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Big Change Goes Small: Are Small Modular Reactors (SMRs) the Future of Nuclear Energy?

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Abstract

Small modular reactors (SMRs) currently represent a promising evolution in nuclear energy technology, offering a range of potential advantages compared to traditional larger-scale reactors. These compact nuclear reactors are characterized by their smaller size, which allows for easier scalability and greater flexibility in deployment due to SMRs modularity when compared to traditional reactors. SMRs, like traditional reactors decades ago, appears to hold promise across many sectors and could serve as a lynchpin in a number of areas tied to the push for green energy and combatting climate change. The adaptability of the SMRs is cited a key factor in the ability of SMRS to serve various purposes beyond just electricity generation (e.g., industrial processes, desalination plants, serve as baseload power for renewable energy sources), and the smaller scale makes SMRs potentially more manageable in terms of safety and security. There are challenges to adoption and implementation of SMR technology similar to what has been experienced over the years with the installation and maintenance of traditional reactors. Generally, for the installation of SMRs to occur many regulatory frameworks will need to be adapted to accommodate the technology unique to these newer technologies used while ensuring safety standards. SMRs require smaller upfront investment costs than conventional reactors, and adoption of SMRs into countries' energy grids has the potential to expand the use of nuclear power and can potentially provide solutions for locations where domestic energy generation is known to be difficult or impossible. Moreover, establishing a sustained supply chain for manufacturing these reactors while simultaneously addressing public perception of nuclear power is critical for the possibility for widespread adoption. This paper begins with an introduction to SMRs, followed by an overview of some industrial markets (e.g., hydrogen generation, desalination) and locations (e.g., remote regions and islands) where SMRs could address existing gaps. There are brief country specific profiles on SMRs for United States, United Kingdom, Russia, and China, each of which have invested in research and development of SMRs. The paper ends with an exploration of the current challenges for SMR adoption, highlighting the regulatory gaps and policy uncertainty which can hinder adoption of this technology.

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Introduction

Although there are fewer than 40 countries in the world with operational grid-connected nuclear reactors (i.e., conventional or traditional), the nuclear industry provides between 10 and 15 percent of the world's total electricity.[1] Nuclear power's outsized share of energy production is due in part to the concentration of production among the largest electricity consumers; of the 15 largest electricity-consuming nations globally, 12 generated nuclear power in 2021.[2] However, newer nuclear generation technologies may expand the power generation footprint of this important electricity generating sector. Notably, the introduction of small modular reactors (SMRs) as a commercially viable channel has emerged as a potential avenue for new nuclear power generation, particularly in areas where large nuclear power plants are not feasible. SMRs, typically between one-third and one-tenth the size of a large nuclear reactor, can generate between 5 and 300 megawatts (MW) depending on design (for context, in April 2022, the United States had approximately 95,400 MW of nuclear power generating capacity, representing approximately 19 percent of total domestic electricity generation).[3]

Although there are currently only two sites with operational commercial SMRs installed globally (in the Russian Arctic and China), there is strong interest from both current nuclear power-generating markets and countries developing nuclear power programs.[4] Due in part to SMRs' smaller footprint, industry experts frequently cite that SMRs have inherent safety advantages (i.e., newer designs and technologies), versatility in design (allowing more variability for potential siting locations), and ease in installation and reduced capital costs—when compared to existing large scale nuclear reactors.[5] These factors have led to growing interest in developing this field.

This paper will explore the budding SMR market, beginning with an introduction to the history and current environment for SMRs, highlighting some of the common features across the approximately 50 existing designs for SMRs. The discussion will then explore potential markets for SMR adoption—in islands and remote regions, for desalination, to supplement existing capacity, for carbon reduction, and to develop hydrogen. The paper will then note contemporary SMR developments in four key markets—the United States, United Kingdom, Russia, and China. It will conclude with an exploration of contemporary challenges to development and adoption of the SMR industry, with a particular focus on regulatory gaps and policy uncertainty.

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[1] These markets are, in order of number of nuclear reactors, the United States, France, China, Russia, Japan, South Korea, India, Canada, the United Kingdom, Ukraine, Sweden, Spain, Belgium, Czech Republic, Pakistan, Finland, Switzerland, Hungary, Taiwan, Slovakia, Argentina, South Africa, Mexico, Bulgaria, Romania, Brazil, Slovenia, the Netherlands, Armenia, the United Arab Emirates, and Iran. Statista, "Nuclear Power Plants by Country 2021," 2021; World Nuclear Association, "Nuclear Power Today," April 2023.

