov/topmarkets/pdf/Civil_Nuclear_China.pdf

⁴¹ http://trade.gov/topmarkets/pdf/Civil_Nuclear_China.pdf

⁴² <http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/india.aspx>

⁴³ <https://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=IN>

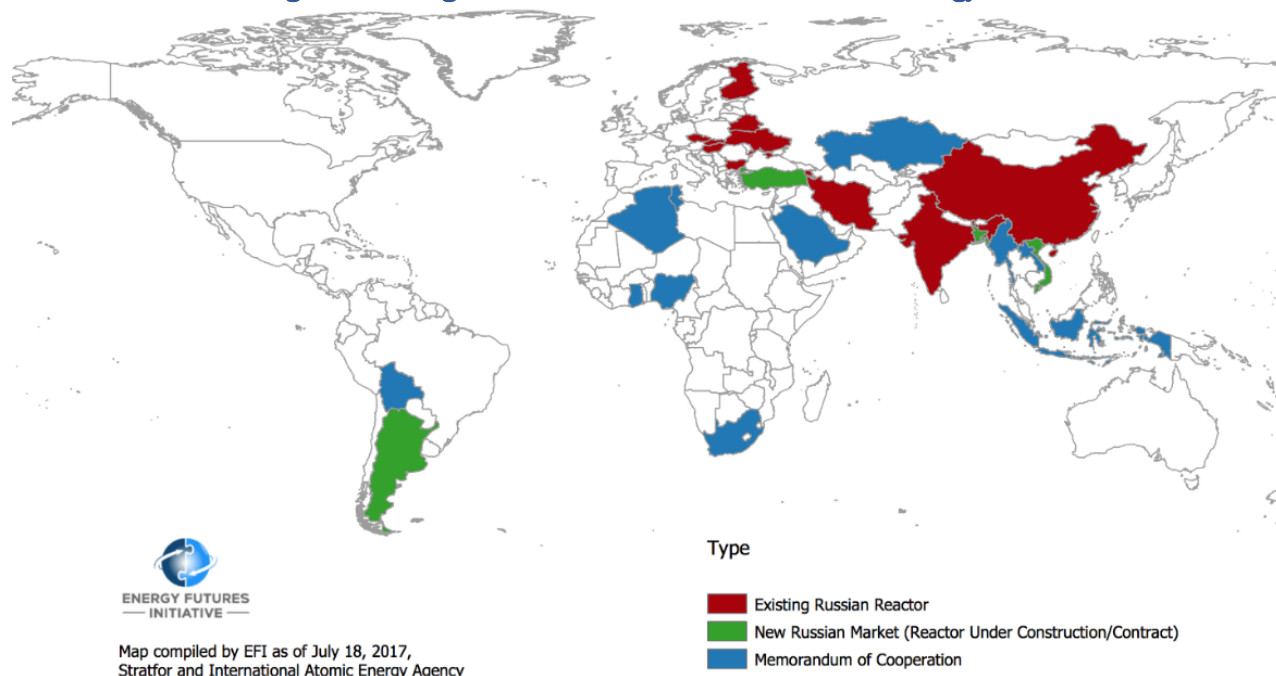
⁴⁴ <https://www.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx>

⁴⁵ <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx>

⁴⁶ <http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx>

to sales in Eastern Europe, where there are 13 new reactors under construction.⁴⁷ Rosatom also has deals in other markets, including the Middle East, Asia, South America, and Western Europe (Figure 4).⁴⁸ Overall, Russia has the world's largest portfolio of foreign reactor construction projects with 34 nuclear plants in 12 countries.⁴⁹

Figure 4. Foreign Markets for Russian Nuclear Technology and Services



A primary component of Russia's global nuclear energy strategy is the government's support for competitive financing and the readiness to take equity or even build, own, and operate (BOO) new facilities. Under BOO deals, Russia provides the facilities, nuclear fuel, fuel processing, education, and operations and maintenance to the purchasing country. These deals benefit Russia by allowing Rosatom to expand into new markets, with prospects for long-term returns based on the highly integrated nature of its supply chain.

These are the terms for Turkey's first reactors, which plan to come online by 2023.⁵⁰ According to the intergovernmental agreement (IGA), signed in 2010, affiliates of Russia's Rosatom will finance, design, build, and operate four VVER-1200 reactors, totaling 3.8 GW of capacity.⁵¹ Once operational, these reactors will represent 5% of Turkey's current installed generation capacity and could account for more than 6% of the country's total power supply.⁵² The Russian company will own a 99% stake in the project, and has pledged to fully finance the project at over \$20 billion.⁵³ In June 2017, it was reported that

⁴⁷ <https://www.iaea.org/PRIS/WorldStatistics/UnderConstructionReactorsByRegion.aspx>

⁴⁸ Analysis from Stratfor and IAEA <http://globalriskinsights.com/2015/10/russia-is-creating-a-global-nuclear-power-empire/>; http://www-pub.iaea.org/MTCD/Publications/PDF/RDS_2-37_web.pdf

⁴⁹ <http://www.rosatom.ru/en/about-us/>

⁵⁰ <http://www.enerji.gov.tr/en-US/Pages/Nuclear>

⁵¹ <https://www.energy.gov/sites/prod/files/2017/01/f34/Global%20Nuclear%20Markets--Market%20Arrangements%20and%20Service%20Agreements.pdf>

⁵² http://www.turkstat.gov.tr/PreTablo.do?alt_id=1029

⁵³ https://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-02-04-02-07-TM-INIG/Presentations/35_S7_Turkey_Camas.pdf

Rosatom will sell a 49% stake in the Akkuyu project, located on Turkey's Mediterranean coast, to Turkish investors.⁵⁴

The Turkish government's role in the BOO deal is to provide Rosatom with the plant site, project support, and a power purchase agreement (PAA) for the sale of electricity. According to the 15-year PPA, Turkey's state-owned wholesale utility will purchase 70% of the electricity generated from units 1 and 2 and 30% from units 3 and 4 at a fixed price of 12.35 cents/kilowatt hour (kWh).⁵⁵ After the 15-year period, the joint-venture company may sell 100% of the electricity generated on the competitive market, though will transfer 20% of its net profit to the Turkish Treasury until the plant is decommissioned.⁵⁶

Russia's expanding role in the global nuclear energy supply chain has led some countries to try to limit their exposure to Russian control and influence. This has been particularly important in Europe, where nuclear energy provides 55% of the EU's low-carbon electricity, and several countries are 100% dependent on Russian nuclear fuel.⁵⁷ In Hungary, for example, four VVER reactors are in operation, which together provided roughly 50% of the country's total electricity supply last year.⁵⁸ The reactors have been operating since the Soviet-era. In 2014, an agreement was signed between Hungary and Rosatom to build two new VVER-1200 reactors at the existing facilities, located in southern Hungary, with a loan for nearly \$12 million.⁵⁹ The new reactors, with planned capacity of 2.4 GW, will increase the share of nuclear to more than three-quarters of Hungary's total electricity supply—all from Russian reactors, with Russian-supplied fuel.⁶⁰

The European Union (EU) expressed concerns that the deal may violate anti-competition laws, and that Hungary should not further expand its dependence on Russia, especially after Russia's annexation of Crimea and military intervention in Ukraine. The deal was approved in 2017 after the Hungarian government committed to reducing the fuel supply contract with Rosatom from 20 to 10 years, after which time alternative suppliers would be able to bid for fuel contracts.⁶¹ In recent months, Rosatom has promised to increase its financial support for the project to 100% of the costs.

