U.S. Department of Commerce
International Trade Administration

The Commercial Outlook for U.S. Small Modular Nuclear Reactors

Manufacturing and Services Competitiveness Report

February 2011

In May 2009, President Barack Obama called for harnessing the power of nuclear energy "on behalf of our efforts to combat climate change and to advance peace and opportunity for all people." Meeting the energy, environment, and climate demands of the 21st century will require creating new solutions and reimagining older but still crucial technologies. Civil nuclear technology combines elements of both approaches.

Although large reactors that produce in excess of 1,000 megawatts of electricity (MWe) are the most common, they are not the only possible designs for power stations. In fact, small modular reactors (SMRs), many of which are built on proven, well-known technology, could meet the power and heating needs of countries worldwide while significantly reducing carbon emissions. SMRs could also help U.S. companies increase exports and create new jobs. And some SMRs could be designed to safeguard nuclear technology and fuel from falling into hostile hands.

This report provides an overview of U.S. SMR development, examines the strengths of the technology, looks at the market characteristics that correlate best with SMRs, and identifies in greater detail the obstacles to SMR deployment. The report will conclude with recommendations for U.S. policy-makers and industry to facilitate the safe and secure deployment of SMRs in the medium to long term and to contribute to national and energy security, climate change mitigation, and economic growth.

SMR designs are promising to industry as a commercial opportunity and to governments as a way to meet growing energy needs with non–fossil fuel–based energy. They must be deployed, however, with the same safety and security measures as for larger reactors. Because of the long life of nuclear reactors, the nature of nuclear waste, and the serious consequences of any potential accident, a thorough design certification and licensing process must be in place. While decades of experience and a world-class regulatory system have given Americans comfort that nuclear power can be safely and securely deployed, evaluating the new U.S. SMR designs will take time and cooperation between vendors and the Nuclear Regulatory Commission (NRC).

Some significant challenges to eventual SMR deployment exist. Some of those barriers relate to foreign markets, such as the need for additional bilateral nuclear cooperation agreements with foreign countries, intense foreign competition (often from state-owned enterprises), and the lack of a global nuclear liability regime. Other obstacles are domestic. Those issues include the erosion of U.S. nuclear manufacturing capacity and the need for strong government assistance, such as manufacturing tax credits and loan guarantees specifically for manufacturers. Although technical hurdles remain before SMRs will be ready for commercial use, overcoming the other obstacles will be critical to the eventual deployment of U.S. SMRs.

INTERNATIONAL TRADE ADMINISTRATION

Terminology Note: Active and Passive Safety Features

Most existing reactors have active safety features, which are electromechanical devices that are engineered to provide reactor cooling and to shut off other systems in the event of a reactor incident. Passive safety features, however, rely on physical forces or properties, such as temperature or gravity, rather than the operation of specific equipment to prevent serious accidents. These features reduce the risk of failure inherent in engineered components.[4]

SMR Overview

The International Atomic Energy Agency (IAEA) defines small reactors as producing equivalent electric power less than 300 MWe, although larger reactors could also be categorized as modular (that is, able to be assembled from standardized, mass-produced subcomponents). In the SMR context, *modular* essentially means that the main components of the reactor are constructed in an off-site factory and are delivered to the plant under construction for final assembly and installation. In contrast to small reactors, most reactors deployed in the United States have electric power capacities between 800–1,200 MWe. Most of the newer large reactor designs, such as the Westinghouse AP1000 and the GE-Hitachi ESBWR, have capacities between 1,100–1,600 MWe. Traditionally, those reactors have been built from the ground up on site; however, an increasing amount of modular components are being used in the newest large reactors.

