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THE GEOPOLITICS OF NUCLEAR POWER AND TECHNOLOGY

Nicola de Blasio
and Richard Nephew

MARCH 2017

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PREFACE

This paper is one of a series of three being released by the Center on Global Energy Policy (CGEP) at the School of International and Public Affairs (SIPA) of Columbia University that focuses on the future of nuclear energy. These papers were made possible, in part, by a grant from the Sasakawa Peace Foundation (SPF) of Japan. SPF played no role, however, in the drafting or review of this paper series.

The series consists of the following three papers:

- "A Comparison of Advanced Nuclear Technologies," by Dr. Andrew Kadak
- "The Role of Policy in Reviving and Expanding the US Global Nuclear Leadership," by Tim Frazier
- "The Geopolitics of Nuclear Power and Technology," by Dr. Nicola de Blasio and Richard Nephew

CGEP chose three different sets of authors to prepare these papers to ensure a wide, diverse range of experiences and perspectives. CGEP also chose to work on these papers more or less in concert, with primary research and drafting of the paper on advanced nuclear reactor design taking place slightly earlier than the two policy papers. As such, though each of these papers reflects some understanding of the research, ideas, and concepts articulated in the other two, there are organic differences in emphasis, concentration, and interest.

There are also areas of clear convergence and stark divergence between and among the three papers. For example, all three papers operate from a baseline that views nuclear power as a useful – if not a necessary – part of the global energy mix. The broader, and important, debate of whether there is a role for nuclear power in a low-carbon society is outside the scope of these papers.

Even with this basic agreement, each of the three papers diverges on key aspects of nuclear power (such as the treatment of and concern with the threat of nuclear proliferation from widespread use of nuclear power). There are other areas in the papers in which differences of opinion exist, and most important, differing conclusions are reached—even when looking at the same historical episodes and present circumstances.

CGEP strongly believes in the importance of bringing together unique perspectives to address the most pressing energy issues. In the competition and comparison of ideas, and in debate and disagreement, the institution sees the acme of academic purpose. We hope this series of papers prompt a discussion about nuclear power and the trade-offs that exist in its pursuit.

AUTHORS' NOTE

The decision to identify this paper as an evaluation of the geopolitics of nuclear power and technology was a conscious one. In our view, the development of nuclear power and technology has been directly linked to geopolitical factors to a degree that is probably unprecedented in the history of science. Simple economics or even political analysis cannot explain how nuclear power has evolved and prospered in some areas of the world and faltered in others. Many variables—security, politics, economics, demographics, perceptions of safety, a desire for prestige—have all interacted at one time or another in most of the countries involved in the global nuclear enterprise to create the current situation. These variables highlight the opportunities and challenges that exist with regard to the development and use of nuclear power and technology.

In considering the geopolitics of nuclear energy, this paper starts with the premise that nuclear energy merits close consideration as a substantial source of zero-carbon energy and that the economic, safety, and proliferation issues around nuclear technology can be identified and managed. We appreciate and understand the significance of the challenges that exist in doing so; were it easy, there would be little need to discuss how and why. However, we also believe there is merit in the attempt.

EXECUTIVE SUMMARY

To a degree unique in science and in energy, nuclear power has been linked to geopolitical issues beyond its control for decades. Matters of safety, waste management, and proliferation are intrinsic to the technology. However, other issues—including the Cold War competition between Western and Eastern blocs for hearts and minds around the world—added to the complexity of the nuclear industry. These issues might have been subsumed for a time with the resolution of the Cold War, but new geopolitical issues—energy security and climate change foremost among them—have also arisen.

The authors believe nuclear power can play a constructive role in addressing the energy needs of the twenty-first century, both in the developed world and in emerging markets. For this to happen, though, policy makers and industry need to grapple with three key questions:

1. How can policy makers and the public better assess and balance the benefits and costs associated with nuclear power?

2. If nuclear is to be part of the global energy mix, what is the responsibility of the United States, Western Europe, and Eastern Asian countries, such as Japan and the Republic of Korea, to be part of it? Beyond international institutions, is there particular value in US, European, Japanese, or Korean companies in nuclear commerce in order to ensure the highest standards for safety, nonproliferation, and security remain at the forefront?

3. How can costs in deployment and research and government funding be managed to ensure adequate private sector investment and participation?

The authors offer three recommendations that can help to address these questions and face the challenges presented to nuclear power today, with an approach to the geopolitical issues around nuclear energy includes the following elements:

1. A concerted approach to demystify the science around nuclear power and to ensure local communities and the public at large have an appropriate appreciation for the role nuclear energy can play.

2. A renewed global partnership for managing the risks of proliferation that combines political and technical factors. This should include cooperation among governments to reduce the risk of nuclear reactors serving as Trojan horses for proliferation (either directly or as a result of their fuel needs), and it should include improved export controls on a global level.

3. Government support for nuclear research and development, both through investment vehicles and private public partnerships. It must also incentivize the safe, economic, and reliable operation of the current fleet of nuclear reactors. This should include mechanisms to streamline the R&D process, which has become saturated with designs that have no chance of entering production and sap millions in resources that might better be applied in bringing new reactor designs to market.

Nuclear power might yet fulfill the sense of promise that pervaded the 1950s and 1960s, when it was considered the energy source of the future, but a combination of policy decisions would be necessary to achieve this vision. To date, geopolitical competition, economic factors, and safety concerns have limited the reach of nuclear power. New geopolitical forces, such as the challenges of development and climate change, could reshape the international playing field for nuclear energy's benefit. Policy makers around the world will need to decide whether they wish to invest in such an effort.

INTRODUCTION

Carbon-rich fuels—coal, petroleum, and natural gas—offer many advantages over other energy sources. They have a superior energy density relative to almost all other fuel sources, they have a wide range of use, and they are relatively easy to transport and to store. Often they are inexpensive relative to other fuels, particularly when existing infrastructure exists so that supply can meet demand. For these reasons, fossil fuels are expected to remain a significant part of the world energy mix for several decades to come. Indeed, the Energy Information Administration (EIA) predicts fossil fuels will still account for about 78 percent of total world energy consumption in 2040.[1]

At the same time, fossil fuels present some downsides, particularly related to the environment and climate change. These well reported issues, taken in combination with the persistent desire on the part of countries around the world for more stable, more secure energy supplies, have sparked interest in alternative forms of energy production. Energy efficiency will play an important role in reducing the salience of fossil fuels, but advances in efficiency alone probably cannot make up what would be lost if fossil fuels were to be phased out. This is particularly true since some applications, such as transportation and petrochemicals, are still likely to be heavily dependent on fossil fuels for the near future. Renewable sources (such as solar or wind power) hold future potential, but given the requirements of the modern global economy, challenges of intermittency, and renewable sources' relative inferior energy density, other energy sources might also be needed. Nuclear power—with its high energy density and low carbon footprint—is a source with which the international community has decades of experience. However, the challenges that come along with the technology have kept it from becoming a more dominant factor in the global energy mix. Geopolitical issues lie at the center of many of these challenges.

Nuclear energy began in war. Albert Einstein and Leo Szilard first prompted the US government to pursue the promise of nuclear energy by appealing to then president Franklin D. Roosevelt to consider the possibility of Nazi Germany possessing an atomic bomb. Nuclear technology—both for weapons and for civilian applications—was then spurred on during the Cold War as a means of deterring war among the superpowers and their politically aligned blocs of states. It was also a means of providing development assistance to countries emerging from centuries of poverty and colonization. Even with the end of the Cold War, nuclear issues continue to play a significant role in global affairs. Concerns surrounding nuclear proliferation have been the cause of at least one war in the past fifteen years and have the potential to spark others. Competition among the exporters of civil nuclear technology has helped reduce the costs of nuclear power to consumers. However, it has also brought into question whether international regulations surrounding the construction, use, and export of nuclear technology are sufficient to ensure nuclear power is safe, secure, and proliferation resistant. While global climate change objectives have prompted a resurgence of interest in nuclear power as a potential source of carbon-neutral electricity, safety and waste management issues remain, and these chill interest. Even if countries forswear nuclear power, the poor safety practices of a state can spill across borders and threaten other entire regions.

To manage these issues, nuclear technology has understandably been swept up in a web of restrictions, regulations, and international conventions. Science still proceeds but with some degree of due caution and no small amount of red tape. These issues, combined with intrinsic problems in technological development and, for the United States, the need to re-create a nuclear supply chain that has withered in recent decades, have resulted in much higher costs and longer construction times than many expected at the dawn of the nuclear age. These costs might be the ultimate impediment to the advancement of nuclear technology and nuclear power to its next generation.