[2] Encyclopedia Britannica, "Nuclear Power," accessed January 1, 2022.

[3] World Nuclear Association, "Nuclear Power in the USA," 2021. To see hour much a U.S. city consumes on average by month see: Statista, "Monthly electricity consumption in major U.S. cities 2017," January 23, 2023.

[4] This installation in the Russian Artic represents the first floating nuclear powerplant in the world and contains two commercially operational reactors. The installation in China represents the first commercial SMRs on land. Liou, "What are Small Modular Reactors (SMRs)," September 13, 2023.

[5] Conversely, the idea of the dispersion of the installation SMRs could raise the cost for security and leads to the question of what to do with the waste. It is important to note that nuclear reactors gained commercial advantages by increasing size and output, so logic could dictate the economics of SMRs would be worse than that of large reactors. Black, "Small Modular Nuclear Reactors," October 18, 2021.

Introduction to SMRs and Nuclear Power

Historically, nuclear power has been used by countries for a variety of reasons, including the development of durable sources of electricity, the ability of countries to ensure that a portion of electricity could be generated domestically (particularly for countries which have lacked the traditional sources of energy, such as coal or oil), and the fact that this source of energy produces low emissions relative to other traditional sources of energy.[6] Additionally, the potential ability to avoid many of the political and economic challenges associated with other sources of energy has often been a key component in favor of nuclear adoption; France in particular cited energy crises in the 1970s as a key justification for the approval of nuclear reactors in the country to bolster the country's energy security.[7]

Today, many countries are seeking energy solutions with low greenhouse gas emissions in order to address climate concerns. Nuclear power is one such energy source, capable of producing base-load electricity with low emissions.[8] Tax and regulatory changes targeting emissions are creating incentives for nuclear investment both in the United States and abroad. SMRs expands the range of options for countries to add nuclear capacity and can potentially bring carbon reducing energy production online quicker than a traditional nuclear plant.[9]

Nuclear power remains an important source for electricity in several markets. However, the share of electricity derived by nuclear power varies substantially among nuclear power producing countries. France, for example, derives between 70 and 75 percent of its electricity from nuclear power, while historically Slovakia and Ukraine derive more than half of their electricity in an average year from nuclear power.[10] In Sweden, Hungary, Belgium, Slovenia, Bulgaria, Finland, and the Czech Republic, more than one-third of domestic electricity consumption comes from nuclear power, while approximately 20 percent of electricity from the United States, Russia, Spain, the United Kingdom, and Romania comes from nuclear power.[11] Additionally, there are a small number of countries that generate no nuclear power themselves, but import electricity derived from nuclear power. For example, Denmark and Italy consume as much as 10 percent of their electricity from nuclear power despite having no active domestic nuclear reactors.[12]

However, current nuclear energy production faces several challenges. Traditional nuclear power consumes large amounts of water (for cooling purposes), necessitates continued radioactive waste

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[6] DOE, "Nuclear," accessed November 2, 2023.

[7] Pethokoukis, "Why France Has a Nuclear-Powered Economy," January 4, 2022; Ataman, "France Announces Plans to Build up to 14 Nuclear Reactors," February 11, 2022.

[8] International Trade Administration, *The Commercial Outlook*, February 2011; Office of Nuclear Energy, "Nuclear Power Is the Most Reliable Energy Source," March 24, 2021.

[9] Liou, Joanne, "What Are Small Modular Reactors (SMRs)?," November 4, 2021.

[10] World Nuclear Association, "Nuclear Power Today," December 2021.

[11] In December 2023 Spain announced that it plans to close the country's nuclear plants by 2035. Reuters, "Spain Confirms Nuclear Power Phase-out," December 27, 2023; World Nuclear Association, "Nuclear Power Today," December 2021; World Nuclear Association, "World Nuclear Performance Report 2023," July 2023, 20–57.