In many ways, the history of small reactors began in the late 1940s and 1950s when the United States pursued using nuclear reactors to power military operations and naval vessels. The *U.S.S. Nautilus*, the first nuclear-powered submarine, was launched in 1955, and today the U.S. Navy operates 82 vessels powered by 103 nuclear reactors.[1] A one-of-a-kind nuclear-powered civilian ship, the *NS Savannah*, was launched in 1962, also using a small reactor to power the vessel. It was used for goodwill tours and even cargo runs before being taken out of service in 1970.[2] Other countries, including China, France, Russia, and the United Kingdom, also operate nuclear naval programs. The U.S. Army also experimented with using small reactors to power military bases and to provide electricity in remote areas; however, the program was halted in the mid-1970s.

Naval reactors are typically pressurized water reactors (PWRs), produce 50–300 MWe depending on ship type, and can be refueled far less frequently than existing civilian reactors. (They are allowed by the Department of Defense to use more highly enriched fuel than civilian reactors.) In some ways, current U.S. SMR proposals resemble the naval reactors that have been operating for decades.

A number of U.S. SMR designs are currently being pursued. They share a number of essential characteristics that set them apart from existing reactor designs: (a) smaller dimensions and scaled-down electricity-generating capacity, (b) reduced number of components, and (c) modularity and potential for factory assembly and rail-shipping. Some SMR designs also include new fuel cycle approaches and new safety and security postures (including passive safety features[3]).

SMR designs can also be generally categorized into two groups: those based on existing light water reactor designs, and those that use a coolant other than water. The second group can be further divided into gas-cooled reactors and liquid metal–cooled reactors.

Light-water reactors (LWRs) use ordinary water as the coolant. The most common types of LWRs are boiling water reactors and PWRs.[5] U.S. SMR designs that also use ordinary water as a coolant include the Babcock & Wilcox mPower, the NuScale Power Module, and the Westinghouse IRIS. The manufacturers of those designs have the advantage of decades of collective industry experience operating LWRs and have the existing manufacturing and infrastructure to support LWR production.

There is also a range of U.S. SMR designs that use coolants other than water and prepare fuel in unconventional ways. Several different government and industry consortiums (including in the United States through the Next Generation Nuclear Plant Program[6]) are pursuing high-temperature gas-cooled reactors. Those reactors use a gas, such as helium, as a coolant, rather than water. This coolant allows the reactor to operate at a higher temperature, which, in turn, produces hot gas that can (a) have its heat transferred through a heat exchanger for use in industrial applications, (b) be put through a steam generator to drive an electricity-generating turbine, or (c) be used to directly drive a turbine. Other advanced designs in the United States include liquid metal–cooled fast reactors, which use liquid metals, such as sodium or lead, as the primary coolant. GE-Hitachi's PRISM, Hyperion Power Generation's Hyperion Power Module, and Advanced Reactor Concepts' ARC-100 are examples of liquid metal–cooled designs.

Strengths of SMRs

A primary advantage of SMRs is in their production. Their small size means that they do not need the ultra-heavy forged components that currently can be made only by Japan Steel Works and Doosan Heavy Industries in South Korea.[7] In most of the current U.S. SMR designs, the reactor pressure vessels and other large forgings could be supplied by domestic vendors, which would create U.S. jobs and potential exports of SMR components to international customers. In addition, most SMR designs allow for factory manufacturing, which could potentially provide opportunities for cost savings, for increased quality, and for more efficient production. Those attributes mean that SMRs could be a significant source of economic growth in the United States.

Some SMR advocates say that smaller reactors have a cost advantage. Conventional nuclear power plants tend to have high capital costs per MWe. Advocates say that the modular production and smaller size could lower capital costs and give quicker returns on investment. The modular nature of SMRs also means that power stations could be built in a stepwise fashion, generating electricity and revenue more quickly to pay for further expansion. Theoretically, SMRs could reduce operating, maintenance, and fuel-cycle costs, because many designs could operate for longer cycles than do existing reactors (although more frequent outages and inspections might be required for safety purposes). Additional cost savings could be realized if a smaller on-site workforce compared to that used for traditional reactors is able to provide the necessary safety and security oversight for plant operations.