After years of development, in 1997, Westinghouse became the first company to deliver an alternative supply of fuel to Russian VVER reactors.⁶² By 2000, the U.S. government began working with Westinghouse to develop a fuel fabrication program for Ukraine, due to the fact that Russian VVERs provide more than 50% of the country's total electricity supply. Since then, the U.S. government has invested \$52 million to encourage the diversity of energy supplies and suppliers in Ukraine, and to advance their common energy security objectives. Led by the U.S. Department of Energy, the U.S.-Ukraine Nuclear Fuel Qualification Project (UNFQP) is designed to provide 42 nuclear fuel assemblies from Westinghouse to the South Ukraine Nuclear Power Plant, equal to one-fourth of the fuel that powers a

⁵⁴ <http://www.rosatom.ru/en/press-centre/highlights/turkish-companies-are-part-of-the-jsc-akkuyu-nuclear-shareholders/>

⁵⁵ https://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-02-04-02-07-TM-INIG/Presentations/35_S7_Turkey_Camas.pdf

⁵⁶ https://www.iaea.org/NuclearPower/Downloadable/Meetings/2014/2014-02-04-02-07-TM-INIG/Presentations/35_S7_Turkey_Camas.pdf

⁵⁷ <http://www.westinghousenuclear.com/uknuclear/About/News/View/Westinghouse-led-Group-Wins-EU-Backing-to-Diversify-Nuclear-Fuel-Supply-to-VVER-Reactors>

⁵⁸ http://www-pub.iaea.org/MTCD/Publications/PDF/RDS_2-37_web.pdf

⁵⁹ <https://www.ft.com/content/0478d38a-028a-11e7-ace0-1ce02ef0def9>

⁶⁰ <http://www.atomeromu.hu/en/AboutUs/Lapok/1default.aspx>

⁶¹ <http://www.reuters.com/article/us-hungary-nuclear-eu-idUSKBN0ML0K820150325>

⁶² <http://ftp4.afpconference.com/Hoglund%20J.pdf>

reactor for up to four years of operation.⁶³ As of today, there are 15 Russian VVERs in operation in Ukraine.⁶⁴

Westinghouse remains the only company to provide fuel supply alternatives to Russian VVERs. In 2015, Westinghouse and eight European partners announced a project to establish alternative fuel assemblies for other European member states that are 100% dependent on Russian reactors and fuel: Bulgaria, Czech Republic, Finland, Hungary, and Slovakia.⁶⁵ The project partners offer a range of knowledge and expertise in fuel manufacturing, licensing, and safety in these European countries most dependent on Russian fuel. The EU funding, part of the European Supply of Safe Nuclear Fuel project, is aimed at diversifying nuclear sources in both the short- and long-term.⁶⁶

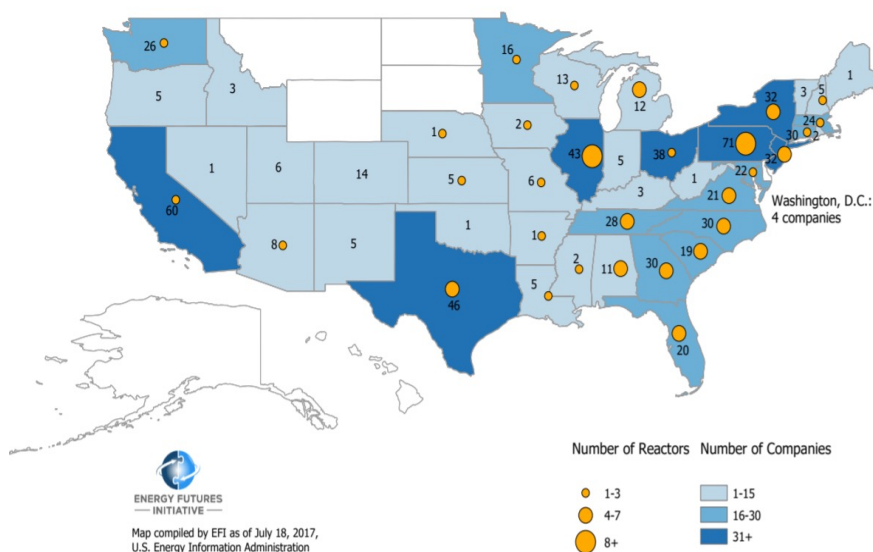
Analysis of the U.S. Nuclear Energy Supply Chain

The United States has been a leader in “all things nuclear” – nuclear energy, nuclear technology for medical and industrial uses, nuclear security – and this leadership is a continuing imperative. As such, the United States historically has had a robust, highly-integrated supply chain of people, businesses, and facilities across the country, providing critical research, technical services, and equipment to customers spanning the commercial nuclear power sector to the nuclear Navy.

While the supply chain remains extensive, it has suffered the erosion of domestic manufacturing capability for a significant number of components as the wave of new nuclear plant construction receded following the Three Mile Island accident in 1979. Consequently, there are some significant gaps in the domestic supply chain. The nuclear renaissance that held promise a decade ago would have been the stimulus to re-invigorate the supply chain. The lack of significant progress and resultant market uncertainty may instead further erode the supply chain capabilities.

Current Domestic Base of Commercial Companies and Facilities. An inventory compiled by the American Nuclear Society (ANS), updated annually, identified more than 700 companies, located in forty-four states that provide products or services in direct support of the U.S. nuclear energy industry (Figure 5). Pennsylvania, California, Texas, Illinois and Ohio were the top five states for nuclear supply chain companies, respectively.

Figure 5. Nuclear Supply Chain Companies and Reactors by State



⁶³ <https://energy.gov/articles/us-commits-14-million-us-ukraine-nuclear-fuel-qualification-project>

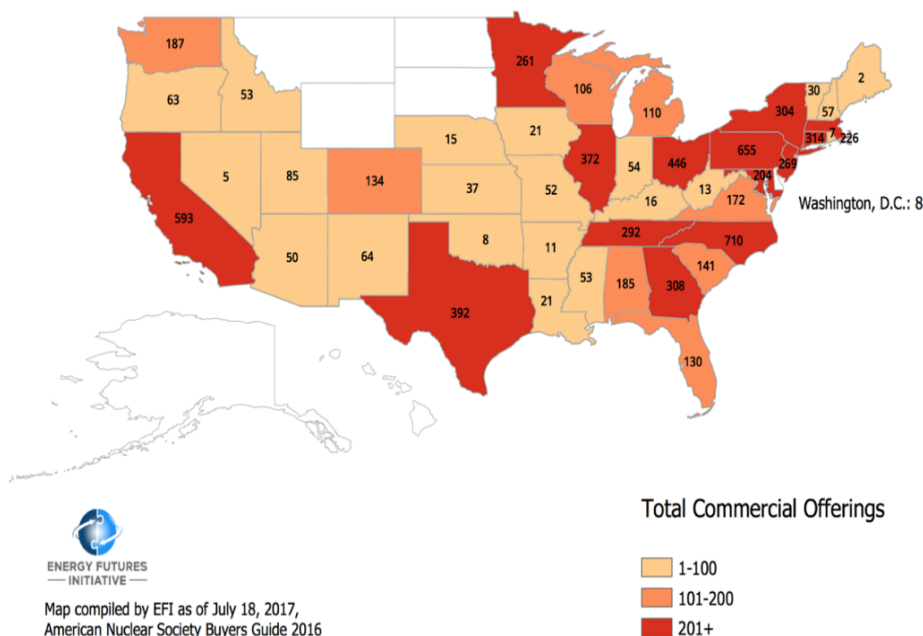
⁶⁴ http://www-pub.iaea.org/MTCD/Publications/PDF/RDS_2-37_web.pdf

⁶⁵ <http://www.westinghousenuclear.com/About/News/View/Westinghouse-led-Group-Wins-EU-Backing-to-Diversify-Nuclear-Fuel-Supply-to-VVER-Reactors>

⁶⁶ <http://www.westinghousenuclear.com/About/News/View/Westinghouse-led-Group-Wins-EU-Backing-to-Diversify-Nuclear-Fuel-Supply-to-VVER-Reactors>

The ANS inventory also provides information on the type of product or service offered by each company in the nuclear supply chain. When considering the number of commercial offerings from nuclear supply chain companies per state (defined as the total number of equipment/products and services offered by all companies within each state), the top five states for total commercial offerings were North Carolina, Pennsylvania, California, Texas and Ohio (Figure 6). These supply chain companies provide equipment and products, operations and maintenance services, or both to the 61 U.S. nuclear power plants. Thousands of unique components are provided by these firms, including special valves, boilers, storage containers, pumps, and concrete, among others, to support the nuclear industry. Companies such as BWXT Technologies, Inc. (BWXT) employ hundreds of specialists in Ohio, Indiana, and Virginia in the

Figure 6. Nuclear Supply Chain Total Commercial Offerings by State



design and supply of reactor components and in providing maintenance, testing, and repair of operating reactor sites. Other companies, such as BNL Industries, Inc. focus on providing individual components that are used across the U.S. nuclear energy supply chain.