[12] Trade in the nuclear energy technology and materials themselves are highly regulated. In the United States, they are subject to export control licensing requirements from Department of Commerce's Bureau of Industry and Security and the Department of Energy's U.S. Nuclear Regulatory Commission. U.S. Department of State, "Overview of U.S. Export Control System," January 26, 2024; Encyclopedia Britannica, "Nuclear Power | Definition, Issues, & Facts," 2021.

management, and if shutdown, the remediation of the site would take decades. Additionally, accidents (or near misses) that have occurred at nuclear power plants—Chernobyl, Three Mile Island and most recently Fukushima—highlight the difficulties associated with 20th century nuclear technology and, when necessary, the difficulties with safely implemented controlled shutdown procedures of nuclear assets (e.g., when unforeseen events occur). As a result, the perception of catastrophic events occurring is high, creating a source of opposition to nuclear energy production.[13]

Implementing new (or expanding existing) nuclear production in recent years has suffered from a series of roadblocks.[14] First and foremost the market for large capacity nuclear power plants is often limited to countries with adequate grid capacity and to locations where grid demand is growing (or other policy considerations, such as reducing carbon emissions, are prominent), to the extent that large nuclear plant capacity would be necessary.[15]

SMRs are presented today by some as a viable avenue for the growth in nuclear energy. Though SMRs are small and based on technologies that have existed for over half a century, some of the main drivers for the current push towards SMRs derive from identified differences between SMR and large nuclear reactors, namely updated safety features, increased standardization, and modularity. The more modular nature of the reactors theoretically allows for economies of scale—SMRs can in some instances be prefabbed and transported and assembled on-site, allowing for standardized manufacturing and construction processes. Other benefits often cited that contribute to lowered costs include lower capital costs, grid connection flexibility, and gains in efficiency.[16]

There are many different ways in which SMRs can be classified, and each design varies widely depending on where they are in terms of research, development, and deployment. For the purposes of this discussion, SMRs are categorized into the five groups coined by the Organization for Economic Co-operation and Development (OECD) Nuclear Energy Agency (NEA):

- Single-unit light water reactor (LWR)-SMRs – SMRs that use well-established LWR technology and fuels to provide stand-alone units that may replace small fossil-fuel units or be deployed as distributed generation;
- Multi-module LWR-SMRs – units that use LWR technology and are not stand-alone. They can be either operated as a replacement for mid-size baseload capacity or in a distributed generation framework, depending upon generating capacity;
- Mobile/transportable SMRs – LWR-based SMRs that are designed to be easily moved from location to location;[17]
- Generation IV (Gen IV) SMRs – non-LWR, utilized advanced SMRs;[18] and

[13] As of 2021 more than 50 new plants were under construction in 19 and all but two are based on water cooled technologies: (1) China (high temperature gas cooled reactor) (2) India (sodium cooled fast reactor). Reports, indicate that the current rate of approximately 5 gigawatt (GW) annual capacity would need to at least double between 2020 and 2040 to meaningfully reduce the amount of greenhouse gasses.
[14] There are number of factors that have stymies capacity addition but namely the high associated cost for nuclear projects. Lovering, Yip, and Nordhaus, "Historical Construction Costs of Global Nuclear Power Reactors," April 2016.
[15] International Atomic Energy Agency, "Technology Roadmap for Small Modular Reactor Deployment," Nuclear Energy Series, 2021, 2.
[16] Ghazaie et al., "Comparative Analysis of Hybrid Desalination Technologies Powered by SMR," January 2020, 5006.
[17] Note that this designation includes floating reactors.

- Micro modular reactors (MMRs) – SMR designs of less than 10 MW of electric capacity (MWe), often capable of semi-autonomous operation and with improved transportability relative to larger SMRs. These technologies are typically not LWR-based and apply to wide range of technological approaches, including Gen IV technologies. MMRs are principally intended for off-grid operation in remote locations where they are expected to be competitive with prevalent sources of electricity.