In addition, some nuclear manufacturers maintain that economies of scale mean large reactors are more cost-effective in the long run, even if SMR capital costs are lower. In other words, although individual SMRs might be cheaper to build than larger reactors, the larger reactors can produce significantly more electricity over long periods of time; thus, the cost per kilowatt-hour of electricity from larger reactors is lower than that for SMRs. One way this cost difference might be resolved is by building SMRs in parallel. In other words, reap the cost savings of modular manufacturing while building enough modules to duplicate the electricity output of a larger reactor.

Some SMRs could be suited for specialized applications. The small size and output of some designs could provide advantages over large nuclear units for industrial or district heating applications because using a traditional reactor would be too expensive and would produce far too much energy to be used efficiently for those purposes. SMRs could also be used for energy-intensive activities located in remote areas, such as desalination plants and certain mining operations. A similar application could be to provide heat and electricity for oil shale recovery, which is a particularly energy-intensive operation. If nuclear reactors, rather than fossil fuel–based technology, could power oil extraction from tight shale then they could significantly lower the carbon emissions from such recovery and make the extraction more attractive.

Another potential long-term strength of SMRs is that some designs could also support nuclear non-proliferation objectives. All U.S. SMRs are designed to be deployed in an underground configuration. Industry observers contend that this would limit the risk for aboveground sabotage (which is a serious consideration for traditional nuclear power plants) or for radioactive release. The fuel cycle (particularly uranium enrichment and reprocessing) is where most non-proliferation concerns lie. The U.S. SMRs likely to be deployed in the near term are similarly fueled as the exist-

Terminology Note: SMRs

The abbreviation SMR is used interchangeably to mean "small or medium-sized reactor" and "small modular reactor," with the latter definition becoming increasingly dominant within the industry. Therefore, this paper defines SMR as "small modular reactor."

ing LWRs, but some U.S. vendors argue that the United States could exercise greater influence in the global nuclear fuel trade if U.S. SMR technology were widely deployed.

Some U.S. SMR vendors claim that their designs could be "black boxed" (that is, they could be deployed already fueled), and once the fuel is spent, the entire unit could be shipped back to the factory for waste handling and reprocessing. If the responsibility for the fuel cycle is taken out of the hands of the reactor operator, then risks of proliferation could potentially be reduced. Significant technical issues, however, remain unsolved for this concept, and there are serious outstanding questions involving transportation, waste handling, safety, and security. Although an attractive idea, such designs are unlikely to be deployed in the near or mid term.

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Markets Ripe for SMR Solutions

Traditional nuclear reactors provide base-load electricity. Those nuclear reactors are usually run on a continual and constant basis to provide electricity to meet the minimum demand, or base load, as opposed to some other power plants (such as natural gas-fired units), which are generally run to provide electricity during peak demand periods. Because nuclear power plants are typically large (both in size and electricity output), they require (a) significant upfront investment (roughly $5 billion per plant, though costs can vary widely); (b) an electricity grid capable of handling the power output of the plant; (c) the ability to responsibly manage the nuclear waste generated by the reactors; (d) a need to account for and to minimize environmental impacts; and (e) general public acceptance. The last point can be especially contentious, particularly in countries where, for historical reasons, nuclear power is viewed as more "dangerous" than other forms of energy. Those factors could significantly limit the markets in which traditional large nuclear reactors can feasibly be deployed.

The significant benefits of nuclear power (in particular the production of base-load electricity with little greenhouse gas [GHG] emissions), however, are causing countries to consider how they could deploy some type of nuclear reactor. SMRs could be a solution for certain markets that have smaller and less robust electricity grids and limited investment capacity, and thus limited ability to build the infrastructure needed for a large reactor.

SMRs might also be a good fit in markets where anticipated electricity demand is projected to increase incrementally, because SMRs could be built in series as needed. SMRs could also be used as a power solution for smaller areas that are experiencing rapid population growth and electricity demand, as a heat solution for specific industrial processes, or as an energy solution for energy-intensive activities such as desalination.