The geographic distribution of nuclear supply chain companies tends to follow the location of operating commercial reactors. There are no states that have operating reactors that do not also have supply chain companies present. There is a strong correlation between states with significant nuclear power and those with a large supply chain presence.

The Nuclear Navy Supply Chain.

There is also a correlation between the commercial and nuclear Navy supply chains. Naval Nuclear Propulsion Program is comprised of military and civilian personnel who design, build, operate, maintain, and manage the nuclear-powered ships and the many facilities that support the U.S. nuclear-powered Navy.⁶⁷ Nuclear reactors provide the U.S. Navy with the mobility, flexibility, and endurance required to carry out its mission to maintain, train, and equip combat-ready naval forces.⁶⁸

The nuclear Navy is central to America's national security strategy of projecting military capability globally. Of the U.S. Navy's 276 deployable battle force ships, 83 are powered by nuclear energy, with a total of 96 reactors in operation.⁶⁹ This includes 10 aircraft carriers, 55 attack submarines, and 18 strategic submarines. U.S. submarines and aircraft carriers are completely reliant on nuclear propulsion to ensure their worldwide, forward presence. Thanks to improvements in reactor design and operation, modern submarines and aircraft carriers can now travel over 1 million miles before refueling.⁷⁰

⁶⁷ https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/nuclear_propulsion_program_8-30-2016.pdf

⁶⁸ <http://www.navy.mil/navydata/organization/org-top.asp>

⁶⁹ http://www.navy.mil/navydata/nav_legacy.asp?id=146;

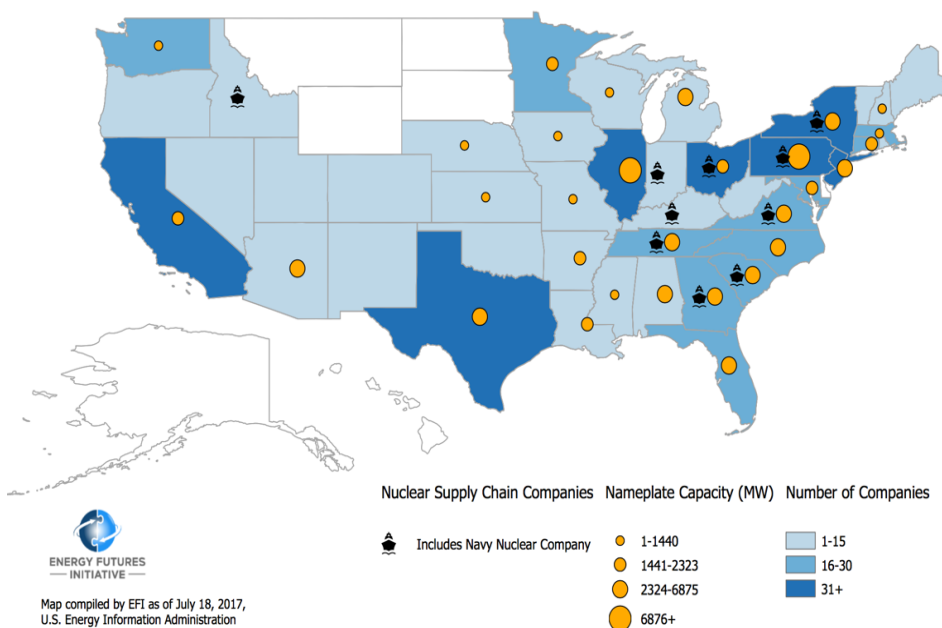
https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/nuclear_propulsion_program_8-30-2016.pdf

⁷⁰ https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/nuclear_propulsion_program_8-30-2016.pdf

The DOE National Nuclear Security Administration (NNSA) provides the design, development, and operational support to the Naval Nuclear Propulsion Program in collaboration with the U.S. Navy. Government and contractor personnel support DOE-owned, contractor-operated Navy Nuclear Propulsion Program sites: *Bettis Atomic Power Laboratory* in Pittsburgh, Pennsylvania; *Knolls Atomic Power Laboratory (KAPL)* in Schenectady, New York; *KAPL – Kesselring Site* in West Milton, New York; and the *Naval Reactors Facility* at Idaho National Laboratory.⁷¹ With combined staffs of over 7,500 engineers, scientists, technicians, and support personnel, Bettis and KAPL develop the advanced naval nuclear propulsion technology and provide technical support for the continued safe, reliable operation of all existing naval reactors.⁷² Private companies, including Westinghouse and Bechtel, have experience operating Bettis and KPL on the government's behalf.

Outside of these facilities, private companies, with over 1,000 contractors, located mostly in the Eastern and Midwestern parts of the country support the design and fabrication of naval reactor components (Figure 7).⁷³ In 2016, there were companies in at least ten states that directly support the U.S. Navy Nuclear Propulsion Program, all of which also work in the commercial nuclear industry. BWXT, for example, which provides materials and services to the commercial industry, also owns four facilities that specialize in the design and manufacturing of large, heavy components used for Naval reactors. BWXT is also one of two private firms licensed to possess and process highly enriched uranium.⁷⁴ Meanwhile, other firms, including Bechtel, Westinghouse, and GE also provide critical supply chain components and services that support both the commercial and U.S. Navy nuclear programs.

Figure 7. Commercial and U.S. Navy Supply Chain Companies by State



Standards for naval applications are far more rigorous and stringent than those required for civilian nuclear reactors because components on warships must be designed to accommodate battle shock; radiated noise limits; crew proximity to the reactor; and frequent, rapid changes in reactor power. As a result, specialists throughout the nuclear energy supply chain work for years to manufacture the specialized components used in Navy nuclear propulsion. Due to these long lead times and special requirements, any spillover effects from the loss of the commercial reactors on the people, companies, and facilities that support the U.S. Navy could present significant challenges.⁷⁵

⁷¹ https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/nuclear_propulsion_program_8-30-2016.pdf

⁷² <http://www.scuref.org/program/rfp-01/>

⁷³ https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/nuclear_propulsion_program_8-30-2016.pdf

⁷⁴ <http://www.bwxt.com/about/business-units/bwxt-nuclear-operations-group>

⁷⁵ https://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/nuclear_propulsion_program_8-30-2016.pdf

An emerging issue for the Navy is the retirement and replacement of its submarine fleet. There has been some concern that an aging fleet could trigger a potential shortfall of mission-ready attack vessels.⁷⁶ A recent report to Congress stated that the Navy was committed to maintaining a new-build rate of two attack submarines per year given a sufficient operating budget and industrial base that is capable of handling the increased work demand.⁷⁷ (The United States has previously built submarines at a rate of three or more per year).⁷⁸ Since the submarine fleet is reliant on nuclear propulsion,⁷⁹ it will be important to maintain a robust and active domestic nuclear supply chain to help ensure critical mission readiness for the U.S. Navy.

