JESSICA LOVERING AND KENTON DE KIRBY

WHY THE UNITED STATES SHOULD PARTNER WITH AFRICA TO DEPLOY ADVANCED REACTORS

US regulators and companies have yet to make the most of rich opportunities for nuclear innovation and deployment across the African continent.

Africa has nuclear power in its future. Interest in nuclear energy technologies among African nations is considerable and growing. Of the 30 countries identified by the International Atomic Energy Agency (IAEA) as interested in nuclear power programs, one-third are in Africa. Although the first commercial nuclear plant in these countries may be decades away, now is the time for potential international partners to start taking Africa's nuclear power ambitions seriously.

But why nuclear for Africa's energy development? The energy density of nuclear fuel is certainly among its primary selling points. Nuclear fuel is so dense that quantities sufficient to power 2 million people for a year can be delivered in a few shipping containers —by truck, rail, or barge. However, nuclear power's most prized attribute for rapidly industrializing countries is its reliability. Once built, nuclear plants provide cheap, reliable electricity for 40 to 60 years. Lack of a reliable energy supply has taken a toll in Africa, compromising economic prospects and environmental quality. A recent paper in *Nature Sustainability* found that the frequent power outages across sub-Saharan Africa increased reliance on backup diesel generators, exacerbating pollution and raising costs for consumers.

Although nuclear power is often opposed, especially by renewable energy advocates, for its costs, technological complexity, and possible risks, no scale-up pathway for energy at the level needed in Africa is without its potential shortcomings. Some observers have argued, for example, that the infrastructure and logistics required for natural gas pipelines and coal delivery by rail can make fossil fuels unreliable in developing countries. And whereas renewables such as wind and solar are growing fast in the developing world, their intermittency and high cost make them a difficult energy source for powering an urbanizing and industrializing Africa. Hydroelectric power has been a foundational and reliable energy source in developed and developing countries alike, but its fuel source depends on geography, and the long-term environmental consequences at least in part offset short-term benefits.

All the same, if its advantages are to materialize in African countries, nuclear's deployment will in all likelihood need to follow a different path than it took in the developed world. The history of nuclear power in the developed world is the story of large-scale light-water reactors (LWRs), which are expensive to build, water-hungry, and require huge grid capacity. The deployment of traditional LWRs in developing African nations, therefore, will need to anticipate and address these challenges. Fortunately, advanced nuclear reactor technology, such as small modular reactors (SMRs), could dramatically reduce these countervailing forces—provided there was an international export market that made them available.

Here, we document the genuine interest in and progress toward commercial nuclear power programs among several African countries. We identify the largest barriers these countries must surmount to realize their nuclear ambitions, and we discuss how new advanced nuclear designs under development in the United States and abroad could lower these barriers to deployment. We then offer recommendations tailored to the United States, with particular attention to the regulatory conditions that make it difficult for US nuclear companies to forge relationships with interested African countries and thus prevent them from competing in the African export market. Finally, we argue that in its engagement with emerging economies, the United States must seek to make nuclear a socially equitable and politically sustainable energy option.

Africa is interested, but faces challenges

Even though there is intense international interest in energy development across the African continent, conventional wisdom holds—South Africa notwithstanding—that nuclear energy makes no sense there. This view can be challenged on a number of grounds. For one, several developing countries in other parts of the world have successfully undertaken nuclear power programs in the past to fuel their rapidly industrializing economies, and there is no reason why African nations could not be similarly successful. For another, a number of African countries have already taken serious steps toward commercial deployment.

South Africa is the only country with an operating commercial nuclear power plant on the African continent, but it's far from the only country with an active nuclear science and technology sector. Nuclear research or medical reactors are operating in Algeria, Egypt, Ghana, Morocco, Nigeria, and South Africa. And many countries are starting to explore international partnerships to import and build their first commercial nuclear power plants. Many of these agreements will likely change, but we recognize at least 11 African nations whose nuclear energy ambitions deserve ongoing attention (see text box).

A number of African nations have also made notable regulatory progress, advancing along the three phases laid out in the IAEA framework Milestones in the Development of a National Infrastructure for Nuclear Power. South Africa has of course completed all three development phases. But Ghana has also hit all the 19 infrastructural milestones set out in the framework's Phase 1 and has established the requisite legislative and institutional structures for procuring a reactor. Nigeria has already drafted a law to establish its national regulator, and in 2015, the IAEA conducted two missions to Nigeria in support of its nuclear program, the results of which showed that the country had adequate emergency preparedness and response framework in alignment with the IAEA's safety standards (although IAEA also concluded that Nigeria needed to improve its policies on spent fuel and radioactive waste management).