SMRs might be particularly attractive in countries that currently rely on diesel generators for producing limited amounts of expensive electricity. Small reactors could make economic sense because of the high cost of diesel generation compared to the low marginal cost of producing electricity from nuclear energy. (This advantage, however, might be eroded by the initial investment costs and the need to establish a national regulatory program.) Some SMRs could also be a solution for markets that lack the qualified engineers and skilled craft workers needed to construct large reactors on site, because they could be modularly fabricated and then delivered for assembly.

Finally, given the growing prominence of climate change concerns, one particularly attractive feature of nuclear power is its ability to produce base-load electricity with negligible GHG emissions. As developing countries in particular move toward low-GHG emissions growth strategies, SMRs could provide a low-emissions power solution. From the perspective of potential SMR vendors, countries that offer tax and other incentives for low-GHG emissions technology are particularly attractive for SMRs, if nuclear is an accepted technology under those development plans. (See the appendix for an evaluation of potential overseas markets for SMRs.)

International Obstacles to U.S. SMR Competitiveness

A number of U.S. companies are pursuing SMR technology for commercial sale, including GE-Hitachi Nuclear, Westinghouse Electric Company, NuScale Power, Babcock & Wilcox, Hyperion Power Generation, Advanced Reactor Concepts, and General Atomics.

Just like exporters of traditional large reactors, U.S. SMR vendors would face intense foreign competition, primarily by state-owned or state-aligned enterprises. Foreign nuclear companies have enjoyed significant government support, ranging from direct government ownership and management to favorable financing, industrial coordination, and support for manufacturers.

Some U.S. suppliers also regard the lack of international licensing standards as an obstacle to expanding their business. They say that obtaining regulatory approval in one market does not provide any "leg up" in obtaining approval in another market, which means that the process has to be repeated for each country that the supplier wants to sell to. However, it is difficult to see how international licensing standards could be developed or enforced given the unique national circumstances that factor into a regulator's licensing decision-making. The discretion of these national regulators cannot be compromised. More generally, U.S. suppliers also say that the lack of regulatory infrastructure in many countries interested in SMR technology is a problem for ensuring the safe and secure deployment of the technology. This challenge also applies to larger, traditional reactors.

Nuclear liability is a significant concern for SMR and large reactor designers. Currently, no global nuclear liability regime exists. This situation not only complicates commercial arrangements, but also means that, in the unlikely event of a nuclear incident, claims for damages would be the subject of protracted and complicated litigation in the courts of many countries against multiple potential defendants with no guarantee of recovery. The IAEA-sponsored Convention on Supplementary Compensation for Nuclear Damage (CSC) is the only international instrument that provides the basis for establishing a global regime, including countries with and without nuclear power facilities. U.S. nuclear suppliers have stated that the implementation of CSC is a necessity for pursuing a major nuclear export program.

Domestic Obstacles to U.S. SMR Competitiveness

There are also domestic policies that hinder U.S. SMR competitiveness, with some policies relevant to all nuclear suppliers and some specific to SMR deployment, both at home and abroad.

One obstacle is diminished manufacturing capacity. U.S. nuclear competitiveness is hampered because U.S. manufacturing capacity has been eroded through the lack of new reactor construction during the past few decades. Some government resources to help manufacturers are not appropriate for nuclear suppliers, or the resources exclude the suppliers entirely. For example, only two U.S. nuclear manufacturers qualified for the advanced energy manufacturing tax credit. The timeline to be eligible for the credit requires a facility to be up and running four years from certification. Some U.S. firms say that the timeline is too short for many nuclear suppliers; just acquiring the high-precision machines necessary to retool and rebuild capacity can require a lead time of several years.