Years of decline in the commercial nuclear energy industry has resulted in increased reliance on a global supply chain of people, services, and components. Already there are a significant number of foreign firms involved in supporting the U.S. commercial nuclear industry, despite the fact that the global nuclear industry still relies on designs and technologies developed in the United States. While the U.S. Navy has developed redundant sources of supply for its nuclear capabilities, and requires that all Naval Reactor Engineers must be U.S. citizens, a sustained decline in the commercial nuclear industry will have impacts on the nuclear engineering labor force which may spillover into the naval program.⁸⁰

Supply Chain Challenges. Despite the robust nuclear supply chain network in the United States, many factors are negatively impacting the U.S. commercial nuclear energy industry. A combination of low natural gas prices, increasing renewables penetration, low electricity load growth, and relatively high capital costs, among others, are exposing many nuclear power plants to the risk of closure.⁸¹ In the last six years alone, five nuclear power plants totaling 5 gigawatts (GW) of capacity have closed in Florida, California, Vermont, Nebraska, and Wisconsin. Four new reactors under construction have experienced delays and cost overruns, in part due to the financial distress of Westinghouse, formerly in charge of the design and construction.⁸² Indeed, construction has been halted on the new AP-1000 reactors in South Carolina. By 2050, EIA estimates that 25% of plants currently operating will be removed from service.⁸³

The restart of the new build program for GW-scale light water reactors revealed some key gaps in the domestic supply chain. For example, Southern Company identified a number of key components that could not currently be supplied domestically and consequently had to be sourced outside the United States including: reactor pressure vessels; steam generators; pressurizers; passive residual heat removal (prhr); and condensers and turbine generators (have limited domestic fabrication capability). The gaps in the domestic supply chain also impact the ability to deploy SMRs as well.

⁷⁶ <http://www.navytimes.com/news/your-navy/2017/07/21/report-navy-can-build-two-virginia-class-subs-yearly-for-foreseeable-future/>

⁷⁷ <https://www.documentcloud.org/documents/3897030-Report-to-Congress-VIRGINIA-Class-Industrial.html#document/p6>

⁷⁸ https://www.rand.org/content/dam/rand/pubs/monograph_reports/2005/RAND_MR456.pdf

⁷⁹ <https://www.navy.com/about/equipment/vessels/submarines>

⁸⁰ https://csis-prod.s3.amazonaws.com/s3fs-public/legacy_files/files/publication/130719_Wallace_RestoringUSLeadershipNuclearEnergy_WEB.pdf

⁸¹ We may be comfortable to list these as they are EIA's assumptions for "at risk" capacity:

[https://www.eia.gov/outlooks/aeo/pdf/0383\(2017\).pdf](https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf)

⁸² <http://www.prnewswire.com/news-releases/georgia-power-southern-nuclear-prepared-to-assume-vogtle-project-management-by-late-july-300481603.html>

⁸³ <https://www.eia.gov/todayinenergy/detail.php?id=31192>

The electric power grid, and thus the U.S. economy, is highly dependent on the nuclear energy industry. The people, companies, and facilities that support the U.S. nuclear supply chain are fundamental to ensuring that commercial nuclear reactors continue to operate efficiently and safely. With operating nuclear reactors in 30 states across the country, and nuclear supply chain companies located in nearly every state, the size and geographic distribution of the commercial supply chain is considerable and supports a sizable well-trained workforce. However, the nuclear energy supply chain is highly integrated. With multiple reactors at risk of closure across the country, the same people, companies, and facilities affected by the loss of the commercial reactors may also provide critical support the Navy's Nuclear Propulsion Program.

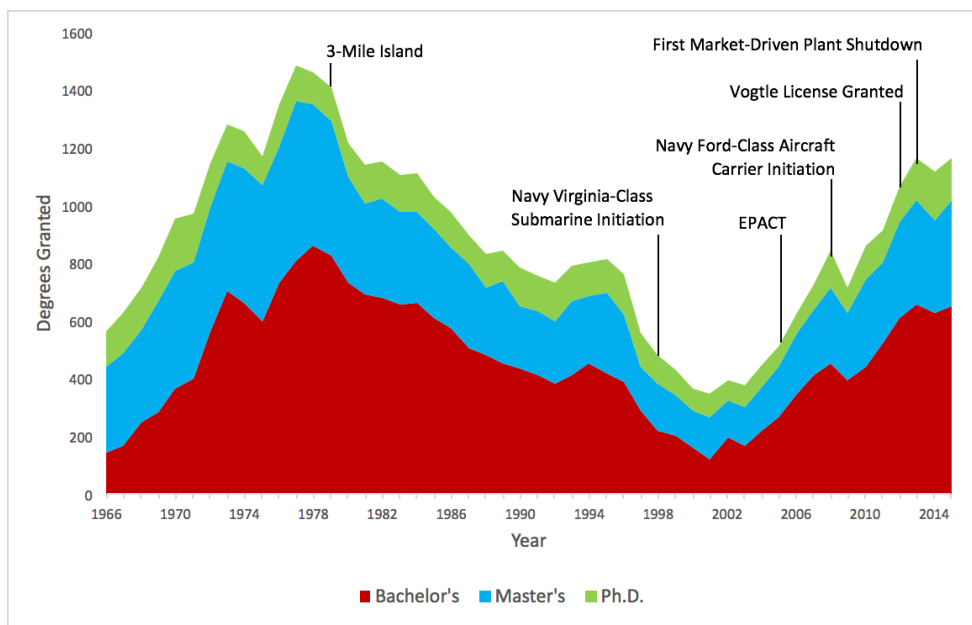
Without new reactor builds in the United States there are expected to be fewer jobs for nuclear engineers. A shrinking labor force and a perception of limited professional opportunity will have long-term consequences to the domestic nuclear supply chain, which has historically positioned the United States as a global leader in the commercial industry and in global nuclear security frameworks. As other countries continue to strengthen their nuclear capabilities and market positions, they are more likely to successfully exert influence over global nuclear priorities.

U.S. Nuclear Engineering Education Pipeline. Servicing the U.S. nuclear supply chain requires a well-trained labor force. Nuclear engineers today work for the Federal Government, nuclear power generation and supporting equipment and service companies, and in the research, development and testing units of defense and engineering companies.⁸⁴ The size of the education pipeline is an important indicator of the health of the industry; a student's choice of a major in college-level engineering education programs is affected by perception of the future prospects in that field. The data for nuclear engineering programs shows a strong relationship in this regard.

Historical Trends in Nuclear Engineering Education. Data on the nuclear engineering educational pipeline had been compiled on a consistent, ongoing basis by the Oak Ridge Institute for Science and Education (ORISE).⁸⁵ The historical trends show a nuclear engineering education pipeline that has greatly fluctuated across time from the 1960s to present (Figure 8).

The number of nuclear engineering graduates experienced a marked increase through the late 1960s and 1970s, and reached a peak of 1485 total students (Bachelor's, Master's, and Ph.D.) in 1977. Following the Three-Mile Island incident in 1979, the number of graduates began a precipitous decline that lasted until the early 2000s. The Three Mile Island accident in 1979 was a significant event leading to a reversal of the nuclear industry. Construction of new

Figure 8. History of U.S. Nuclear Engineering Graduates, 1966-2015



⁸⁴ <https://www.princetonreview.com/careers/99/nuclear-engineer>

⁸⁵ <https://orise.orau.gov/stem/workforce-studies/nuclear-engineering-enrollments.html>