Although there is understandable concern about weapons proliferation and the security of nuclear facilities in developing countries, African nations have made laudable progress on non-proliferation, with all but two countries (South Sudan and Western Sahara) ratifying or acceding to the international Non-Proliferation Treaty. Over half of the countries have ratified the Additional Protocols to the treaty, which allow the IAEA to verify that states are complying with their comprehensive safeguards agreements (including all the countries pursuing nuclear power, except Tanzania). Almost all countries have signed the African Nuclear Weapon Free Zone Treaty (also known as the Pelindaba Treaty)—prohibiting all activities related to nuclear weapons development, transport, and use—and a majority have ratified it.

A security nonprofit group in the United States, called the Nuclear Threat Initiative (NTI), publishes a security risk index for developing countries, based on the threat of theft of nuclear materials. Ghana is in the group's lowest risk group, and several of the other prominent nuclear power aspirants on the continent—Kenya, Nigeria, Uganda—have rankings in the middle. Only Egypt was placed in the highest risk group. While the NTI's evaluation suggests room for improvement, it places several African nations at a level comparable to countries already constructing their first nuclear power plants in other parts of the world, such as Bangladesh and Turkey (both of which are having Rosatom, the Russian state energy corporation, build their first plants). That may be still be concerning, but it suggests that some African countries could be close to first deployment if they received assistance from a nuclear vendor such as Rosatom. The United States should engage early to help these countries improve their nuclear security infrastructure, rather than dismiss them as not ready for commercial nuclear.

But the ambitions and preparations of African nations for nuclear power are matched by serious obstacles. The challenges of starting a commercial nuclear program—controlling costs, building the necessary infrastructure, resolving water scarcity, and ensuring sufficient highly skilled human resources—can be daunting for any country, much less a developing one.

Playing nuclear leapfrog

Such obstacles suggest that African nations are unlikely to achieve their nuclear ambitions by adopting expensive, high-capacity LWRs. Instead, they will need to pursue advanced nuclear technologies that can dramatically lower the barriers to deployment and allow them to leapfrog today's dominant reactor designs. One of the most mature advanced reactor technologies is small modular reactors, which are similar to the reactors that have been deployed on naval vessels since the 1950s. Several US companies are pursuing SMRs with capacities up to 300 megawatts (MW) that can be manufactured in a factory and transported to the power plant site for deployment by ship, train, or truck. Because of their much smaller size and factory fabrication, they are projected to have lower capital costs and shorter construction times than LWRs. And due to their modularity, additional units can be added to meet growing demand and as grid capacity permits.

The most mature SMR design in the United States comes from the company NuScale Power, which has submitted its design for licensing and is looking to start construction in the early 2020s for its first commercial customer, the Utah Associated Municipal Power System. Of particular promise in the African context are new SMR designs with integrated desalination facilities to provide clean water for drinking or agriculture. In South Korea, the SMART Power Company is marketing a 100MW SMR that can also produce some 10 million gallons of potable water every day. Jordan and Saudi Arabia have both shown interest in deploying this technology.

A small number of US and European companies are also working on extremely small modular reactors, or microreactors, which have capacities of 20MW or less and can operate for up to 10 years without refueling. The owners and operators of these reactors, sometimes dubbed "nuclear batteries," do not have to handle fueling or maintenance, thus making them suitable for African countries that lack a technical workforce with training in nuclear technology. Microreactors could also be a good option for off-grid industrial and mining operations, which are often the largest energy consumers in developing countries.

Using already proven reactor technology, several companies are developing floating and stationary offshore

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Grid capacity is among the greatest barriers that African countries face. The typical nuclear reactor under construction around the world today has a generating capacity of well over 1 gigawatt (GW). A rule of thumb for power grids is that a single power plant should not make up more than 10% of their total grid capacity, so as not to disrupt the system if the plant is offline. This consideration alone would rule out many African countries that are looking toward a nuclear future, including Kenya (with a 1.5GW grid capacity), Ghana (3GW), and even Nigeria (6.5GW).

Financing nuclear plants presents another intimidating hurdle. A 1GW power plant could cost upward of $3 billion (in US currency), which would be a tough sell to the government of Ghana with a 2016 gross domestic product of $43 billion or Kenya with $71 billion.

Because thermal power plants withdraw significant quantities of water, worsening water scarcity could also be a limiting factor for South Africa, Namibia, Algeria, and Tunisia, each of which are projected by the World Resources Institute as facing severe water stress by mid-century.

nuclear plant designs, using either SMRs or traditional large LWRs mounted on vessels or offshore platforms. These nuclear plants have easier access to cooling water, and their location away from land makes them not subject to damage from hazards such as tsunamis and earthquakes, which could make them easier to license from a safety perspective. Rosatom in Russia and two companies in China are developing small-scale floating plants, less than 200MW. In the United States and South Korea, groups of engineers at universities have put forward conceptual designs to deploy existing large-scale commercial designs on offshore platforms, such as Westinghouse's AP1000 reactor. Although the larger designs may not be appropriate for countries with smaller grids and budgets, for smaller floating plants, siting and construction challenges could be greatly eased. Plants could be manufactured elsewhere and shipped to the host country, ready to plug into the grid. Sudan has expressed interest in being the first foreign customer for Rosatom's floating design.