Some U.S. suppliers also note that the United States currently levies tariffs between 3.3 percent and 5.2 percent on key nuclear reactor components, but the tariffs are currently suspended in some cases (specifically for reactor pressure vessels and steam turbine generators that were ordered before July 31, 2006). Tariffs around the world, particularly in the European Union and South Korea, are higher on such components. Coupled with significant foreign government support, foreign suppliers can more easily enter the U.S. market, while U.S. manufacturers face a significant trade barrier in key foreign markets.

Generally, SMR vendors say that additional 123 agreements (see terminology note) are needed

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Terminology Note: 123 Agreements

The term 123 agreements refers to nuclear cooperation agreements required by section 123 of the U.S. Atomic Energy Act of 1954, as amended, before significant transfers of nuclear material, equipment, or components from the United States to another nation can take place. Without a 123 agreement in force, U.S. firms cannot engage in substantial nuclear trade with another country. Currently, the United States has bilateral agreements with 21 countries and Taiwan, plus agreements with the European Atomic Energy Community (which includes the 27 European Union member countries) and the IAEA.

with new markets overseas to legally permit U.S. companies to engage in trade of major nuclear reactor components and fuel with those markets. Once the 123 agreements are in force, U.S. companies may still need to obtain authorizations and licenses from the Departments of Commerce, Energy, and State, as well as from the Nuclear Regulatory Commission (NRC). Many companies say that the process is challenging to navigate. The Department of Commerce, through its Civil Nuclear Trade Initiative, published the "Civil Nuclear Exporters Guide" in 2009 to help U.S. companies with this process.[8]

According to some U.S. suppliers, several other U.S. government policies may pose challenges to SMR deployment. For example, to meet the requirements of the Omnibus Budget Reconciliation Act of 1990, as amended, the NRC assesses a uniform annual fee for each licensed nuclear power reactor under 10 CFR Part 171.[9] The total annual fee for each operating power reactor includes a spent fuel storage and reactor-decommissioning annual fee. Separate from the annual fees assessed under 10 CFR Part 171, an annual premium for the nuclear liability insurance pool is required by the Price–Anderson Act. In 2009, the NRC issued an Advance Notice of Proposed Rulemaking to consider whether to amend 10 CFR Part 171 to establish a variable annual fee structure for power reactors based on the reactor's licensed power limit contained in the operating license. If the NRC issued regulations based on a variable fee structure accounting for reactor size, then it is reasonable to assume that the annual fee assessed to SMRs would be less than the annual fee assessed to the current large LWRs.

Another consideration U.S. SMR vendors have to address is that the NRC's requirement for the emergency planning zones (EPZs) around reactors does not generally take into account the size of a reactor. SMR vendors argue that the smaller size means that a smaller protection area could suffice, which would maintain safety while providing cost savings. The NRC's regulations do allow the size of the EPZ to be adjusted on a case-by-case basis for reactors that are gas cooled (such as the high-temperature gas-cooled reactor designs mentioned earlier) or have a thermal output of less than 250 MW. This exception would cover many of the proposed SMR designs, if the vendors can demonstrate that a smaller EPZ is acceptable on the basis of their emergency planning. Adjusting the 250 MW limit could cover the rest of the U.S. SMR designs not currently eligible for this potential size exception. Aside from the size regulation, additional costs related to emergency planning stem from state and local regulations, which cover environmental protection, police and fire coverage, and other services. SMR vendors will need to work with operators and state and local authorities to determine if SMRs warrant adjustments to those other existing regulations.

Other suppliers suggest that current NRC requirements for staffing and security systems at a reactor site would be unnecessary for an SMR, because the requirements should be tied more closely to reactor size. The staffing and security requirements (colloquially referred to as "guns and guards") are a necessary expense for reactors to ensure the safe operation of the reactor and the security of the nuclear material. If the deployment of SMRs allows for reduction in those costs, SMRs could be more attractive to potential customers. For the NRC to consider adjustments to those requirements, however, SMR vendors must engage in a technical discussion with the regulator and demonstrate how the reactors could be safely and securely operated with fewer control room operators and guards. U.S. suppliers also say that they enjoy a cooperative relationship with the NRC and that progress is being made on addressing those issues.