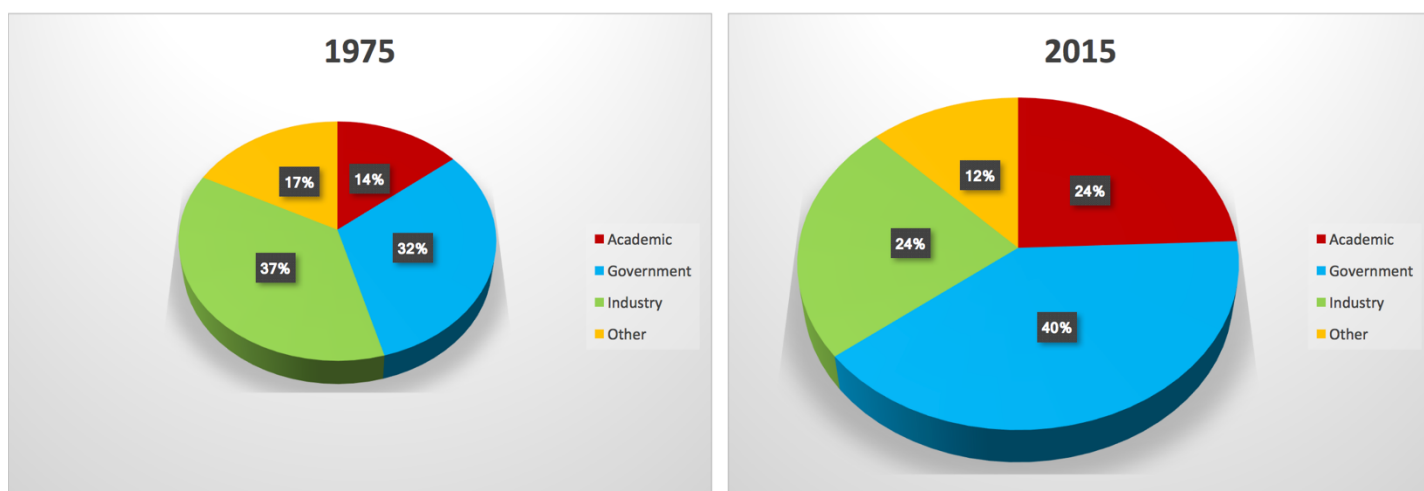
commercial nuclear power plants began a period of decline in the 1980s and 1990s as existing projects were either cancelled or completed, and new orders ceased. This trend appears to have led to a similar decline in nuclear engineering education, where the number of total degrees granted plummeted to a drastic low of 345 total students in 2001.

The perception that the domestic nuclear power industry was entering a Renaissance period began to take hold in the early 2000 period. The key transformative event was the enactment of the Energy Policy Act of 2005 (EPACT20005), authorizing loan guarantees, standby insurance and production tax credits for the construction of new nuclear power plants. EPACT2005 also authorized expansion of nuclear energy research and education programs. These events appear to be correlated with a revival of university nuclear engineering programs. The total number of nuclear engineering programs began to recover in 2005, with six new programs added by 2010. According to the U.S. Department of Energy there are currently 32 universities throughout 26 states that offer advanced degrees (Masters' or Ph.D.) in nuclear engineering.⁸⁶ Although U.S. universities that offer nuclear engineering programs are fairly dispersed across the country, states with the most universities that offer nuclear engineering programs tended to be in the Eastern and Midwestern portions of the country. The data show continued growth in the total number of nuclear engineering graduates, approaching the 1977 historical peak. The uptick in total graduates was reflected in all three degree-types from the early 2000s until 2015, when the number of graduates reached 1162 total students (78% of the 1977 peak).

The data on job placement of graduates, however, shows a notable decline in the share of graduates taking positions in the commercial nuclear power industry and its associated supply chain companies (Figure 9).⁸⁷

In 2015 there were approximately 147 Ph.D. nuclear engineering graduates in the U.S. Of those who reported post-graduation plans, 40% listed government service (Federal, DOE contractor, state and local, military) as their plans for post-graduation job industry placement. Nearly half as many graduates (24%) listed industry as their plans for post-graduation job industry placement.

Figure 9. Nuclear Engineering Post-Graduation Plans
Post-Graduate Plans for Nuclear Engineering Ph.D. Students
 1975: 92 Post-Graduate Plans, 2015: 115 Post-Graduate Plans



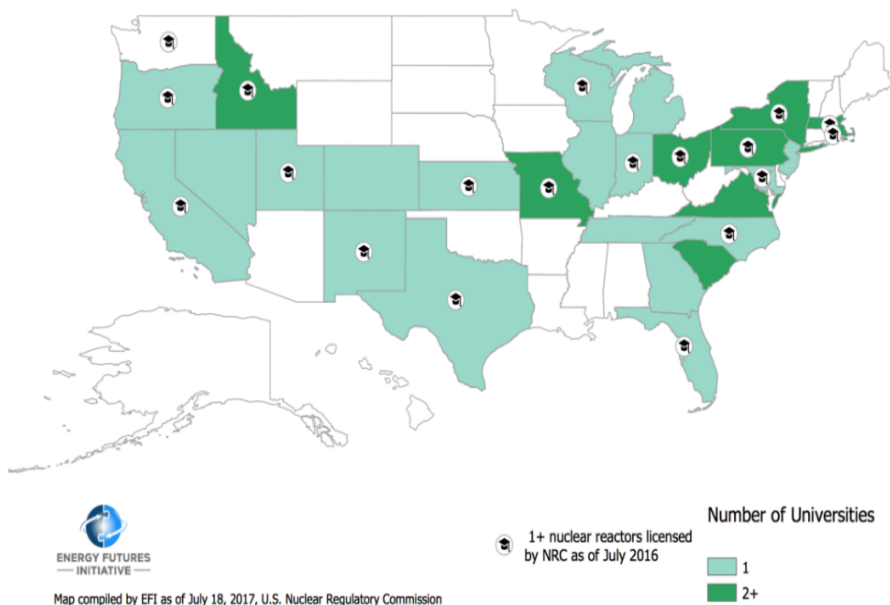
⁸⁶ <https://www.energy.gov/ne/downloads/nuclear-science-and-engineering-education-sourcebook>

⁸⁷ <https://orise.orau.gov/stem/workforce-studies/nuclear-engineering-enrollments.html>

These data stand in noticeable contrast to those of the 103 Ph.D. nuclear engineering graduates in 1975. Of those who reported post-graduation plans, industry was the largest post-graduation job placement category at 37%, while government was 32%. This difference suggests a shift in early career outlook away from industry and toward government and academia between 1975 and 2015.

Universities play many important roles in shaping the future U.S. nuclear supply chain. In addition to preparing nuclear engineers for the labor force, they also play an important role in hosting some of the

Figure 10. Nuclear Engineering Programs and Research and Test Reactors by State



nation's nuclear research and test reactors.⁸⁸ As of July 2016, nearly all of the 31-operating research and test reactors were located on university campuses (Figure 10).⁸⁹ While these reactors serve as vital educational tools in nuclear engineering programs, as well as in biological and medical programs, 82 research and test reactors have been decommissioned since 1958.⁹⁰

Universities with nuclear engineering programs also tend to be located in states with robust nuclear supply chain companies (Figure 11).⁹¹ Of the 26 states that currently offer a Bachelor's, Master's, or Ph.D. in nuclear engineering, each state had at least one company involved in the supply chain. New York and Ohio, which had the most universities that offered nuclear engineering

programs, both contained more than 30 supply chain companies.

Workforce Outlook and Implications. If past is prologue, the recent spate of announcements of early closures of existing nuclear power plants, as well as the most recent announcement of cancellation of the two new builds at the Summer nuclear facility, could precipitate a new downturn in nuclear engineering education. This could have serious implications for the ability to provide trained personnel to service both the domestic commercial nuclear power industry as well as support the Navy Nuclear Propulsion Program.