This paper identifies the geopolitical issues that have plagued nuclear technology, nuclear power, and nuclear science since the 1940s. It presents a number of interconnected issues that policy makers will need to address if they wish to truly capture the possibilities inherent in nuclear technology. This paper also offers possible solutions to help policy makers and business leaders make educated decisions regarding the challenges and opportunities of nuclear power.

Ultimately, there are tremendous advantages to either increasing investment in nuclear energy or holding the current course. Policy makers in particular must wrestle honestly and openly with these questions in order to devise the best solution with regard to nuclear energy, both for their own countries and for the international community as a whole.

BRIEF HISTORY OF NUCLEAR GEOPOLITICS

Though some initiatives sought to utilize nuclear energy as a chit in the global power struggle of the Cold War, civilian nuclear technology has struggled to move past its association with geopolitical conflicts, which has hampered its development around the world despite the energy needs of many populations and nuclear energy's own potential as a carbon-free energy source.

This is not to say there were no attempts to isolate civilian nuclear technology or to control military nuclear technology. In fact, shortly after the end of the Second World War, there were various proposals on both sides of the Cold War that would have either limited or reversed the nuclear arms race. These initiatives collapsed partly due to various implementation concerns—verification foremost among them—and the overarching imperatives of the East-West struggle, which seemed to dictate expanding the arms race instead.

The US response to these challenges was to try to clamp down further on sharing any information that might have permitted others to follow in the U.S. path of nuclear weapons production. The Atomic Energy Act of 1946 is striking in its various provisions that sought to prevent the proliferation of not only equipment and material associated with nuclear technology but also the underlying scientific data. Section 10(b)(1) of the act defined "restricted data"—to be controlled by the newly formed Atomic Energy Commission (AEC), which was later dissolved and incorporated into the new US Department of Energy after a brief period as the Energy Research and Development Administration (ERDA)—as "all data concerning the manufacture or utilization of atomic weapons, the production of fissionable material or the use of fissionable material in the production of power."[2] The AEC was empowered to license the dissemination of information but under very tight restrictions. The penalties for disclosing restricted data were also severe, ranging from five-figure monetary fines to ten to twenty years in prison to the death penalty for any person who "communicates, transmits, or discloses [various forms of restricted data], with the intent to injure the United States or with intent to secure an advantage to any foreign nation."[3]

A different mind-set emerged in the 1950s. By the time President Dwight Eisenhower took office in 1953, the Soviet Union had tested its first nuclear weapon, as had the United Kingdom. The Eisenhower administration realized that, though nuclear proliferation was a serious concern, it was increasingly impossible, in Secretary of State Dulles's words, to "dam…the flow of information" and prohibit its exploitation by other states.[4] Consequently, they determined they needed to change the approach.

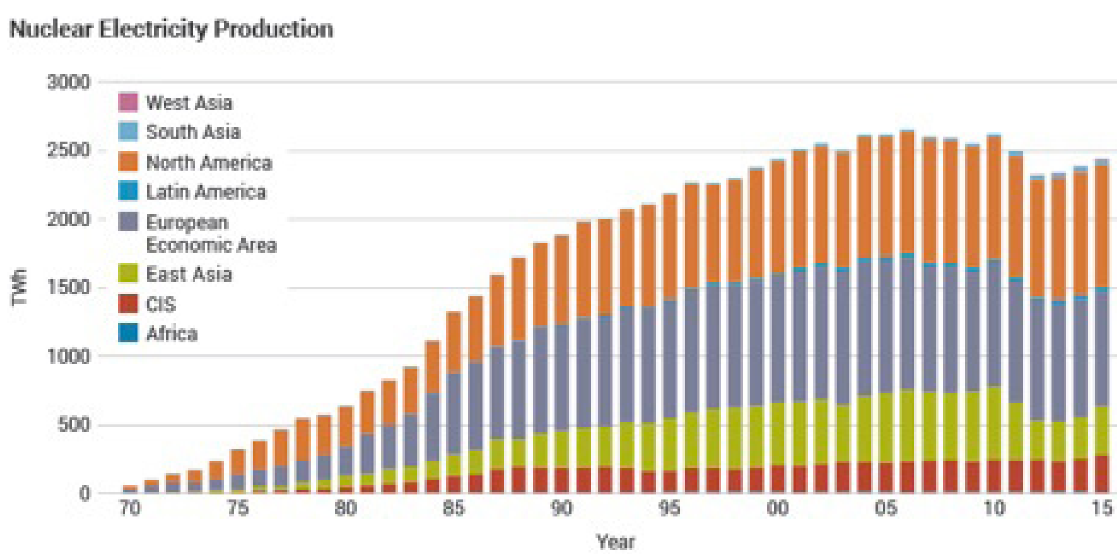
It began with an ambitious proposal, which President Eisenhower briefly outlined at a meeting of the UN General Assembly in December 1953. At its center was the idea of creating the International Atomic Energy Agency (IAEA), the mandate of which would be to explore the potential of civil nuclear technology. He noted explicitly:

> The United States knows that peaceful power from atomic energy is no dream of the future. That capability, already proved, is here—now—today. Who can doubt, if the entire body of the world's scientists and engineers had adequate amounts of fissionable material with which to test and develop their ideas, that this capability would rapidly be transformed into universal, efficient, and economic usage?[5]

The mission and functions of the IAEA grew into something different over time, and the concept of it actually serving as a nuclear fuel repository was dormant until the 2000s. At its heart, though, was the concept of enabling countries that were not among the advanced nuclear powers to take advantage of the nuclear age for a variety of uses and ensuring that nuclear facilities were not diverted from civil to military uses. The United States augmented this effort through its own national program, which was called "Atoms for Peace." President Eisenhower's speech would one day be called this. This program involved providing nuclear technology training and equipment to states around the world, including research reactors. This permitted scientists in a variety of countries to learn more about nuclear science and begin making their own contributions. This was enshrined in a 1954 revision to the original 1946 Atomic Energy Act (AEA), which allowed "nuclear technology and material exports if the recipient countries committed not to use them to develop weapons."[6] This policy led to the training of hundreds of foreign experts from industry and academia,[7] as well as the conclusion of nuclear cooperation agreements with dozens of countries.[8] The AEA also intensified US investment in civil nuclear development domestically. This was consistent with the Eisenhower administration policy that saw nuclear power as a potential future driver of economic growth.[9, 10]

The United States was not alone, and Atoms for Peace had a role in the global competition for hearts and minds. The Soviet Union built its first nuclear power reactor in 1954, which contributed electricity to the Soviet grid.[11] From there, it sought to expand its international nuclear presence, including by exporting reactors to those countries[12] that were within its geopolitical orbit. By 1975, 373 research reactors were operating in fifty-five countries, and throughout the 1980s and 1990s, the number worldwide more than doubled.[13]

Figure 1: Nuclear Electricity Production Worldwide



Source: IAEA PRIS

Notwithstanding the optimism around nuclear power and nuclear technology more generally, two problems would materialize: the reemergence of nuclear nonproliferation concerns and nuclear accidents.

Rebirth of nuclear nonproliferation

In the late 1960s and 1970s, concerns that states could take advantage of nuclear power to advance military uses reemerged. President Kennedy's warning in 1960 that ten to twenty nuclear weapon states could exist by the end of 1964[14] seemed on the verge of becoming true. Nuclear weapon tests by France and China, a "peaceful" nuclear explosion by India in 1974, and subsequent reports that Israel had developed nuclear weapons suggested runaway nuclear proliferation.

The international community responded in a variety of ways, though not uniformly and haltingly in some parts of the world. First, states joined together to negotiate and conclude the Treaty on the Nonproliferation of Nuclear Weapons, commonly known as the NPT. This treaty coalesced around a central bargain: that five states (China; France; the Soviet Union, which was later Russia; the United Kingdom; and the United States) would possess nuclear weapons but pledge to work toward disarmament. The treaty also stated the rest of the NPT's member nations would not pursue nuclear weapons and would submit to international monitoring to confirm this status. States in possession of nuclear know-how were expected to share the nonmilitary benefits of this knowledge with those not in possession of nuclear weapons, while ensuring they did not contribute to nuclear weapons development. The NPT did not ban the production or use of nuclear weapons altogether. In fact, states were permitted to withdraw from the treaty if they felt it was no longer meeting their needs, and the treaty itself was set to expire twenty-five years after it entered into force in 1970. However, it created the circumstances by which nuclear weapon states could agree with one another not to contribute to proliferation and by which nonnuclear weapon states could have confidence that the decision not to pursue such capabilities would not put them at the mercy of duplicitous neighbors.