Another obstacle is that the NRC is facing a significantly increased workload as it reviews new LWR designs and prepares to issue the first combined operating licenses for new large reactor construction in the United States. Many industry representatives say the NRC needs more funding and additional resources to properly review SMRs in a timely fashion. Yet the NRC has significantly increased its staffing during the past several years, including hiring almost 500 new staff members for the Office of New Reactors, which was established in 2006.

One additional obstacle is beyond the scope of this report but could play a significant role in whether SMRs are commercially deployed: public opinion. To the extent that the smaller profile of SMRs results in their deployment closer to population centers, public opposition to their deployment might rise. Deployment at existing sites, or in industrial applications away from residential areas, however, might minimize the impact of public opinion. Education about the safety features of SMRs and nuclear reactors in general could also ameliorate this concern.

Impact of SMRs on U.S. Job Creation

A serious obstacle to the resurgence of traditional nuclear power in the United States is the eroded domestic manufacturing capacity for the major nuclear components. A robust program of building SMRs, however, could make use of existing domestic capacity that is already capable of completely constructing most proposed SMR designs. SMRs would not require the ultra-heavy forgings that currently can only be made overseas. U.S. suppliers say that firms could retool using existing capabilities and resources and could source most of the components of SMRs here in the United States. This ability could mean tremendous new commercial opportunities for U.S. firms and workers.

A substantial SMR deployment program in the United States could result in the creation of many new jobs in manufacturing, engineering, transportation, construction (for site preparation and installation) and craft labor, professional services, and ongoing plant operations. As SMR manufacturers prove their designs in the domestic market, they will likely consider export opportunities. The modular nature of SMRs and their relative portability means that locating export-oriented SMR manufacturing and assembly could make sense for U.S. companies, as opposed to the localization that is typically necessary for building larger reactors.

Outlook

Although SMRs have significant potential and the market for their deployment is growing, their designs must still go through the technical and regulatory processes necessary to ensure that they can be safely and securely deployed. Light-water technology–based SMRs may not be ready for deployment in the United States for at least a decade, and advanced designs might be even further off. Light-water SMRs and SMRs that have undergone significant testing are the most likely candidates for near-term deployment, because they are most similar to existing reactors that have certified designs and significant operating histories. NuScale is on track to submit its reactor design to the NRC by 2012, as is Babcock & Wilcox for its mPower design. In addition, GE-Hitachi, which already completed an NRC preapplication review for its PRISM reactor in 1994, plans to submit its PRISM design for certification in 2012.

With fierce competition for commercial deployment of U.S. SMRs anticipated, the U.S. government is accelerating its efforts to support the licensing of new reactor designs. The fiscal year 2011 budget request for the Department of Energy includes $39 million for a program to support design certification of SMRs for commercial deployment, as well as a research and development portfolio that will address the technology development needs of both near- and longer-term SMRs. The Department of Energy is also in discussions with several U.S. companies to facilitate the light-water SMR design certification by the NRC within a reasonable timeframe. The department also continues to support research and development efforts toward advanced reactor designs through the Advanced Reactor Concepts program, which focuses on metal-cooled reactor technologies.

As designs move closer to deployment, the Department of Commerce is ready with resources to help both U.S. SMR designers and the broader nuclear supply chain. The Department of Commerce has launched the Civil Nuclear

“A substantial SMR deployment program in the United States could result in the creation of many new jobs.”