Yet another advanced design under development is the high-temperature gas reactor (HTGR). Because these reactors use gas rather than water as their primary coolant, they operate at much higher temperatures and thus much higher efficiencies, making them smaller and vastly reducing water demand. They also use a ceramic fuel that can withstand significantly higher temperatures, making a meltdown extremely unlikely. China's State Nuclear Power Technology Corporation has completed construction of its first modular HTGR, which was slated to start producing electricity for the grid in 2018. There are also several US companies developing HTGRs, some of which expect to start the licensing process within the next five years.

African countries have expressed great interest in the potential use of such advanced reactor designs, but in interviews with representatives from state utilities and atomic energy agencies, they insist that they need proven technology. With no desire to be the world's guinea pig for untested nuclear technologies, these countries want the new reactors to be first built and operated successfully in their country of origin. And indeed, even though most advanced reactor designs being developed are likely at least a decade or more away from deployment, this time frame matches well with the development planning schedules for the most mature programs in Africa. Countries such as Nigeria and Ghana, which are furthest along, most likely will need at least a decade to build out their regulatory structure and human capital to be ready to operate their first nuclear power plant.

Mutually beneficial partnerships

Although advanced reactors hold great promise, the countries that dominate the African nuclear export market—overwhelmingly Russia and China—are offering

NUCLEAR ASPIRATIONS IN AFRICA

ALGERIA has two research reactors, one supplied by China, the other by Argentina. The government had a goal to have its first nuclear power plant operating by 2029. It signed nuclear cooperation agreements with Russia and the United States in 2007 and with China in 2008. In 2014 it signed another agreement with the Russian state energy corporation Rosatom to build its first nuclear power plant by 2025, four years earlier than its previous goal.

EGYPT's early nuclear power ambitions were supported by the Soviet Union, but later commercial efforts were interrupted by conflict with Israel in the 1960s and political unrest in the 2010s. In 2017, Egypt signed a new agreement with Russia to build up to four 1.2 gigawatt (GW) reactors to start operation in 2026.

GHANA has been interested in nuclear since the 1980s. Currently, the Ghanaian government's road map for nuclear power set a target of 700 megawatts (MW) of capacity ready for commissioning by 2025 and later expand to 1GW. A joint study by the International Atomic Energy Agency and UN Energy conducted in 2006 found that Ghana could realistically have a 300MW reactor generating electricity by 2025. Ghana signed a nuclear cooperation agreement with Rosatom in 2015 to allow Ghana and Russia to partner on nuclear projects.

KENYA is looking at coastal and river sites to meet its goal of developing 1GW of nuclear power capacity by 2027 and expanding to 4GW by 2030. The Kenya Nuclear Electricity Board signed an agreement with China General Nuclear Power in 2015 and two more with Rosatom and the Korea Electric Power Corporation in 2016. *Continued on next page →*

NAMIBIA would like to leverage its large uranium deposits, which constitute about 7% of global reserves, to produce electricity from nuclear power. Namibia has received a proposal from China General Nuclear Power to build its first nuclear power plant.

NIGERIA's Atomic Energy Commission in 2010 selected four potential nuclear power sites to install 4GW of nuclear capacity by 2025. The commission and Rosatom have signed an agreement to develop a plan for building two reactors at two different sites. Additionally, Nigeria has signed a Memorandum of Understanding with a US company to develop small modular reactors.

SOUTH AFRICA is the only African country with an operating nuclear power plant, which has been producing 5% of the country's electricity since 1984. South Africa still has plans to expand its nuclear power capacity to 9.6GW, but has faced heavy financial and political constraints.

TANZANIA has issued a permit to mine uranium to a subsidiary of Rosatom called Uranium One, and the country also has an agreement with Rosatom to help it develop nuclear power by 2025.

TUNISIA signed a nuclear cooperation agreement with France in 2007 and Russia in 2015, but concrete plans have not been released.

UGANDA has signed several international agreements with the goal of developing two 1GW reactor units by 2031. These agreements are with China Central Plains Foreign Engineering Company and the China Nuclear Manufacturing Group in 2017 and then another with Rosatom in 2016.

ZAMBIA signed an agreement with Rosatom in 2016 with a target of building about 2GW of nuclear power capacity in the country within 10 to 15 years. The agreement also includes local worker training and educational programs for the public.

only traditional LWRs.