The entry into force of the NPT also led to the second significant change: the restructuring of the IAEA and its mission. Given responsibility for monitoring nuclear programs around the world in article three of the NPT, the IAEA began to execute what were known as "safeguards agreements" with countries. These outlined the scope and mechanisms of IAEA's access to declared nuclear sites and the agency's right to investigate undeclared ones. These agreements applied the lessons of facility-specific safeguards approaches, which had existed since the 1950s. This time, though, it was on a bigger scale and with bigger stakes. Though the IAEA was not authorized to make judgments as to compliance by states with the NPT, it was assigned the task of verifying the correctness and completeness of the declarations given under these safeguards agreements. Should inconsistencies be uncovered, the IAEA was assigned the task of investigating them further and, if necessary, reporting problems to the UN Security Council.

This period also saw a reemergence of emphasis on nuclear export controls. These had not disappeared in the United States—even under Atoms for Peace. As discussed, the 1954 AEA only reset the level for how nuclear exports were to be conducted and with whom. However, the development of foreign nuclear weapons programs around the world put a spotlight on the differences in export control practices among states. The United States and other countries decided to work together to harmonize their practices and control lists. This was first manifest in the creation of the Zangger Committee in 1971, which sought to identify the kinds of goods the IAEA should monitor pursuant to the NPT, and in 1974, with the creation of the Nuclear Suppliers Group (NSG). Both these organizations consisted of states with significant nuclear technology or expertise, and they have sought, since that time, to create best practices and standards for nuclear trade. They have the objective of preventing nuclear weapons proliferation while still facilitating civil nuclear commerce. For example, the guidelines for nuclear trade the NSG developed and to which all participants pledged to adhere established the need for IAEA safeguards to be in place at the location to which nuclear technology would be transferred. Those guidelines also established commitments not to pursue nuclear weapons. The pendulum, having swung in favor of more transparency and openness in the 1950s, was swinging toward more restrictions.

Nuclear Accidents

Two nuclear accidents—one in the United States and one in the Soviet Union—contributed to increasing concern with nuclear technology safety.

In 1979, a mechanical failure at the Three Mile Island nuclear plant in Pennsylvania (aided by human error and design deficiencies) resulted in the partial meltdown of the nuclear core and unwarranted fears of a reactor rupture, which would have spread radioactive material around the region and, ultimately, the globe.[15] In the end, the incident is believed to have had minimal adverse health impacts on the surrounding area and even less on anything outside a few-mile radius. It contributed, though, to public fears about nuclear power and the risk of accidents.

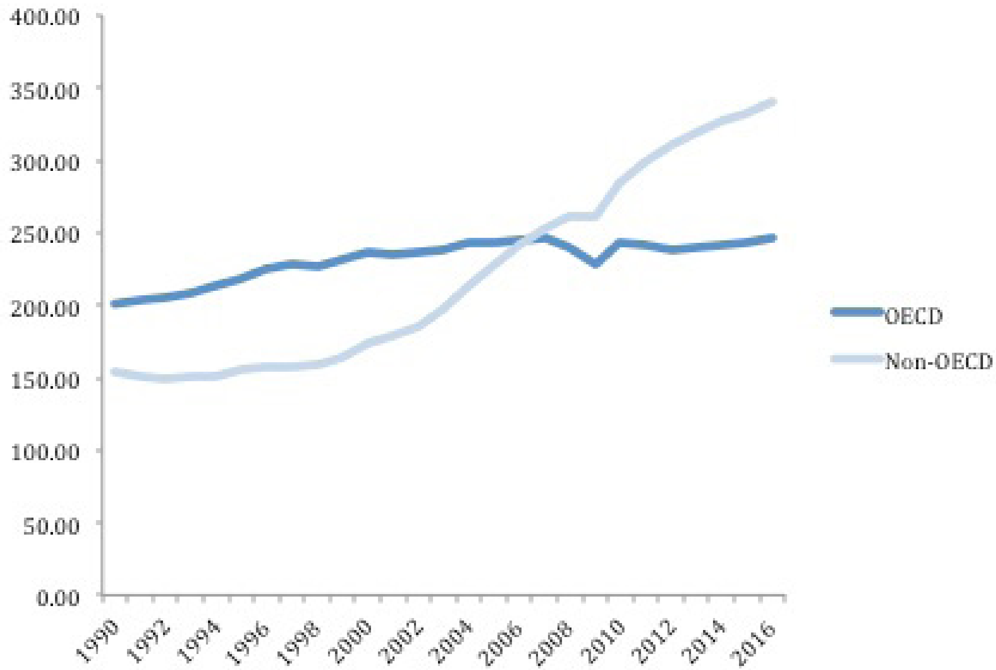
These concerns were heightened significantly by the far worse accident in Chernobyl, Ukraine, in 1986, which was then still part of the Soviet Union. This accident resulted in a steam explosion at one of the reactors at the site, the release of radioactive material, twenty-eight deaths, and radiation exposure to thousands more.[16] Though remedial steps were taken to limit exposure and address future risks from the site, it still contributed to a sense of unease internationally with respect to nuclear power.[17, 18] That these concerns did not show up immediately in the nuclear power developments identified in figure 1 is not surprising. Nuclear power plants are long-term development and construction projects, but, as figure 1 demonstrates, investment in nuclear power tapered off just as popular opinion was souring on the technology.

Into the 1990s and 2000s

For all this skepticism and concern, the benefits of nuclear power has allowed it to remain a consistent part of the developed world's energy mix from the mid-1990s through the early 2000s. It has also contributed to the exploration of new nuclear power programs by forty-five countries, with varying degrees of seriousness.[19] This can be explained by two related factors: the increased energy intensity of modern society and the associated costs of nonnuclear energy production.

Global energy demand continued to rise during the 1990s and 2000s, but in contrast to the pre-1990 period, most of this demand now shifted to developing countries and emerging markets. Figure 2 demonstrates this shift and the significant increase in energy demand. At the same time, there was a growing awareness of the costs associated with traditional fossil-based fuels, which have, thus far, spurred most global development. Between climate change and, prior to the recent drop in prices of both oil and natural gas, the economic costs and energy security concerns of relying on fossil fuels, there has been an incentive for countries to consider nuclear power as part of the energy mix.

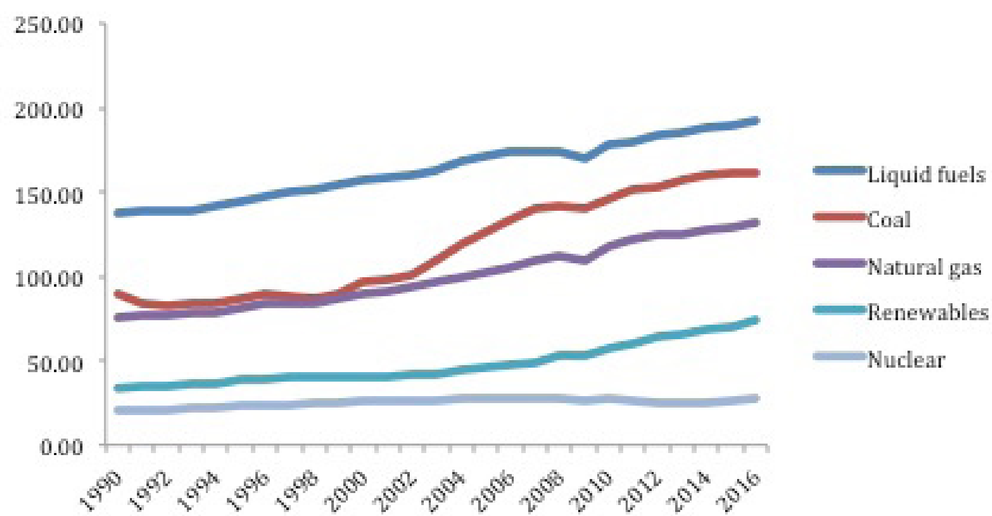
Figure 2: World Energy Consumption, 1990–2016 (Quadrillion Btu)



Source: EIA (Historical Data 1990–2012, Projections 2013–2016)

However, EIA data underscore that, while nuclear power has been part of the mix, it still provides a marginal contribution to the global energy mix. (See figure 3.)

Figure 3: World Energy Consumption by Energy Source, 1990–2016 (Quadrillion Btu)



Source: EIA (Historical Data 1990–2012, Projections 2013–2016)

This begs an obvious question: Why? Three reasons seem most likely: one, cost, including as compared to renewables, which are often incentivized via production credits; two, safety-related issues; and three, continued concerns about nuclear proliferation and security, which prompt greater restrictions on nuclear technology transfers.

Indeed, though the 1990s saw the end of the Cold War, they did not see the end of global competition or interest in nuclear arms as a means of dealing with perceived security needs. This, in turn, yielded an attempt to clamp down still further on the availability of certain types of nuclear technology.