Trade Initiative, which identifies the U.S. nuclear industry's most pressing trade policy challenges and the most significant commercial opportunities. The initiative then coordinates public- and private-sector efforts to address the opportunities and challenges in a way that supports the industry's endeavors to rebuild its manufacturing base. To accomplish the goals, the initiative includes four pillars: (a) an interagency working group on civil nuclear trade; (b) the Civil Nuclear Trade Industry Advisory Committee; (c) trade policy and promotion activities, including trade missions, official advocacy, and industry programs; and (d) stakeholder resources, such as the "Civil Nuclear Exporters Guide."[10]

Policy and Industry Recommendations

Policy-makers and U.S. companies can take a number of actions to move toward the commercial deployment of SMRs. For policy-makers, these include the following actions:

- Strengthen U.S. government efforts to bring the Convention on Supplementary Compensation for Nuclear Damage into force.
- Consider additional 123 agreements for markets that might be appropriate for SMRs.
- Continue to provide support to countries in their efforts to develop the regulatory infrastructure needed to ensure the safe and secure building and operation of nuclear reactors.
- Explicitly include civil nuclear projects in future clean-energy programs, such as the Advanced Energy Manufacturing Tax Credit Program, and ensure that the terms of such credits are applicable to nuclear projects (including allowing for longer lead times).
- Set aside a portion of future nuclear loan guarantee funds to support the rebuilding of U.S. nuclear manufacturing capacity.
- Support NRC's consideration of adjustments to annual assessments, EPZs, and reactor staffing and security requirements, contingent on U.S. vendors' demonstration and the NRC's evaluation that such adjustments will not compromise the safe and secure operation of nuclear reactors.

U.S. SMR companies should consider the following actions:

- Provide a list of priority markets to the U.S. government for additional 123 agreements.
- Report specific trade barriers and policy challenges, both domestic and international, to the Department of Commerce.
- Schedule preapplication reviews for SMR designs with the NRC and provide requested information in a timely manner.
- Ensure that emergency plans include detailed explanations of the technical reasons SMR designs merit NRC adjustment to some requirements, while still meeting safety and security objectives.
- Participate in U.S. government–sponsored nuclear efforts, including multilateral forums such as the International Framework for Nuclear Energy Cooperation; bilateral dialogues with key markets; trade policy and promotion activities, including trade missions and the U.S. Industry Promotion Program at the IAEA general conference; and industry advisory committees, such as the Civil Nuclear Trade Advisory Committee.

Appendix: Potential Best Prospect Markets for SMRs

Methodology

Twenty-seven countries were identified by the Department of Commerce as markets of interest for new nuclear expansion, but the countries varied from existing nuclear powers to nations at preliminary stages of readiness to actually undertake a nuclear program. The countries were then rated on the basis of how closely they matched seven characteristics of a potential SMR market: (a) low population density, (b) anticipated population growth, (c) anticipated carbon emissions growth, (d) anticipated economic growth, (e) anticipated energy consumption growth, (f) importation of electricity, and (g) existing nuclear capacity. Countries were ranked for each category into quartiles depending on their scores (the bottom quartile has six countries instead of seven) and were assigned a score of 1–4 for the first five categories and either 1 or 0 for the latter two categories. The higher the score is, the closer the country is to the ideal characteristics of an SMR market. "Population density" is the only category in which the listed score has an inverse relationship to the underlying data, because lower population density is considered a stronger indication that SMR deployment may be appropriate.