The SMRs that use LWR-based concepts (i.e., design and technologies) are considered the most mature of all the technologies, and reports indicate that these types of reactors will likely be the first. The Gen IV technologies are distinguishable from LWR-SMRs in that they use alternative coolants; some examples being liquid metal, molten salts, or gas.[19] Because these represent more of a "new" avenue, there is little to no regulatory precedent, and many of these technologies are still in the testing or prototype stage (i.e., farther away from a commercial rollout). Reportedly the most mature of these types of technologies are those that are metal- and gas-cooled.[20] Each design and technology when used individually or combined presents both challenges and benefits when it comes to installation and deployment.[21]

As of 2021, there were dozens of SMR concepts and designs under various stages of development around the world; approximately half of the designs are based on LWR tech and the other half Gen IV technologies.[22] Additionally, some SMR designs can contain technologies from multiple of the categories listed above, and the term "SMR" has often been adopted around the world to simply refer to all small reactor designs.[23] In addition to design differences, SMRs can also differ based on power output and the degree of design modularization. And while employing these updated SMR designs and technologies can allow for more advanced safeguard and security features that cannot be used for conventional nuclear reactors, often the regulatory requirements are based on LWRs (discussed in further detail in the Challenges to adoption section below).[24] Differences in regulatory requirements based on these newer technologies and designs can lead to different and/or increased costs.

Nuclear Market Characteristics and SMRs

Unlike other industries in the electricity sector, there is currently only one commercially operational SMR globally, so it is difficult to determine exactly what the SMR market is, and even harder to determine what the future market will look like. The lack of installation can make it difficult to discern projected trends for both policymakers and investors. However, some broad trends can be identified in the nuclear sector overall which may hint at the market potential for SMR deployment.

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[18] Include many of the concepts that have been investigated by the Generation IV International Forum (GIF) in past years. OECD and NEA, "Small Modular Reactors: Challenges and Opportunities," 2021, 16.
[19] OECD and NEA, "Small Modular Reactors: Challenges and Opportunities," 2021, 16.
[20] It should be noted that although these technologies are nascent in terms of deployment some of the base designs described have been around for decades.
[21] As a point of reference Russia's floating based SMRs are modular water reactor (i.e., a steam generating station) so it would be grouped under LWR-SMR. OECD and NEA, "Small Modular Reactors: Challenges and Opportunities," 2021, 16.
[22] OECD and NEA, "Small Modular Reactors: Challenges and Opportunities," 2021, 9.
[23] See: OECD and NEA, "Small Modular Reactors: Challenges and Opportunities," 2021.
[24] OECD and NEA, "Small Modular Reactors: Challenges and Opportunities," 2021, 12, 29–30.

Within the electricity market(s), large scale nuclear energy generally supplies an assortment of national and regional electric grids. And in every market or country, the mix of electricity sourcing and supply needs to balance with electricity demand.[25] However, as the infrastructure costs of manufacturing and deploying a large-scale nuclear reactor are substantial, long term pricing contracts are typical for large nuclear reactors installation and adoption.[26] Ultimately, these contracts help provide consistent revenue streams, and attempt to balance the high capital costs prior to electricity generation with future revenue expectations, though negotiations can be difficult and can further draw out deployment prospects.[27] As noted above, one of the oft-cited advantages of SMRs lies in anticipated reductions in capital costs, which may reduce some of the pressure to project future demand and pricing years ahead of deployment.[28]

The 31 markets with operational nuclear reactors collectively consumed more than 70 percent of global electricity in 2019; when Bangladesh and Turkey (two countries without any current nuclear capacity, but are actively pursuing reactor construction) are included, collective consumption rises to nearly 80 percent.[29] Therefore, despite the small number of countries with operational nuclear capacity, the potential market for increased nuclear capacity is substantial. As a result, the potential market for SMRs globally is potentially large, but ultimately depends on industry and government assessments of both the need for and use of SMRs in national and local energy mixes.[30]

Growth in the nuclear reactor generation sector may be tempered by limited electrical demand growth in some markets. Of the 31 markets identified above, only six—China, the United Arab Emirates, India, Iran, Pakistan, and South Korea—had electricity consumption growth above the average growth rate (4

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[25] This requires daily, and often hourly, estimates of expected demand to ensure that the supply of electricity from a variety of sources balance with demand. Sommer, “California Just Ran on 100% Renewable Energy, but Fossil Fuels Aren’t Fading Away Yet,” May 13, 2022.

[26] For more information on the economics of nuclear energy see: World Nuclear Association, “Economics of Nuclear Power,” updated August 2022.

[27] Costs can range from $5 to $10 billion dollars. Since the 1960’s the price to install a nuclear power plant in the U.S has increased 6-fold. Regulatory compliance and lack of reactor design standardization across domestic markets are cited as major cost contributors. Plumer, “Why America Abandoned Nuclear Power,” February 29, 2016; Lovering, Yip, and Nordhaus, “Historical Construction Costs of Global Nuclear Power Reactors,” April 2016, 371–82.