The Nuclear Energy Institute reports that the nuclear power sector will soon lose 25,000 skilled workers to retirement.⁹² Because of the current and future retirements of nuclear reactors throughout the country, there are low expectations that these positions will need to be filled. Furthermore, projections from the Bureau of Labor Statistics (BLS) suggest that nuclear engineering jobs will experience the largest decrease in new positions between now and 2024 compared to all other engineering disciplines—despite the fact that nuclear engineers are some of the highest paid.⁹³

⁸⁸ <https://www.nrc.gov/reactors/operating/map-nonpower-reactors.html>

⁸⁹ <https://www.nrc.gov/reading-rm/doc-collections/datasets/>

⁹⁰ <https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/research-reactors-bg.html>

⁹¹ Data obtained from American Nuclear Society Buyers Guide 2016 for company information, and independent research cross-referenced through the American Nuclear Society for university information

⁹² <https://www.nei.org/News-Media/News/News-Archives/help-wanted-25000-skilled-workers>

⁹³ <https://data.bls.gov/projections/occupationProj>

The issue is not simply a numbers issue; there also is a potential concern regarding American versus foreign students in U.S. nuclear engineering education programs. The growth of nuclear energy on a global scale is attracting more foreign students into nuclear engineering educational programs. While a number of these students may decide to remain in the United States and seek employment in the domestic supply chain industries, many will return to their native countries. This suggests that the current level of students in U.S. nuclear engineering programs may not necessarily be an indicator for future trained nuclear workforce.

Figure 11. Nuclear Supply Chain Companies and Nuclear Engineering Programs by State

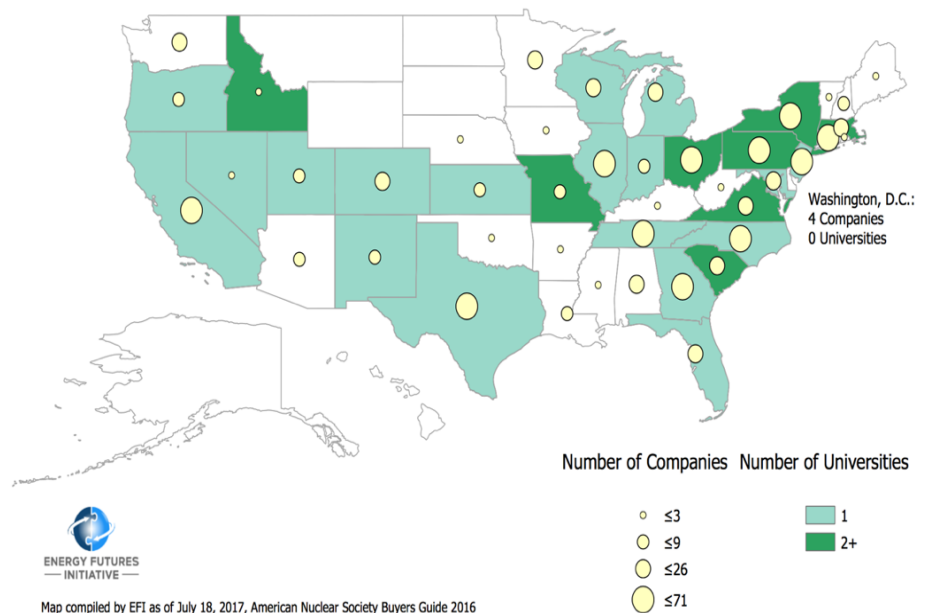
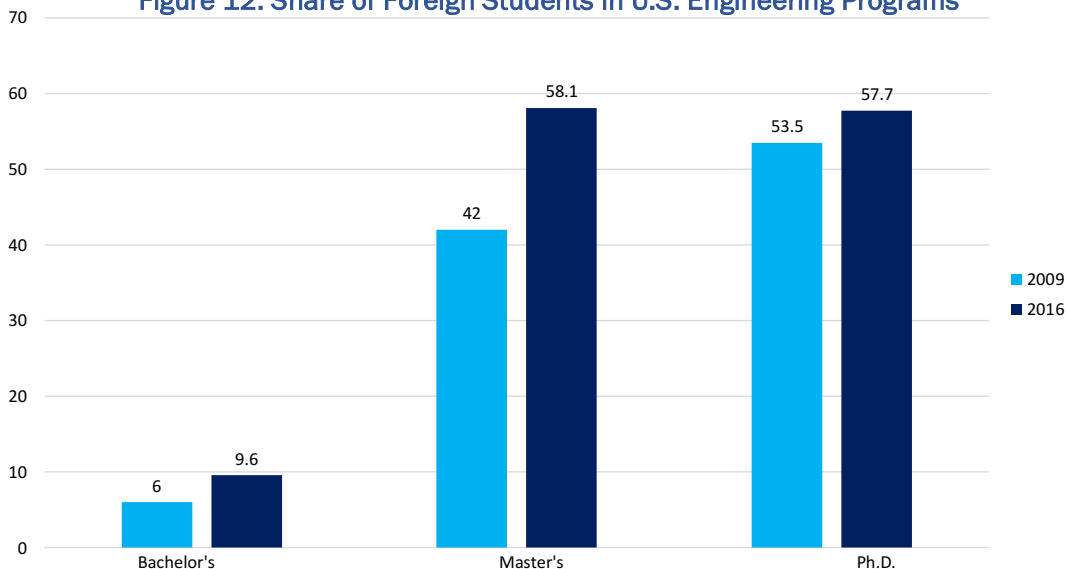


Figure 12. Share of Foreign Students in U.S. Engineering Programs



The number of foreign-born students enrolled in engineering programs has been increasing. Estimates from the American Society for Engineering Education (ASEE) show that in 2016, more than half of graduate students in engineering (58.1% of Master's students and 57.7% of Ph.D. students) in the United States were not born in the U.S. (Figure 12).⁹⁴

The most significant potential impact may be on the Navy Nuclear Propulsion Program. Typically, nuclear engineers working on Navy nuclear programs must be U.S. citizens with appropriate security clearances. An educational pipeline that is shrinking, together with an increased proportion of non-U.S. citizens, could pose greater challenges to the Navy nuclear program in the future than it does to the domestic commercial nuclear energy industry. If the prospects for further expansion of the domestic nuclear power are extinguished for the next decade or so, the ramifications for both the educational pipeline as well as the domestic supply chain could be significantly adverse.

⁹⁴ <https://www.asee.org>

The U.S. Nuclear Energy Enterprise as A Key National Security Enabler: Considerations for Policymakers

The analysis suggests that the imperatives of global climate change, collective energy security, balance of trade and U.S. national security require a viable domestic commercial nuclear power industry, including a robust supply chain of technology, services and human resources. Recent events and future trends point in the opposite direction: commercial reactors are shutting down, new builds are struggling, the supply chain is at risk, and it is likely that the educational pipeline will negatively respond to these challenges.

National security is an inherently Federal responsibility. Externalities such as climate change and fuel diversity, although not yet adequately accounted for, may be partly taken into account in state level policy and regulatory actions. It is unrealistic, however, to anticipate state or regional level internalization of the national security benefits of a strong nuclear enterprise. In this context, we close with a summary of issues that need to be taken up at the Federal policy and regulatory level, including through possible statutory changes or fixes that would require Congressional action.

Considerations for Policymakers. It is essential that policymakers recognize that a robust nuclear energy enterprise is a key enabler of the Nation's nonproliferation goals, and that it supports both the fleet modernization plan of the U.S. Navy, as well as the global strategic stability and deterrence value of nuclear weapons. To ensure that these issues and concerns are addressed going forward, the Federal government could:

- ✓ make maximum flexible use of its existing resources and capabilities, including credit support, tax incentives and federal siting and/or purchase power agreements, to bolster support for current new builds and to encourage additional new builds. This could include legislative action where necessary, to extend the availability of the current PTC and the DOE Title XVII loan guarantee program.
- ✓ work with states to harmonize federal and state policies affecting the design of organized electricity markets to appropriately value attributes of nuclear electricity including supply diversity.
- ✓ direct FERC to place greater emphasis on the national security importance of nuclear power and its associated supply chain.
- ✓ foster the organization of a broad-based consortium of nuclear supply chain companies, power generation companies, financing institutions and other appropriate entities to share the risk and benefits of additional new builds domestically, and a competitive offering internationally of new commercial nuclear power plants. The federal government should make maximum flexible use of existing resources and capabilities, including export financing assistance, as an inducement for formation of the consortium.
- ✓ expand and accelerate support for RD&D for a new generation of advanced nuclear reactor technologies. The program should be fully competitive, stage-gated and cost-shared. The 2016 SEAB Task Force report provides a good template. The initial phase of technology development, engineering and systems analysis and conceptual design should be funded at a level of about \$2 billion over the next 5 years.
- ✓ maintain and expand current programs to provide support for nuclear engineering education, including fellowships as well as training grants targeted to key occupational needs.
- ✓ regain U.S. leverage in using 123 Agreements to advance nuclear nonproliferation objectives by developing more flexible approaches for negotiating future agreements.