This began with the discovery in 1991 that Saddam Hussein's Iraq was much further along in the development of nuclear weapons than had been suspected. Iraq had developed sophisticated nuclear technology for the production of weapons-grade material in secret—sometimes using buildings located on the same site as known, declared, and inspected civil facilities. This prompted the international community to consider and debate changes to the international regimes that guarded against proliferation. The result was a system of enhanced inspection authorities for the IAEA. This was contained in the Additional Protocol, or AP, so named because it would be additional to the safeguards agreements developed in the 1970s. There was also a tightening of export controls, particularly around dual-use items. These goods are called "dual use" due to their potential application in a variety of civil applications as well as for military uses. They are, therefore, more difficult to control without unfairly and unnecessarily impinging on normal economic activity. For example, some of these goods are relatively specialized valves, pipes, and metals, but they still have wide nonmilitary uses. However, in recognition of their potential applications in nuclear weapons and out of acknowledgment of Iraq's use of dual-use procurement mechanisms to develop its clandestine nuclear program, the NSG began to subject these transfers to additional scrutiny. The NSG also began to require countrywide IAEA safeguards before any nuclear transfers could be conducted, and the NSG sought other measures to prevent misuse of otherwise civil technology. This only intensified after revelations in 2003 and 2004 that a clandestine nuclear procurement network run by the father of Pakistan's nuclear weapons program, A. Q. Khan, had relied on inconsistencies in international export controls and practices in order to supply the nuclear programs of Libya and Iran and perhaps others. Taken in combination with the collapse of the Soviet Union and subsequent degradation of Soviet (Russian) nuclear security practices and controls, the result was an intensification of nuclear nonproliferation work throughout the 1990s and 2000s. In 1995, the NPT was extended indefinitely. This was partly out of recognition of the threat from the spread of nuclear arms—even after the end of the Cold War.

Not all this work was successful, though. The AP itself was a voluntary commitment that states would have to agree to accept. This reduced its immediate value and created the need for engagement and diplomacy to convince potential adherents of the value of the AP. Efforts to further tighten access to nuclear goods and technologies—particularly uranium enrichment and spent fuel reprocessing—foundered in the 2000s due to questions surrounding the inherent fairness of nuclear export controls. Many in the developing world suggested that developed countries sought higher standards for such transfers and related technical support so as to preserve their nuclear monopoly and not to address nuclear proliferation risk. For this reason, though proposals to expand the scope of export controls and to change the standards by which nuclear cooperation between states would function (such as requiring adherence to the Additional Protocol before any nuclear transfers could be entertained by NSG members), they were unsuccessful. The result has been at least the theoretical opening of gaps in standard practices by nuclear supplier states. Some, such as the United States, restrain nuclear cooperation absent significant assurances of good conduct, and others take a less strict approach. The zenith of this was the adoption of the "gold standard" for nuclear cooperation, which was found in the US–United Arab Emirates nuclear cooperation agreement of 2009. In this agreement, the UAE agreed to forswear development of uranium enrichment or spent fuel reprocessing technology, provided no other state in the region got a different arrangement for nuclear cooperation with the United States, and UAE could reconsider its pledge if need be. This standard later became problematic, as the UAE was the only willing adherent the United States could identify.

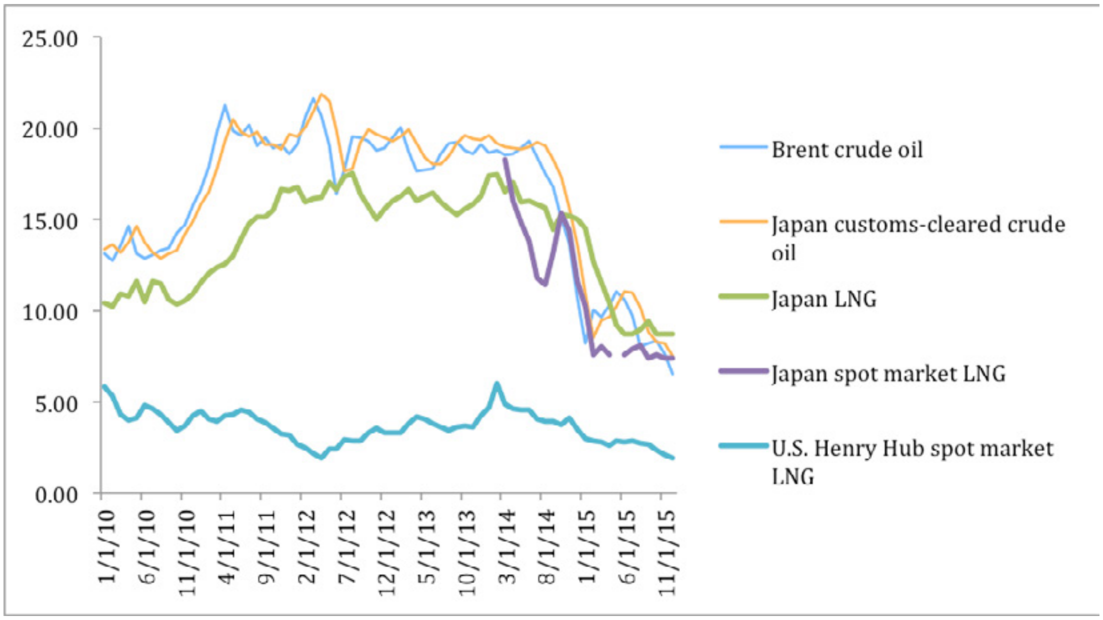
This too had a geopolitical component as nuclear trade became an important part of potential future commercial opportunities for some countries, such as Russia and China. Russia, in particular, has prioritized nuclear exports in its foreign trade policy, and its nuclear agency, Rosatom, has reported substantial economic returns on its nuclear export investments due to the long value chain that usually accompanies such deals.[20] By contrast, nuclear exports constitute a much smaller proportion of US international trade, which some attribute to the different (and higher) standard taken with respect to nuclear commerce by the United States.[21] This difference in economic significance also lends itself to different interpretations of the geopolitical significance of nuclear commodity and service controls.

Of course, demand was also changing, not least because of residual concerns regarding the safety of nuclear reactors. Though one could consider the events surrounding the Fukushima nuclear accident in 2011 to be a once-in-a-lifetime situation (involving a massive earthquake and subsequent tsunami), the fact that such an accident could take place in the highly developed country of Japan might be responsible for the decision of many countries in Europe—not to mention Japan itself—to reconsider the investments made in nuclear technology over the preceding years. That debate is still ongoing. Germany, for example, decided to phase out nuclear power in the country by 2022 immediately following Fukushima (though interest in Germany for less risky renewables predated the accident),[22] which led to an increased use of coal for electricity production in Germany.

The nuclear industry might have been able to manage these various different pressures in a different cost environment. However, a number of other factors, including the falling price of fossil fuels (especially natural gas) relative to nuclear power, the lack of a clear regulatory system, and a lack of signals from markets to invest in new low-carbon capacity, combined to further stymie the sector. Indeed, one of the many selling points the Russian government has taken to advertise its nuclear power programs is the integrated and long-term nature of the investment, essentially arguing that initial costs might be high, but when amortized across the sixty- to eighty-year life-span of many nuclear power plants, nuclear power ends up being a cost-savings investment—not to mention one with carbon-free value. The Russians are also marketing their nuclear plants as "build, own, and operate," – in which Russia would provide all of the technical services and sell power to the local utilities or governments.

To give an idea of the challenges nuclear power has been facing, let us briefly focus on energy markets and competition with natural gas. Until the US shale revolution and the associated drastic reduction in natural gas prices, as shown in figure 4, when people mentioned that nuclear power was risky, they often referred to the possibility of an accident. Today, for people in the nuclear industry, the biggest threat is natural gas. For different reasons, much the same could also be said for renewable energy sources. Natural gas is not only inexpensive and (for now) abundant, but the associated plants can be efficiently cycled to follow electric demand. Renewable energy from solar and wind sources, while intermittent by nature, is carbon free and subsidized around the world in various way, giving it a competitive advantage. In the United States, for example, federal renewable energy production and tax credits and state renewable portfolio standards tend to favor renewable generation and dispatching. This increases renewable competitiveness with respect to other energy sources. On top of this, nuclear power plants need to operate around the clock, both from an economic and technological standpoint. They cannot be cycled to meet electricity demand during the day. Taking all this into consideration, and when combined with relatively low natural gas prices, nuclear power's ability to compete is simply less.

Figure 4: Various prices



Source: Energy Information Administration, International Energy Outlook 2016, May 2016

The world is now facing a global environment that is deeply conflicted about the role of nuclear power in its energy mix. The current geopolitical challenges associated both with its spread and with resistance to its spread are immense. They merit further examination in our next section.