[28] For estimates on the cost to implement an operational SMR in the U.S. see: Vegel and Quinn, “Economic Evaluation of Small Modular Nuclear Reactors and the Complications of Regulatory Fee Structures,” May 2017, 395–403.

[29] Bangladesh started the construction of its first nuclear power reactor in November 2017, and is expected to be commissioned in 2024. Conversely, Turkey has had plans for establishing nuclear power generation since 1970 but construction of its first nuclear power reactor just began in April 2018. World Nuclear Association, “Country Profiles Bangladesh,” May 2023; World Nuclear Association, “Country Profiles Turkey,” September 2023. By mid-2023 there were currently 34 countries with operational nuclear reactors. Note that both Germany and Belgium had announced that their existing nuclear capacity will be shut down. Germany completed its’ nuclear phaseout in April 2023. Belgium originally planned for all nuclear power plants to be closed by 2025. However, in March 2022 the timeline was extended so the 2032 would be the date of decommissioning for all operational reactors except for the two newest reactors which will remain in operation until 2035. World Nuclear Association, “Country Profiles Germany,” April 2023; World Nuclear Association, “Country Profiles Belgium,” December 2023. See appendix for full list.

[30] NEA and OECD, Small Modular Reactors, October 26, 2016, 10.

percent) from 2000–19.[31] Higher relative increases in demand may partly contribute to the growing number of nuclear reactor sites globally; 32 of the 50 reactors expected to come online between 2022 and 2027 are from the six contemporary nuclear power-producing countries where energy growth exceeded the global average.[32] The remaining 25 markets' annual electricity consumption was less than the average global rate during the same period, and the growth of nuclear power in these countries appears to be similarly limited.

Despite the general challenges and opposition to nuclear adoption, which sometimes extends to SMRs (see Challenges to adoption section below), a market has and will likely continue to exist for nuclear power and for SMRs. There is currently approximately 395 gigawatts (GW) of installed global capacity for nuclear power in the world, providing between 10 and 15 percent of the world's electricity, with 50 projects currently in construction to add an additional 55 GW of power to existing nuclear capacity between 2022 and 2027 (though some reactors are also expected to shut down during this period).[33] At an average of 1,100 MW per project, these new projects are mostly large-scale large nuclear reactors. The largest is Finland's Olkiluoto 3 plant, which will provide 1,720 MW of power to Finland's electricity come online in 2023 (after being originally slated for completion in 2009).[34]

Markets for SMR Adoption

The size of the future market for SMRs will depend on several elements, including the overall demand for nuclear power noted above. However, there are unique features of SMRs which can distinguish them from other energy sources (including large reactors) in the electricity sector. These features include the ability to ease energy challenges on islands and remote regions, smaller footprints can support hyperlocal energy demands such as desalination as well as replace existing capacity in other energy generation facilities with small footprints (coal and natural gas processing facilities in particular), they can amplify existing nuclear capacity, generate nearly zero carbon emissions, and can be used to generate hydrogen. The extent to which these elements are viewed as sufficient to encourage added capacity, despite policy uncertainty and high upfront costs, will depend on both government and private sector investment and support decisions, which although touched upon in the Challenges section below, are largely not addressed in this paper. One overarching element of each of these factors is that they represent conditions where a higher relative cost of electricity can be accepted by the market, which can allow for the deployment of newer technologies that may have higher upfront costs (particularly in the absence of existing infrastructure) but where need is sufficiently high to justify this cost.