APPENDIX A

Snapshot of U.S. Nuclear Energy Market

The United States is the world's largest producer of nuclear power.⁹⁵ The first-ever nuclear reactor was constructed in the United States in the 1940s, and since then a long history of research, science, and engineering has supported the U.S. commercial nuclear power industry as it grew rapidly throughout the 1970s. Utilities saw the new form of electricity production as economical, environmentally clean, and safe.⁹⁶

Electricity generation from nuclear sources has averaged 20% of the total U.S. supply since 1990. The U.S. nuclear energy industry has maintained this level of output for decades, despite the fact that few new reactors have been built. This was made possible, in part, by the robust nuclear supply chain. Research, technical services, and ingenuity led to enhancements at existing power plants that increased capacity by more than 7.30 GW since 1977—the equivalent of adding seven new reactors to the electric grid.⁹⁷ Operators were also able to shorten the length of time reactors needed to be offline for refueling.⁹⁸ As a result, the capacity factors of U.S. nuclear plants have increased by nearly 30% since the 1990s without sacrifice to reactor performance or safety.⁹⁹ In 2016, nuclear power plants generated approximately 805 billion kilowatt hours (kWh),¹⁰⁰ enough electricity to power Japan.¹⁰¹ This represented 19.7% of total U.S. electricity output, while installed capacity of nuclear was only 9% of the U.S. total.¹⁰²

Status of the Current Reactor Fleet. As of July 2017, there are 61 nuclear power plants with 99 commercially active reactors across 30 states (Figure 13).¹⁰³ This is twice as many reactors as the next two largest countries combined (France and Japan). Twenty-six of those states with active reactors had between one and five, while four states had six or more. The majority of reactors are located in the Eastern and Midwestern parts of the country. As of June 2017, the average age of U.S. commercial reactors is 36 years, with the oldest operating reactors entering into service 48 years ago.¹⁰⁴ The newest reactor to enter service was in October 2016 and has a 1.150 gigawatts (GW) capacity.¹⁰⁵

Approximately 80% of the electricity generated from nuclear power in the United States comes from plants with multiple reactors.¹⁰⁶ The economies of scale allow plant operators to spread costs over multi-unit sites, resulting in lower generating cost. In 2016, the average total generating cost at multi-unit facilities was \$31.63 per megawatt hour (MWh) compared to \$41.39/MWh for single-unit plants. While these

⁹⁵ In terms of annual average kWh

⁹⁶ https://www.energy.gov/sites/prod/files/The%20History%20of%20Nuclear%20Energy_0.pdf

⁹⁷ <https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants>

⁹⁸ <https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants>

⁹⁹ <https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Capacity-Factors>

¹⁰⁰ <https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants>

¹⁰¹ http://www.japantimes.co.jp/news/2016/01/29/business/japan-power-use-drops-17-year-low-amid-slower-economic-growth/#.WXjYP_nytaQ

¹⁰² <https://www.eia.gov/tools/faqs/faq.php?id=427&t=3>

¹⁰³ <https://www.eia.gov/tools/faqs/faq.php?id=207&t=21>

¹⁰⁴ <https://www.eia.gov/tools/faqs/faq.php?id=228&t=21>

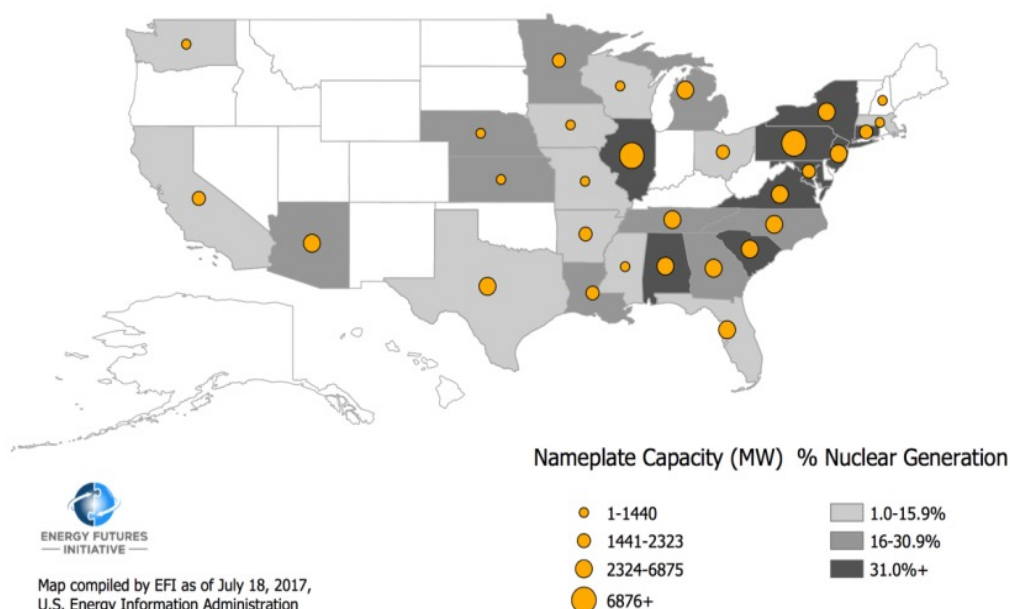
¹⁰⁵ <https://www.eia.gov/tools/faqs/faq.php?id=207&t=21>

¹⁰⁶ <https://www.nei.org/CorporateSite/media/filefolder/Policy/Papers/Nuclear-Costs-in-Context.pdf?ext=.pdf>

costs have fallen in recent years, total generating costs, including capital, fuel, and operating costs have increased by nearly 20% between 2002 and 2016, due mostly to significant increases in capital costs. To ensure that reactors continue to operate effectively and safely over their lifetimes, operators invest

substantial resources in their facilities.

Figure 13. Active Commercial Nuclear Reactors and Generation by State, 2017



Nuclear power plants in the United States are licensed to operate for 40 years. Each nuclear power plant is licensed based on a given set of requirements called the “licensing basis,” which are determined primarily by the type of plant.¹⁰⁷ The original determination of a 40-year initial licensing term was not based on limitations of nuclear technology.¹⁰⁸

Beyond the 40-year operating period, plant operators may apply for extensions for up to 20 years. License renewals represent the most

inexpensive option for future electricity generation for the operator. At the end of a nuclear reactor’s 40-year license, initial capital costs are likely to have been fully recovered and decommissioning costs are likely to be fully funded. The U.S. Nuclear Regulatory Commission (NRC), the agency in charge of regulating power plants and other uses of nuclear materials, has renewed licenses for 84 of today’s 99 operating reactors, and is currently reviewing applications for another 11.¹⁰⁹ The nuclear sector depends on these life extensions, without which nearly the entire current nuclear fleet would be forced to retire by 2030.¹¹⁰

Beyond the 20-year life extension, two companies have announced their intentions to seek a second 20-year license renewal. According to research from the Electric Power Research Institute and the U.S. Department of Energy (DOE), there are no general technical issues that would impact the safe operation of a nuclear power plant during the second license renewable period.¹¹¹