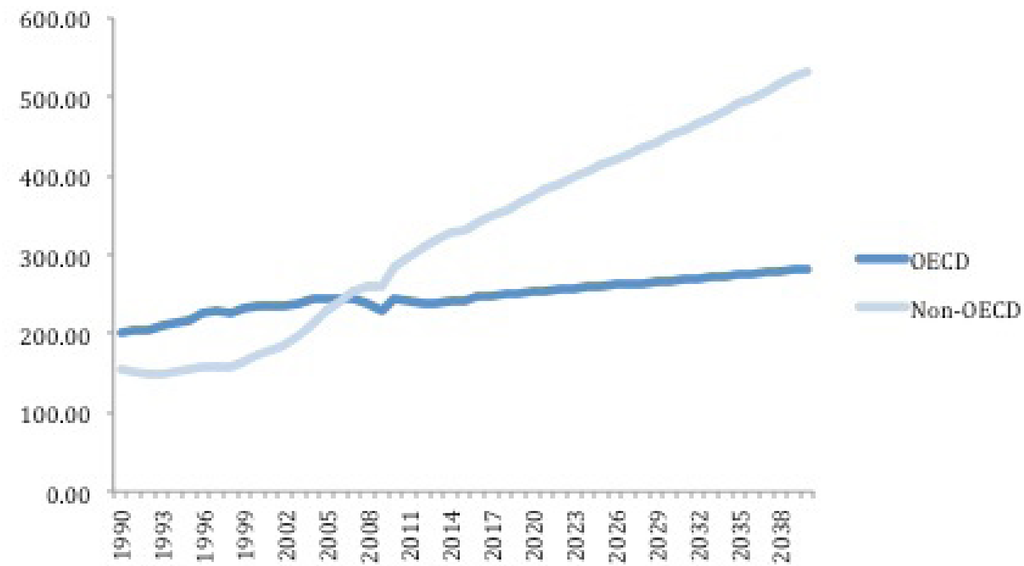
Current Geopolitical Issues

Going into the twenty-first century, the breadth of potential geopolitical issues has expanded from its twentieth-century conception. Beyond issues of nuclear proliferation and great power competition, new issues have emerged—energy security, climate change, and development foremost among them. This section reviews the state of nuclear power as it relates to these various issues.

Energy Needs in the Twenty-First Century

According to EIA, energy demand for the entire planet is going to grow precipitously from now until 2040, with non-Organization for Economic Cooperation and Development economies expected to be the primary drivers of growth. As figure 5 underscores, non-OECD energy demand in 2040 will be nearly double that of OECD economies. The average growth in consumption will fall between 1.5 and 2.6 percent annually after 2017. OECD energy consumption will average less than 1 percent annually during the same period.

Figure 5: World Energy Consumption, 1990–2016 (Quadrillion Btu)

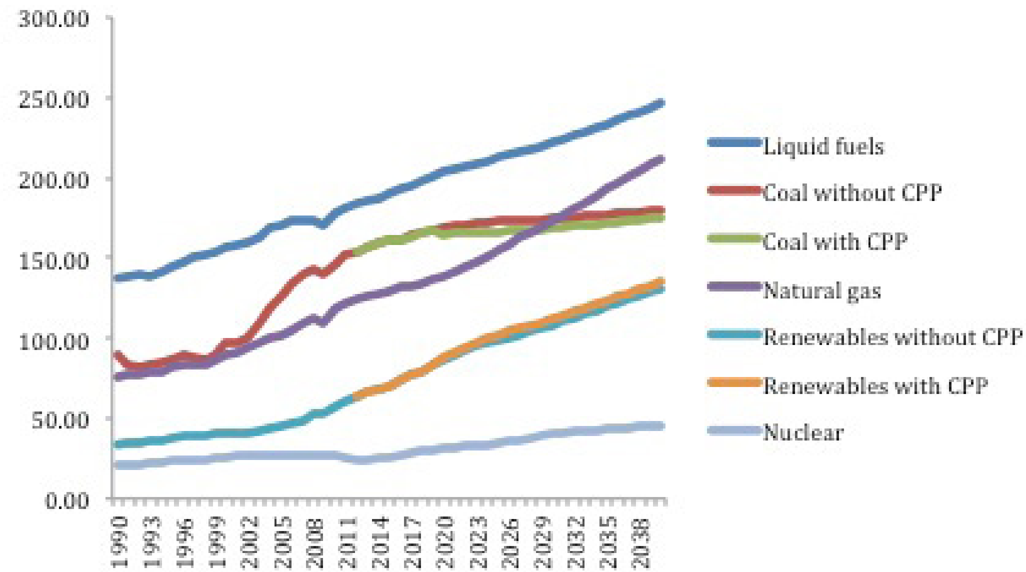


Source: EIA (Historical Data 1990–2012, Projections 2013–2016)

According to EIA, electricity generation from nuclear power worldwide is projected to increase from 2.3 trillion kWh to 4.5 trillion kWh between 2012 and 2040. This growth in new nuclear capacity is supported by growing concerns about energy security, greenhouse gas emissions, and air quality. Virtually all the projected net expansion in the world's installed nuclear power capacity occurs in the non-OECD region. This is led by China. Among OECD countries, only South Korea is expected to show a sizable increase in nuclear capacity—about 15 gigawatts (GW). At the same time, capacity reductions in Canada, OECD Europe, and Japan more than offset the increase in South Korea's capacity. As a result, the combined capacity of all OECD nuclear power plants will drop by 6 GW from 2012 to 2040.

Indeed, though consumption of nuclear energy will likely increase into the future, its role in the overall energy mix will remain modest under present projections.

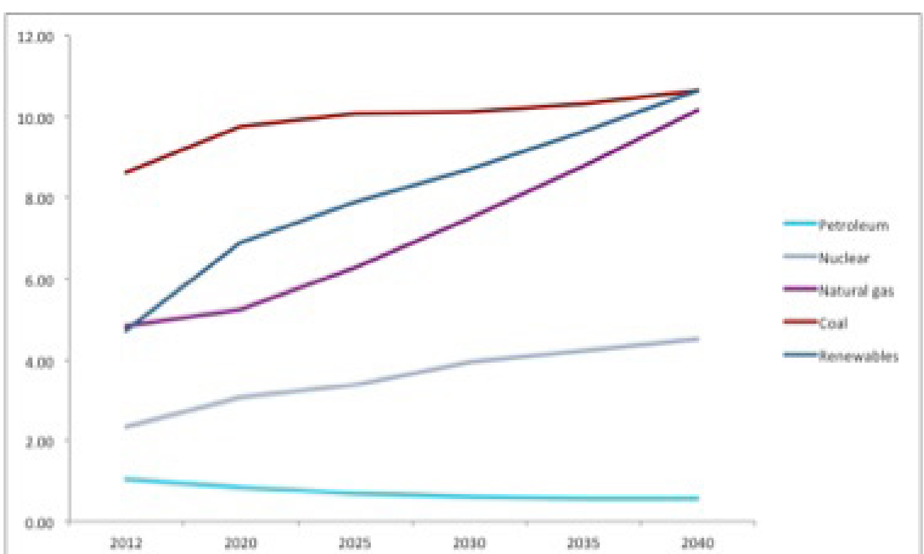
Figure 6: World Energy Consumption by Energy Source, 1990–2040 (Quadrillion Btu)



Source: EIA (Historical Data 1990–2012, Projections 2013–2040)

As shown in figure 6, by 2040, nuclear energy is only expected to fulfill 6 percent of global energy demand. Far from helping to address the problems of climate change, reliability, and energy security, nuclear will largely remain a marginal energy source. Its contribution to the global energy mix will be a mere 1 percent more than in 2016. A similar dynamic plays out with respect to electricity production specifically, as demonstrated in figure 7.

Figure 7: World Net Electricity Generation by Fuel, 2012–2040 (Trillion Kilowatt-Hours)



Source: EIA (Historical Data 2012, Projections 2020–2040)

The United States underscores this trend. In the United States, nuclear power contributes almost 20 percent of electricity production. It represents the single largest source of carbon-free electricity generation, accounting for almost 60 percent. Currently, there are ninety-nine commercial reactor units in operation, of which sixty-five are pressurized water reactors (PWRs) and thirty-four boiling water reactors (BWRs). The total combined capacity accounts for about 100 GW, but capacity is aging, and there are few near-term prospects for construction of new plants beyond the four units under construction.

Almost all US nuclear capacity comes from reactors built between 1967 and 1990. Due to the combination of market forces (including strong competition from natural gas generation), remaining useful life considerations, and regulatory effects, US nuclear capacity could begin declining rapidly after 2030. Many of the nation's active nuclear plant units are operating under license extensions that are due to expire in the next fifteen to thirty years. Only further license extensions, together with the development and deployment of new-generation reactors, could potentially offset this decline.

In light of expected electricity demand growth, to simply keep the current 20 percent share of overall US electricity production in 2040, nuclear generation capacity would need to increase to at least 125 GW. This is without even taking into account national and international emissions reduction goals or efforts to electrify the transportation sector. After factoring these into the scenario analysis, about 200 GW of nuclear capacity could be needed by 2050.