[31] These 25 markets are Mexico (3.7 percent annual growth in electricity consumption during the 2000–19 period), Argentina (3.3 percent), Brazil (3.3 percent), Taiwan (2.9 percent), Armenia (2.8 percent), Russia (1.6 percent), Hungary (1.5 percent), Spain (1.3 percent), Slovenia (1.3 percent), Romania (0.9 percent), Bulgaria (0.8 percent), Czech Republic (0.8 percent), Belarus (0.8 percent), Netherlands (0.7 percent), South Africa (0.6 percent), the United States (0.6 percent), Finland (0.5 percent), France (0.5 percent), Canada (0.5 percent), Switzerland (0.5 percent), Slovakia (0.3 percent), Ukraine (0.0 percent), Japan (-0.1 percent), Sweden (-0.2 percent), and the United Kingdom (0.5 percent). Germany and Belgium, which plan to remove their current nuclear capacity, had growth rates of 0.1 percent and 0.3 percent respectively, while Turkey and Bangladesh had growth rates of 8.1 percent and 25.8 percent respectively.
[32] World Nuclear Association, "World Nuclear Power Reactors," accessed November 8, 2022.
[33] Nuclear Energy Institute, "World Nuclear Generation and Capacity," June 2021.
[34] World Nuclear Association, "World Nuclear Power Reactors," accessed November 8, 2022; Rogers, "14 Years Late, Finland's New Reactor, Olkiluoto 3, Starts Generating Power," April 17, 2023.

Islands and Remote Regions

Small modular reactors have several unique characteristics that reportedly provide advantages in several sectors. One unique characteristic of SMRs is their ability to provide a relatively large amount of emission-free energy relative to their physical footprint, which can be advantageous for areas which are difficult to connect to national and international grids and have smaller space to generate energy domestically, in particular islands and remote regions.

It is estimated that worldwide more than 730 million people live on islands, ranging from densely populated islands such as Great Britain and Taiwan, to more remote and lower population islands such as Iceland, Hawaii, and Nauru.[35] It can be difficult to provide islands with electricity; electric grids situated on a nation's mainland often do not extend to islands without substantial cost, or the islands may only be connected by a single grid connection (which can make the island or remote region vulnerable to significant power disruption). Additionally, direct generation of electricity on islands can be difficult, particularly on islands with high population density, inconsistent weather patterns, and/or limited infrastructure.[36]

Similar to islands, getting electricity to remote regions on the mainland such as the Arctic, densely forested inland regions in South America and central Africa, desert regions in the Middle East and North Africa, and the steppes of central Asia has been proven difficult for electricity generators. As the U.S. Department of Energy (DOE) has noted, SMRs are beneficial due to their ability to provide power to isolated and/or remote areas where large plants cannot be supported (i.e., lack of infrastructure) or the amount of power that large reactors could produce would not be warranted (i.e., not enough demand).[37]

As stated above the first commercially installed SMRs have been placed in a remote region. Specifically, SMRs were deployed on a floating barge off Russia's Arctic Coast in 2021.[38] These SMRs provide electricity to the northernmost city in Russia (Pevek), removing the need for it to receive heat and electricity from a nearby coal-fired power plant.[39] SMRs likely to come online globally over the next several years further illustrate this use-case;[40] such as the SMRs under construction on the tropical island of Hainan, in the southernmost province off China's coast.[41] Reportedly, countries with highly forested areas (Brazil), desert regions (several Gulf states and Argentina), and flatlands in central Asia (Kazakhstan, Uzbekistan, Armenia) are all looking into SMRs as a way to support local electricity

[35] "How Many Islands Are There in the World 2024," accessed January 9, 2024.
[36] Alternatively, islands with low population density can also be challenging to add energy capacity, due to isolation and high per capita costs.
[37] Examples specifically cited by DOE include smaller electrical markets, isolated areas, smaller grids, and sites with limited water and acreage. U.S. Department of Energy, "Benefits of Small Modular Reactors (SMRs)," 2020.
[38] Collectively the two small modular nuclear reactors are referred to singularly (i.e., reactor) or as a nuclear power plant. Liou, "What are Small Modular Reactors (SMRs)?" September 13, 2023.
[39] For more information on the SMRs off of Russia's Arctic Coast see: Supplemental Capacity Building and Replacement of Retiring Plants and Russia.
[40] Expected to come online in 2023. World Nuclear Association, "Nuclear Power Today," December 2021.
[41] It is worth noting that the first commercially operational SMR in China was located in Shandong Province (about 30 hours north of Hainan). Reuters, "China Starts Up World's First Fourth-Generation Nuclear Reactor," December 8, 2023.

generation in remote or difficult-to-reach regions without having to rely on coal- or natural gas-fired power plants or imported energy (all of which are generally expensive).[42]