When the NRC licenses a commercial nuclear power plant, it sets limits on the maximum heat output, or power level, for the reactor core. To increase a plant’s maximum power level, the operator submits designs and plans to the NRC for approval. These “power uprates” may come in the form of improved power measurements, changes in the plant’s equipment to boost output, or in significant modifications to the facility’s design and operation.¹¹² Since the 1970s, power uprates account for adding 7.30 GW of

¹⁰⁷ <https://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/License-Renewal-of-Nuclear-Power-Plants>

¹⁰⁸ <https://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/License-Renewal-of-Nuclear-Power-Plants>

¹⁰⁹ <https://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/License-Renewal-of-Nuclear-Power-Plants>

¹¹⁰ <https://www.aps.org/policy/reports/popa-reports/upload/nuclear-power.pdf>

¹¹¹ <http://energy.gov/ne/downloads/lwrs-program-and-epri-long-term-operations-program-joint-rd-plan>

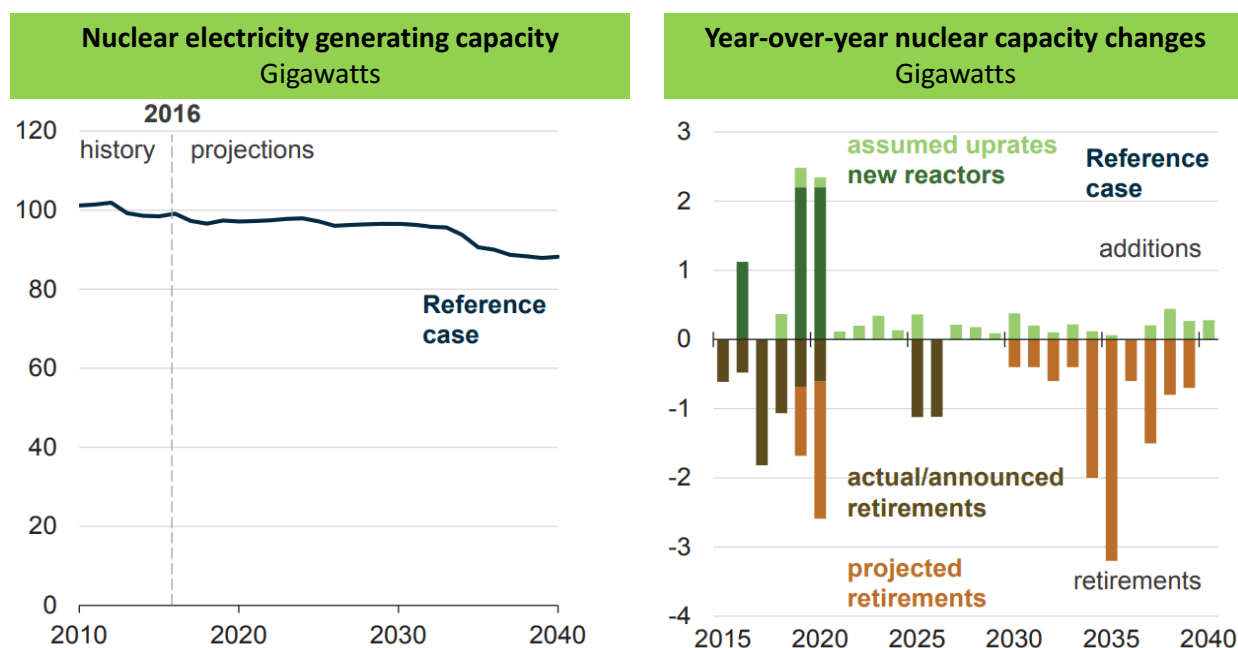
¹¹² <https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/power-uprates.html>

capacity to the grid, the equivalent of seven new reactors.¹¹³ According to the EIA, power uprates are expected to account for another 4.7 GW capacity from existing facilities by 2040. However, based on current trends in the nuclear sector, the EIA expects no additional uprates beyond 2040.

Reactor Closures. Since the first commercial U.S. nuclear reactor came online in 1957, more than 30 nuclear reactors have retired. While no nuclear power plants closed between 1998 and 2013, five plants totaling 5 GW of capacity have closed in the last five years in Florida, California, Vermont, Nebraska, and Wisconsin.¹¹⁴ Economic reasons were cited as the main drivers of the plant retirements, as each of the facilities retired before the end of the 20-year extensions.¹¹⁵ In the case of Vermont's Yankee facility, the 604 MW capacity plant was retired after 42 years of service—2 years into its 20-year extension. According to the plant operator, the U.S. Northeast's shift toward natural gas was the primary reason for the shutdown.¹¹⁶ At the time of its closure, Yankee was responsible for 70% of Vermont's and 4% of New England's total electric generation.¹¹⁷ The plant employed 600 people, and provided hundreds of millions of dollars of local and state tax revenue.

According to EIA, an additional six plants are scheduled to retire in the next nine years (Figure 14).¹¹⁸ Four of these—Palisades (811 MW), Pilgrim (688 MW), Oyster Creek (625 MW), and Three Mile Island

Figure 14. Projections of the Decline in Nuclear Power Generation



¹¹³ <https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants>

¹¹⁴ <https://www.eia.gov/todayinenergy/detail.php?id=31612>

¹¹⁵ https://www.eia.gov/nuclear/spent_fuel/ussnftab2.php

¹¹⁶ <https://www.usatoday.com/story/news/nation/2014/12/30/vermont-yankee-nuclear-plant-winds-down-operations/21037371/>

¹¹⁷ <https://www.eia.gov/todayinenergy/detail.php?id=19811>

¹¹⁸ EIA AEO 2017

(837 MW)—have planned retirement dates more than a decade before their operating licenses expire.^{119,120} According to the plant operator, the Three Mile Island facility has not been profitable in the last five years.¹²¹

A combination of low natural gas prices, increasing renewables penetration, low electricity load growth, and relatively high capital costs, among others, are exposing many nuclear power plants to the risk of closure.¹²² By 2050, EIA estimates that 25% of nuclear plants currently operating will be removed from service.¹²³

New Builds. Since the mid-1990s, only one new reactor has entered service in the United States: the 1.15 GW Watts Bar Unit 2, located in Tennessee. As of January 2017, the NRC had 10 applications for new reactors in various stages of review. The NRC review process can take up to five years to complete, which includes a review of the reactor design—using an NRC-certified reactor design may shorten the application process—and the construction plans.¹²⁴

There are four new reactors under construction in the United States, with two in Georgia and two in South Carolina. In 2008, Westinghouse signed agreements with electric utilities in those states for the construction of four reactors with AP-1000 models. Since then, project delays and cost overruns has created uncertainty around the future of the plants, especially after Westinghouse filed for Chapter 11 bankruptcy in March 2017.¹²⁵ In July 2017, the project owners in South Carolina announced that the Virgil C. Summer Units 2 and 3 would be abandoned.¹²⁶ According to Santee Cooper and South Carolina Electric & Gas Company, to complete the project would cost more than double the original budget and not conclude until 2024—five years late.¹²⁷

¹¹⁹ Operator websites

¹²⁰ <https://www.eia.gov/todayinenergy/detail.php?id=31612>

¹²¹ <https://www.eia.gov/todayinenergy/detail.php?id=31612>

¹²² [https://www.eia.gov/outlooks/aeo/pdf/0383\(2017\).pdf](https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf)

¹²³ <https://www.eia.gov/todayinenergy/detail.php?id=31192>

¹²⁴ https://www.eia.gov/energyexplained/index.cfm/index.cfm?page=nuclear_use

¹²⁵ <https://www.forbes.com/sites/jamesconca/2017/03/31/westinghouse-bankruptcy-shakes-the-nuclear-world/#7ef312c26887>

¹²⁶ <https://www.nytimes.com/2017/07/31/climate/nuclear-power-project-canceled-in-south-carolina.html>

¹²⁷ <https://www.ft.com/content/aaaeda90-761d-11e7-a3e8-60495fe6ca71>