Country	*Population density*[a]	*CO_2 emissions*[b]	*Electricity imports*[c]	*Economic growth*[d]	*Energy consumption*[e]	*Nuclear capacity*[f]	*Total*
Latvia	4	4	1	4	4	1	18
Turkey	2	4	0	4	4	1	15
Jordan	3	2	1	4	4	1	15
Lithuania	4	4	0	3	2	1	14
India	1	4	1	4	3	0	13
Armenia	2	3	0	4	4	0	13
China	1	4	0	4	4	0	13
United Arab Emirates	3	4	0	1	4	1	13
Morocco	3	3	0	2	4	1	13
Estonia	4	2	0	3	3	1	13
Bulgaria	3	2	0	3	3	0	11
Brazil	4	3	1	1	2	0	11
Indonesia	1	4	0	2	3	1	11
Ghana	2	2	1	3	2	1	11
South Korea	1	3	0	3	3	0	10
Nigeria	1	2	0	3	3	1	10
Kenya	3	3	0	1	2	1	10
Mexico	3	3	0	1	2	0	9
South Africa	4	1	0	3	1	0	9
Slovak Republic	2	1	1	4	1	0	9
Ukraine	3	2	0	2	2	0	9
Poland	2	2	0	2	2	1	9
Egypt	2	1	0	2	3	1	9
Canada	4	1	0	1	1	0	7
Czech Republic	1	3	0	2	1	0	7
Slovenia	2	1	0	2	1	0	6
Netherlands	1	1	1	1	1	0	5

Explanatory notes for this table appear on page 10.

Notes

Explanatory Notes to Appendix Table

a. Calculated using 2009 Central Intelligence Agency *World Factbook* data for population and geographic area. A higher score means a lower population density. SMRs could be more appro priate for a scarcer population distribution.

b. Calculated as the percentage change in carbon dioxide (CO_2) emissions between 2004 and 2008, according to Energy Information Administration (EIA) data. A higher score means a higher percentage increase in CO_2 emissions. SMRs could serve to reduce CO_2 emissions by providing emissions-free base-load power.

c. Rated using 2008 EIA net electricity imports data. A "1" means the country is a net importer, and a "0" means the country either is a net electricity exporter or does not import or export electricity. Countries with more electricity demand than domestic generating capacity might see SMRs as an option for meeting that additional demand.

d. Calculated by averaging annual gross domestic product (GDP) growth from 2004 to 2008 using World Bank data. A higher score means higher average annual GDP growth. Countries with increasing GDP growth, particularly growth that is occurring incrementally, might use SMRs to meet concomitant increases in energy demand.

e. Calculated on the basis of growth in kilowatt-hour per capita consumption from 2004 to 2007, using World Bank data. A higher score means a higher increase in kilowatt-hour per capita consumption.

f. Rated using World Nuclear Association information. A "0" means the country has an operating reactor, and a "1" means the country does not have an operating reactor. SMRs may be an attractive option for countries with limited or no nuclear experience, whereas countries with an operating reactor might find that expanding traditional-sized reactors at existing plants makes more sense.

Text Notes

1. World Nuclear Association, "Nuclear-Powered Ships," September 2010, *www.world-nuclear.org/info/inf34.html*.

2. U.S. Maritime Administration, "Nuclear Ship Savannah," *www.marad.dot.gov/ships_shipping_landing_page/ns_savannah_home/ns_savannah_home.htm*.

3. So-called Generation III+ large reactor designs, including the Westinghouse AP1000 and the GE-Hitachi ESBWR, also have passive safety features.

4. World Nuclear Association, "Small Nuclear Power Reactors," October 2010, *www.world-nuclear.org/info/inf33.html*.

5. Nuclear Regulatory Commission, "Online Glossary," August 2010, *www.nrc.gov/reading-rm/basic-ref/glossary/light-water-reactor.html*.

6. The Next Generation Nuclear Plant program is sponsored by a Department of Energy initiative to fund research projects in support of developing a high-temperature gas-cooled reactor.

7. Additional capacity for ultra-heavy forging is in the planning stages in China, France, India, and the United Kingdom.

8. The guide, which is currently being updated, is available at *www.export.gov/civilnuclear*.

9. Title 10, Code of Federal Regulations, lists regulations promulgated by the NRC.

10. For more information on the Civil Nuclear Trade Initiative, please contact ITA's civil nuclear industry specialists at *civilnuclear@trade.gov*.

The International Trade Administration's mission is to create prosperity by strengthining the competitiveness of U.S. industry, promoting trade and investment, and ensuring fair trade and compliance with trade laws and agreements.

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