The role of nuclear power

Understanding the potential advantages and disadvantages of nuclear energy is critical for those stakeholders and decision-makers facing national energy challenges.

The case of the Tennessee Valley Authority's Watts Bar 2 reactor, which came online in October 2016, illustrates the challenges facing nuclear power in the United States. The 500 MWe pressurized water reactor was twenty years late and came in billions of dollars over budget because of various impediments to its completion and operation. Less than a week later, the Forth Calhoun nuclear power plant, run by Omaha Public Power District in Nebraska, was taken off-line for the final time. Market conditions, including historically low natural gas prices and lower energy consumption, were cited as reasons.

In the case of Japan, which needs to import about 84 percent of its energy requirements, nuclear energy has been a strategic national priority since 1973. This came under review following the Fukushima accident in 2011, but nuclear energy still officially remains a national priority. The first commercial nuclear reactor began operations in 1966, and pre-Fukushima, Japan's fifty-four reactors accounted for about 30 percent of the country's electricity production. This was planned to increase to about 40 percent by 2017. Following Fukushima, though, the entire fleet was shut down, and prospects are still very unclear. The forty-eight reactors currently operable are in the process of getting restart approvals, but this has been challenged by the ruling of district courts in response to local-level protests. Two approved reactors were stopped shortly after restarting due to a court injunction. This underscores the reality that, even in countries where there is a clear and pressing need for a stable, secure energy supply consistent with carbon emission levels, political factors can interfere with economic and scientific rationale.

In China, on the other hand, a totally different dynamic exists. Approximately 73 percent of China's electricity was produced from fossil fuels—predominantly coal—in 2015. This reliance on fossil fuels has led to a significant increase in air pollution in major urban areas and associated deep economic impact. The World Bank, for example, has evaluated the economic loss due to pollution at about 6 percent of GDP.[23] In response to these challenges, the Chinese leadership has prioritized extensive investments in nuclear and renewable energy. As such, the EIA now forecasts coal use in China will increase by only 0.3 percent per year, which is much lower than the average annual growth of 6 percent seen over the past thirty years.[24]

In China, nuclear power contributes to a tiny fraction of electricity production today. However, China is expanding its electrical generation from nuclear sources. Currently, there are thirty-six reactors in operation, but at least twenty-one additional reactors are under construction, and many more are planned. It is important to note that the age structure of these reactors differs remarkably from that of the United States. Almost 70 percent of the fleet was built within the last decade. As mentioned, though, in the United States, at least half of the fleet is over thirty years old. From a technological point of view, China has been making full use of Western technologies while adapting and improving them, and it is now self-sufficient not only in reactor design and construction but also with the nuclear fuel cycle. China's plan to export its technology abroad has raised questions about how China will engage in nuclear commerce and whether China will use its market position to push, as others have, for the highest standards of safety, security, reliability, and proliferation resistance. Certainly, as relates to proliferation, China's history is checkered. China might have helped to create the Pakistani nuclear weapons program,[25] and it might have engaged in nuclear commerce with Iran[26] and Algeria,[27] which raised questions about the nature of those countries' nuclear intent. On the other hand, China's nonproliferation character has improved since that time, with China joining the NPT in 1992 and NSG in 2004 and generally improving its export control practices.

Beyond questions about individual countries and their approaches, from a technological point of view, many factors influence the development and deployment of nuclear reactors. The accompanying Center on Global Energy Policy study on advanced reactor design identified and analyzed five of them: cost, safety, nonproliferation features, commercialization road map (including feasibility of construction and licensing), and management of the fuel cycle.[28] The paper also showed that optimization of one factor can lead to an adverse effect on another. For example, nonproliferation concerns might have a significant impact on fuel cycle management challenges.

Overall, though, there are some reactor designs that more efficiently and effectively satisfy the interest of enhanced safety, reduced cost, mitigated waste issues, managed regulatory questions, and reduced risk of contributing to nuclear weapons proliferation. Consideration should be given by policy makers around the world to identifying mechanisms for prioritizing further research and development on these types of reactor designs while reducing uncertainties surrounding whether regulators will approve the designs. These uncertainties greatly hinder the development and deployment of advanced nuclear technologies and increase associated costs. At the same time, the study also clearly shows there are at least fifty new reactor designs being developed, with at least thirty-five countries looking into adding nuclear power to the energy mix. These numbers highlight the discussed need to prioritize R&D further. In other words, a technology down-selection and standardization by the international community is needed in order to reduce R&D and licensing costs and truly leverage economies of mass production.

The significant technical, cost, and regulatory uncertainties of new nuclear technologies alone do not fully explain the private sector's reluctance to invest significantly in US nuclear power. Three more factors need to be taken in consideration:

1. The pressing need for a leveled playing field in order to recognize the cross-cutting benefits and costs for all generation options (for example, the value of carbon-free electricity production and of baseload capacity).

   In the United States, current policy and market designs fail to fully recognize the zero-carbon aspect, baseload, and diversity of fuel supply value of nuclear power generation. For example, the original goal of the Environmental

Protection Agency (EPA) Clean Power Plan (CPP) was to improve the competitive position of all new low-carbon electricity sources relative to fossil fuels. Even if CPP is now held up in courts and is facing uncertainty with respect to the Trump administration's approach to it, CPP brought good and bad news for nuclear power in the United States. New reactors and expansions of existing plants would have counted toward the plan's requirements for new sources of low-carbon energy. This presumably would incentivize the construction of new reactors. (This is certainly part of the equation in China, where nuclear energy growth is a core component of China's ability and endeavor to cut carbon emissions.) At the same time, because existing reactors would not count toward the plan's requirements, these reactors might have been priced out of the market, even if they still have years of usable life and investment ahead of them. CCP is just an example of the unintended consequences that policies can have on nuclear development and deployment. In the United States, the picture is complicated also by the federal renewable energy production and tax credits and state renewable portfolio standards, which tend to favor renewable generation and dispatching. This further reduces nuclear power competitiveness. Similar dynamics might take place in other countries needing to meet their climate change commitments, suggesting that a different approach ought to be taken with respect to nuclear power's pricing and contribution to the fight against climate change.

2. Persistent fear of unanticipated internal or external events to the project (such as nuclear accidents), which both chill investment and introduce reputational risk to utilities and investors alike.

3. The simple economic reality that nuclear technology requires a much longer project time horizon for private investors (up to sixty to eight years) compared to alternative investments. When financiers have a choice between multiple vehicles for investment, it is harder to sell them on the kinds of long lead times required for nuclear power to demonstrate its complete value. This risk was clearly exemplified in February. Japanese conglomerate Toshiba announced a dramatic exit from the nuclear business, landing another blow to a struggling sector. Toshiba had acquired a majority stake in Westinghouse Electric in 2006 and had plans for developing and deploying a new generation of smaller, cheaper, and safer power plants, as well as improved full-scale reactors. This included the four new reactors that, as we mentioned, are being built in the United States. The company cited cost overruns, technical problems, conflicts with contractors, and regulatory challenges as reasons.

Safety Questions

An unquestionable element in the declining attractiveness of nuclear power in OECD countries is the unsettled nature of the safety issue—at least in terms of public perception. In 2010, the Nuclear Energy Agency of the OECD released a comparison of safety statistics for various forms of energy production over 1969 to 2000, and it found that far more people had died because of conventional energy production than nuclear power.[29] Even after Fukushima, nuclear power remains a comparatively safe form of energy production, and development of new reactor designs continues to improve the safety characteristics. This is particularly the case with reactors that include passive safety features. These reactors don't require the involvement of personnel in order to deal with potentially dangerous situations. Today's new-generation reactors are already ten times safer than the previous generation of reactors, as addressed in the accompanying Center on Global Energy Policy study on advanced reactor design.

Moreover, the safety culture worldwide around nuclear reactors continues to improve, though with notable exceptions. The IAEA has published 128 specific safety standard documents that identify the best practices for addressing safety concerns in a variety of nuclear facilities, and work continues in order to develop new standards and to revise existing ones.[30] The IAEA also continues to engage in capacity building at the governmental, organization, and individual levels with a substantial program of technical assistance.[31] Countries have made commitments to nuclear safety. Eighty countries have ratified and are now implementing the Convention on Nuclear Safety, the foremost international nuclear safety agreement. This was finalized in 1994.[32] Nuclear companies have also contributed, forming organizations such as the World Association of Nuclear Operators and the Institute of Nuclear Power Operations in order to share information and best practices within the industry.