Rosatom, which manages Russia's nuclear assets globally and offers high-capacity LWRs, is the world's largest exporter of nuclear technology to developing countries, thanks to its generous financing and worker training. Rosatom has signed nuclear power agreements with Ghana, Kenya, Nigeria, and Uganda, some of which include concrete plans to build power plants. But there is hesitation to build a power plant that may constitute over 50% of their electrical generation, especially if it was built and operated by a foreign firm. Even in Tanzania, there are reports that Rosatom has its subsidiary proposing the country's first nuclear research reactor. Russia was also asked to bid on the construction of 9.6GW of new nuclear power in South Africa.

China, which is currently building more LWRs domestically than any other country, is also highly engaged in developing the African market. China completed its first nuclear export project in Pakistan in 2000 and is looking to gain a larger share of the nuclear export market, particularly in developing economies. China has recently signed nuclear agreements with Kenya, Sudan, and Uganda to share information and train personnel on its domestic Hualong reactor, and its leaders appear keen on increasing the country's scope of nuclear influence on the African continent. In 2014, two Chinese companies, the China Nuclear Engineering Group Corporation and the State Nuclear Power Technology Corporation, signed agreements with the Nuclear Energy Corporation of South Africa, with both agreements focused on training for nuclear power plant construction and project management. China General Nuclear owns and operates the world's second-largest uranium mine, in Namibia, and its subsidiary Swakop has submitted a proposal to build a small LWR power plant there. China has also built research reactors in Algeria, Ghana, and Nigeria.

The world's other nuclear exporters—including the United States, Canada, and France, which dominated global exports historically—have minimal roles in Africa, if any. The United States' retreat from fostering nuclear power in Africa, or anywhere really, has been magnified of late with the bankruptcy of Westinghouse, which was the main US nuclear vendor bidding for projects abroad.

Kenya for now remains the only African country to sign a major nuclear agreement with a South Korean nuclear developer, the Korean Electric Power Corporation. The deal, signed in 2016, has both countries agreeing to share nuclear expertise and collaborate on the construction of nuclear power technology.

Argentina has built research reactors in both Algeria and Egypt, but may lack the diplomatic clout to carry out a large-scale commercial power project. Argentina's

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national atomic energy commission is developing a domestic 100MW SMR, but African countries may be unwilling to sign an agreement with Argentina without the financial, regulatory, and infrastructural support of a country with an established track record in nuclear construction.

Yet the United States still has an opportunity to help interested African nations overcome the obstacles to realizing their energy ambitions. Whereas Russia and China have large government investments in a few advanced nuclear technologies, the United States has a robust and thriving private sector for advanced nuclear development, drawing on both decades of public research and development and a high-tech investment ecosystem. From large national laboratories to small venture-backed start-ups, the United States has over 50 firms working on a diverse portfolio of advanced nuclear designs, many targeting smaller or niche markets.

The US government should pave the way for advanced nuclear companies to market their products in Africa. This means signing bilateral agreements much earlier with African nations sincerely interested in nuclear power, without which US nuclear companies will have trouble getting approval to collaborate, share information, or export nuclear technology with these nations. Unfortunately, the United States has tended to wait until a country wants to import a particular nuclear technology to sign bilateral agreements.

Finally, the government should tackle one of the largest barriers to the development of nuclear power in newcomer countries: opposition from international financing institutions, including the World Bank, which have long-standing, explicit policies against funding nuclear power projects. The US government should lobby these institutions to change such policies in light of new technologies and business models. Small and advanced nuclear designs could actually be a better fit for sustainable development than many projects that the institutions fund today. The United States has significant power in these organizations and should use it to effect change.

There is a future in which innovative US nuclear companies develop mutually beneficial partnerships with African nations, deploying advanced nuclear technology that better matches their needs—simultaneously helping US companies make their technologies cheaper and fueling Africa's economic development without contributing to climate change. Realizing this synergy, however, will take work, but the potential payoff for all parties would be well worth it.

If the United States is to become more involved in the emerging nuclear market in Africa, however, it must not repeat the mistakes of the past. From French atomic weapons testing in Algeria to the extensive US mining of uranium in the Congo and cooperation with the white minority government in South Africa, the history of nuclear technology in Africa is rife with exploitation. Today, there are similar concerns of exploitation through China's investment policies and Russia's all-inclusive power projects. The United States should chart a new course, with the intention of creating equitable partnerships—supporting strong democratic institutions, promoting good governance over nuclear projects, and helping African governments meet their own economic and energy goals.

__Jessica Lovering__ is the director of the energy program at the Breakthrough Institute and a doctoral student at Carnegie Mellon University. __Kenton de Kirby__ is the content director at the Breakthrough Institute.

Recommended reading

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