Still, there have been exceptions and questions raised with respect to this overall improved situation. Iran, for example, has yet to ratify the Convention on Nuclear Safety, notwithstanding its operation of the Bushehr Nuclear Power Plant in a zone of higher-than-average seismic activity. The result has been questioning on the part of other countries in the Middle East about the integrity of Iran's safety culture and the potential risks from it. The Joint Comprehensive Plan of Action (JCPOA), which addressed the problem of Iran's near-term ability to produce nuclear weapons, also included language about improving Iran-IAEA and Iran-EU cooperation on safety.

The IAEA has also worked to improve the overall performance of the international system, learning in particular from the lessons of Fukushima. Particular areas of interest have been the development and maintenance of independent regulators who are willing and able to enforce safety standards on their domestic industries.[33]

Waste

As mentioned, nuclear waste management continues to be an unresolved challenge for nuclear power. This is less because of the absence of technical solutions but more because of the politically problematic nature of those solutions. First and foremost, spent fuel reprocessing introduces questions about proliferation risk. This, in turn, generates interest in simple storage, but this also implies that spent fuel is treated as a waste—even if only a small fraction of the natural uranium is actually used. In addition, long-lived plutonium and other elements in the spent fuel pose long-term hazards that significantly increase the complexity of finding suitable disposal sites. On top of this, the political issues involved are immense. Though interest in nuclear power might persist, no jurisdiction wishes to become a geological nuclear waste disposal site (or, as the jurisdiction might see it, a nuclear waste dumping ground). In the United States, the Yucca Mountain controversy is instructive. After billions were spent to develop and prepare a site to house spent nuclear fuel, the facility was scrapped in 2009 due to policy—and, according to some, political—concerns with the plan in Nevada.[34]

Other countries have also dealt with this challenge. Starting in 1956, Japanese policy has been to maximize the utilization of imported uranium by reprocessing and recycling the unburned uranium and plutonium as mixed-oxide fuel (MOX). Even with the now low price of uranium, Japan has maintained this approach. Nuclear utilities are required to cover reprocessing and MOX production costs through fees based on kilowatt-hour of nuclear electricity generated. High-level radioactive waste interim storage facilities are in place to store used fuel before being reprocessed. As with the United States, the Nuclear Waste Management Organization (NUMO) has been searching for a permanent storage site for years.

China, which has no proliferation risk per se, given its declared nuclear weapon possession, also has a substantial reprocessing effort. This is considered vital for two reasons: first, to close the fuel cycle and to manage the increasing quantities of used fuel produced domestically and, second, to provide an export service in connection with the desire to sell nuclear reactors abroad. The main operator, China National Nuclear Corporation (CNNC), has in place both a series of agreements with French Areva and local initiatives. In addition to the reprocessing capabilities, siting together used fuel storage and high-level liquid waste vitrification facilities is also planned. To match planned growth, the World Nuclear Association estimates that an 800 ton per year reprocessing plant will be required every ten years. A site for geological disposal is under investigation.

From a technological point of view and for the long term, this issue could be addressed in two ways: either by developing and deploying advanced recycling or reprocessing technologies to extract the still-usable elements (plutonium and uranium) from the spent nuclear fuel or by designing advanced nuclear reactors that can fully use or burn these elements.

Finding a technical solution will also be essential, given the potential spread of nuclear reactors to even more countries and the consequent risk of proliferation. Left unattended, only political solutions will remain to deal with the problem of spent fuel management. Such solutions do exist and can play a role, such as Russia's long-term contract with Iran to repatriate its spent nuclear fuel back to Russia. However, because these solutions are also subject to revision, contest, and confusion (none of which is helpful insofar as international confidence in nuclear power is concerned), a more sustainable long-term approach would be advantageous. Here, though, we once more edge up against the problem of nuclear proliferation that is inherent in the use of the technology for power. For any new reactor or reprocessing design to be viable politically, it must demonstrate that the risk of contributing to future proliferation is less than whatever system it is replacing. This has yet to be achieved, notwithstanding the overall positive record that exists with respect to the nonproliferation character of nuclear power reactors.

Nuclear proliferation

Of course, the proliferation threat from nuclear technology stems from more than the nature of new reactor design and operation. There are a few signal cases of particular international concern, such as the nuclear weapons program of North Korea and Iran's nuclear activities (even after the 2015 JCPOA). There are also questions about the nature of nuclear technology dissemination, particularly as relates to dual-use items, the emergence of 3-D printing, and the availability of specific technical data on the Internet.

With respect to the first category of problems, as noted previously, regional concerns with the development of neighboring nuclear programs have been a feature of the nuclear age. What marks a difference today, though, is the degree to which one state's actions can be matched by others. Prior to the 2000s, a decision by one country to proceed down a nuclear weapons path could be matched by a modest number of neighbors. There simply was an insufficient technical and resource capacity in most countries around the world to make the kind of commitment necessary to a weapons program. Some exceptions do exist among states that were prepared to take the necessary risks and to make the necessary investment. This includes China in the 1960s, India and Pakistan in the 1970s and 1980s, and Iran and North Korea in the 1980s and 1990s. However, despite some strategic rationale for doing so in a variety of neighborhoods, the number of states that went far enough along to take the final step into nuclear weapons is comparatively small. The NPT helped to remove this strategic rationale for many of these countries, making technological impediments even less subject to challenge.

However, there has been renewed speculation that states as diverse as Japan, South Korea, Saudi Arabia, and the UAE might reconsider their non–nuclear weapon status to manage their relationships with their neighbors (North Korea and Iran in particular).

Some of this incentive has been reduced by international efforts to address proliferation behavior, particularly in the case of Iran. The JCPOA arrested Iran's nuclear program for at least ten to fifteen years and increased transparency into it for the international community. As one of the authors of this paper has written about separately, this probably has reduced the incentive for nuclear weapons development by other states in the Middle East.[35] Whether the JCPOA remains in effect under the Trump administration remains to be seen. In the case of North Korea, after ten years of opposition from the international community, that fact that it still possesses nuclear weapons might create long-term pressure on non–nuclear weapon states in the area to match its capabilities. The current alliance between the countries most affected by North Korea's weapons program—Japan and South Korea—has thus far helped to address the risk of proliferation there. In response to then candidate Donald Trump's statements that were interpreted to indicate acquiescence to their potential future acquisition of nuclear weapons,[36] both countries have reaffirmed their commitment to nuclear nonproliferation. Again, the degree to which this remains the case will be affected by the policies implemented by the Trump administration.

Outside of specific regional contexts, there are technical risks of proliferation that are not presently on the radar. In the past, national industry and sophisticated procurement networks were necessary to facilitate proliferation, but future proliferators might need far less infrastructure and support, reducing their detection risk and identification profiles. Between dual-use goods, the capability of states to fashion their own sensitive components free from the constraints of international export controls, and the widespread availability of technical data on sensitive nuclear processes, there is a real risk that undetected proliferation could take place.

This risk has naturally created an incentive to expand restrictions on nuclear commerce and nuclear know-how on the part of states concerned with proliferation. Some of this has a technical dimension. Organizations such as the NSG and IAEA continue to work to improve standards in export controls, nuclear safeguards, and nuclear security. Likewise, improvements in reactor design might, in time, reduce the overall proliferation profile of nuclear power, which could contribute to its wider use and acceptability internationally.

Nonproliferation also has its overtly political dimension. Some states have prioritized the nonproliferation mission to the extent that they have conditioned future nuclear trade on it. The United States has been at the forefront of this effort, requiring various forms of commitments from nuclear commercial partners to nonproliferation standards. This includes a voluntary renunciation of uranium enrichment and spent fuel reprocessing technology. The United States has not been alone, though. Japan also made nonproliferation a key element of its 2016 agreement on nuclear cooperation with India, and other suppliers have long histories of tying specific transfers with nonproliferation obligations.

Still, this is not a universal sentiment. Russia moved forward with the construction and fueling of the Bushehr Nuclear Power Plant in Iran during the height of international concerns with the Iranian nuclear program. China has maintained a plan to export nuclear power plants to Pakistan, claiming its contract to do so preexisted its NSG obligations to only export such reactors to NPT adherents (of which Pakistan is not one). Of course, the US decision during the Bush administration to open nuclear trade with India—which, like Pakistan, is outside of the NPT—helped to reduce some of the perceived barriers to proliferation abetting trade or, at a minimum, created unhelpful ambiguities.

At the beginning of 2017, there are many different crosscurrents in nonproliferation—just as there are in the broader sphere of nuclear commerce, nuclear power, and nuclear safety. The potential and value of nuclear power for energy production, climate change management, and contributions to a reliable alternative to existing sources is real but, clearly, so are the challenges.

Fundamental Questions Policy Makers Need to Resolve

Looking forward, there is a glaring need for policy makers in the United States, Europe, Asia, and beyond to address some critical questions about the future of nuclear power.

1. How can policy makers and the public better assess and balance the benefits and costs associated with nuclear power?

2. If nuclear power is to be part of the global energy mix, what is the responsibility of the United States, Western European countries, and Eastern Asian countries, such as Japan and the Republic of Korea, to be part of it? Beyond international institutions, is there particular value in US, European, Japanese, or Korean companies being in nuclear commerce to ensure the highest standards for safety, nonproliferation, and security remain at the forefront?

3. How can the costs of deployment and research and government funding be managed to ensure adequate private sector investment and participation?

These questions are not new. In fact, some have been present since the dawn of the nuclear age. However, they have not been satisfactorily answered to date, and the result has been a disjointed and confused approach to nuclear power worldwide. Moreover, how some of these questions are answered matters incredibly with respect to other parts of the puzzle.

For example, if we assume the issue of cost is not adequately addressed, then we can also assume the growth of nuclear power will continue to be as marginal as it is today. This, to a great extent, reduces the salience of nuclear power as a solution to energy security, climate change needs, and the need to manage proliferation and safety issues in a more flexible and adaptable manner. Indeed, if nuclear power remains a modest part of the energy mix, then there is even greater incentive (and certainly no disincentive) to pursue tighter restrictions for proliferation purposes because the negative effects of such a posture would be less salient.

For our part, we believe nuclear power is a comparatively safe form of energy with manageable proliferation, cost, and waste burden implications, and we believe it has potentially profound and positive impacts on climate change issues. In particular, nuclear power needs to remain a viable part of US and global electricity generation, especially if national and international emissions goals are to be met. To be successful, though, key public concerns—including plant operation, decommissioning, and waste management—need to be addressed. Moreover, given significant technical and cost uncertainties of new nuclear technologies, markets are not sending the necessary signals to invest in new low-carbon capacity. Policy makers need to provide long-term guidance and stability, both for their domestic purposes and as part of an international endeavor.

From this perspective, we would recommend an approach to nuclear geopolitics that includes the following elements:

1. **A concerted approach to demystify the science around nuclear power and to ensure that local communities and the public at large have appropriate appreciation for the role nuclear energy can play.** Certainly, this is easier said than done. However, it could start with a recognition by all stakeholders that nuclear energy could provide significant advantages in dealing rapidly with the challenge of climate change in a way that is sustainable for development and economic growth. Those eager to exploit the economic potential of nuclear power but resistant to the science of climate change could actually damage their objectives by not recognizing the carbon-free value of nuclear power, and they should take a more constructive attitude in addressing this challenge. Local communities could be supported with both educational campaigns and financial support to deal with the potential consequences of nuclear energy in a way that is reassuring as to its relatively safe nature and not alarmist.

   Globally, the international community can be assured of the relative security of nuclear power through enhanced nonproliferation, safety, and security measures.

2. **Renewed global partnership that combines political and technical factors in order to manage the risks of proliferation.** The last twenty years have seen considerable improvement in global nonproliferation, notwithstanding the cases that often make their way to the headlines. Improved export controls, safeguards, and nuclear security measures have reduced the risk of nuclear terrorism as well as proliferation. Progress is not the same thing as success, though. There are still nascent proliferation problems that should be addressed early on in order to prevent them from becoming serious security threats and impediments to the civil nuclear energy market. Many improvements could be made in the system, such as making the kind of extensive verification and monitoring provisions contained in the JCPOA a standard for IAEA safeguards in the future. However, a primary focus of effort ought to be on the likely upswing in nuclear commerce that will be necessary to support the non-OECD's projected appetite for nuclear energy.

An element of this will need to include export controls and transparency mechanisms to guard against dual-use goods and 3-D printing from contributing to proliferation. Simple steps, such as reporting requirements to the Nuclear Suppliers Group or to the IAEA, can provide information to support nuclear network analysts and to identify potentially sensitive—if not illicit—transfers of nuclear-usable commodities to unknown entities in unknown places. End-use verification mechanisms, which any exporter has a right to claim as part of the export process, can also help, particularly for items and materials that have a close overlap to nuclear use. Technical analysis of sensitive goods is the comparatively easy part of this equation; securing political support is far more difficult—especially given charges of cartelism on the part of the nuclear haves. To a certain degree, this is an intractable, persistent problem that can only be managed (and not overcome completely) by transparency into the proceedings that lead to tightened export controls and dialogue about the simple reality that, to enable nuclear commerce, proliferation risks must be mitigated.

Nuclear exporters should also strengthen the common guidelines that already govern this commerce to ensure they meet the highest standards for proliferation resistance. The guidelines published by the NSG go a long way, but there are improvements that could be made. Overcoming resistance to enhanced safeguards as a condition of supply, with the AP as its base, would be a good outcome. However, given the politics surrounding the AP and charges of discrimination among nuclear states, this might not be possible. NSG states could, therefore, consider modifying their guidelines to identify grades of nuclear supply and cooperation conditioned on the nonproliferation commitments and practices of the recipient states. For example, the NSG could agree that a state lacking an Additional Protocol would only be permitted to receive complete nuclear power reactor fueling and take-back packages. (This would essentially codify the Russian arrangement with Iran at Bushehr on a wider scale.) Such states could still receive technical assistance on other small-scale nuclear projects but nothing of any great sensitivity or proliferation risk (such as cooperation on fuel manufacturing or design). There might be other grades or criteria, but a central concept would be to reward and incentivize greater nonproliferation cooperation—with the promise of nuclear commerce the result.

This, of course, requires countries inclined to push these sorts of policies to be in the game and able to drive the consensus-based decisions that would be needed at the NSG. As outlined above, though, the current investment climate—from private and public sources—is decidedly negative in this regard. Government intervention and support in the United States and potentially in other countries sharing the same perspective (Japan, South Korea, partners in Europe, and so on) will need to be part of the effort.

3. **Government support for nuclear research and development—both through investment vehicles and private public partnerships.** The safe, economic, and reliable operation of the current fleet of nuclear reactors must be incentivized. Different countries can address investment barriers in different ways, but as discussed, identifying investment priorities and investors will be of paramount importance in determining the extent to which nuclear power will remain a viable part of the global energy future. At the same time, it is important to keep in mind that geopolitical factors can tip the scales in favor of a country investing in nuclear power or not. In the context of energy security, these factors include using nuclear power as a hedge for uncertain natural gas supply, price outlook, and climate policies. From a foreign policy perspective, these factors can include the utility of using nuclear power to demonstrate technological expertise or as a bargaining chip in a national security context.

One important way to reduce the overall cost of nuclear energy and its associated R&D would be to explore ways to develop a consolidated list of advanced power reactor designs to be pursued. Nuclear reactor design work can and should be a field in which any good idea gets an airing. However, as the advanced reactor design study conducted by the Center on Global Energy Policy highlights, as of today, the number of new designs being developed is problematic. It suggests an expenditure of resources on many designs that have no plausible chance of being built. It also suggests a risk that dozens of distinct reactors will be built in time, increasing the cost of each individual reactor by taking away some of the possibility of mass production.

To date, at least in countries like the United States, the answer to this problem has been straightforward: let the market decide among the reactor designs. However, the nuclear market has already been subject to so many severe distortions (from regulatory risk to nonproliferation instruments to a more positive pricing environment for alternative sources of fuel) that a purely market-based solution might be less effective. It might instead be prudent to find a way of reducing costs and streamlining the industry without swerving into cartelism.

There are many different forums in which nuclear energy experts meet to discuss and consider the future of the industry. One function of this ongoing dialogue could be an attempt to find ways of pooling R&D resources and down-selecting from this prodigious list of potential reactor options. Naturally, there are competitive impulses that would hamper such an effort, and generally such market forces ought to be encouraged. Moreover, certain reactor designs and types might be more appropriate in one market or geographic area than another. Still, some consideration ought to be given to identifying a short list of preferred reactor types that could meet a variety of different operating parameters and needs. This would help to create redundancy in nuclear fuel supply, which would help to reduce the need for states to develop their own fuel cycle capabilities as fail-safes in the event of a disruption, and to ensure a common view of the proliferation, safety, and security factors.

This last point bears particular mention: with down-selecting and a more harmonized list of nuclear reactor designs, it would also be easier for nonproliferation, safety, and security standards to be developed and enforced because they will all cover (more or less) the same standard facilities. This has great potential for reducing some of the various safety and security risks that exist with nuclear facilities, but it also has the potential to address the problem of fairness and equal treatment.

Nuclear power might yet fulfill the sense of promise that pervaded the 1950s and 1960s in regard to nuclear power as the energy source of the future, but a combination of policy decisions would be necessary to achieve this vision. To date, geopolitical competition, economic factors, and safety concerns have limited the reach of nuclear power. New geopolitical forces—such as the challenges of development and climate change—could reshape the international playing field for nuclear energy's benefit, and policy makers around the world will need to decide whether they wish to invest in such an effort.

NOTES

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