Supplemental Capacity Building and Replacement of Retiring Plants

SMRs have also been noted for their ability to provide supplemental capacity to existing large reactor nuclear capacity, or replace existing capacity for coal, natural gas, or diesel-powered plants. One industry expert in Poland noted that although SMRs cannot often compete with large-scale power generation, they can "be an excellent complement and gradually replace some of the electricity produced from fossil fuels."[43]

Both the floating SMR plant in the Russian Artic and SMRs under construction in China demonstrate this capacity building or replacing capability of SMRs. The SMR in Russia off the Arctic coast is designed to primarily serve Pevek, which has no domestic energy production capabilities aside from a coal-fired power plant that generates electricity through coal imports. In China, the Hainan 100 MW SMR is designed to supplement existing capacity at the Changjiang nuclear power plant, which currently has two operating 650 MW reactors and two other large reactors in construction.[44] Poland also signed an agreement in September 2021 to convert a coal-fired power plant to a plant that instead produces electricity via four 300 MW SMRs.[45] And leading energy providers in the United States noted that SMRs are a potential alternative to replace retired coal-fired power plants, particularly as those facilities have existing grid connections and water availability. Notably, the Montana state Senate has announced a study exploring replacing its old coal-fired power plants with SMRs, the installation of which could eventually complement an SMR at a research laboratory that is being constructed in Idaho.[46]

Desalination

Between 2010 and 2020, the rate of severe storms, droughts, and heat waves globally increased by more than 30 percent (at a rate twice as frequently as occurred in 1980); these weather events align with a 2012 estimate that there could be up to a 40 percent shortfall in the availability of fresh water worldwide by 2025.[47] The existence of limitations in water supply for consumption (e.g., agricultural and industrial uses) has in part driven countries to invest in desalination facilities, which is the process of removing salts, other minerals, and contaminants from non-fresh water sources (e.g., seawater, brackish water, and wastewater effluent).[48] As of 2019, more than 19,000 desalination plants were operational

[42] World Nuclear Association, "Nuclear Power Today," December 2021.
[43] ABWR, "Partners to Study the Deployment of SMR in a Polish Coal-Fired Power Plant," September 1, 2021.
[44] World Nuclear News, "China Starts Construction of Demonstration SMR: New Nuclear," July 13, 2021.
[45] ABWR, "Partners to Study the Deployment of SMR in a Polish Coal-Fired Power Plant," September 1, 2021.
[46] Gardner, "Shut U.S. Coal Plants Seen as Potential Sites for Small Reactors," April 28, 2021, sec. Energy.
[47] Additionally, over the past 20 years, droughts accounted for more than $100 billion in damage and impacted more than 1.1 billion people. UNESCO, "Water and Climate Change: United Nations World Water Development Report 2020," 2021, 23-24.
[48] Asadollahi, Bastani, and Musavi, "Enhancement of Surface Properties and Performance of Reverse Osmosis Membranes After Surface Modification," October 2017, 330–83.

globally and produced more than 95 million cubic meters/day, nearly half of which is produced in the Middle East and North Africa (MENA) region.[49]

Several industry sources and national regulatory authorities have recognized that SMRs can be useful in establishing and running desalination facilities.[50] There are several complementary factors that make it potentially advantageous to utilize SMRs for desalination, and SMRs designed specifically for desalination purposes have been developed by SMR manufacturers in South Korea, Argentina, China, and Russia.[51] Principally, the thermal energy produced by nuclear reactors can be used both for the electricity needed to run a desalination facility as well as produce steam used to desalt water.[52] Additionally, nuclear is the only energy source in many locations which can provide emissions-free non-intermittent electricity (desalination requires constant electricity to provide fresh water continuously).[53]

Due to the densely concentrated desalination facilities in the Middle East/North Africa (MENA) region, several studies have been conducted to determine the viability of deploying SMRs in the area. Four studies published between 2015 and 2021 found that the integration of SMRs into the region's desalination systems could produce increased freshwater and reduce emissions by replacing natural gas-powered facilities.[54] The most recent study estimated that a variety of SMR models could decrease the cost of desalinated water while operating at maximum capacity by between 6.4 and 7.6 percent.[55]

Nuclear power for desalination purposes has historically been used in a variety of countries, and projects for both large and small nuclear reactors are ongoing. Kazakhstan, India, Russia, and Japan have nuclear powered-desalination projects, while Algeria, Egypt, Saudi Arabia, Pakistan, China, Russia, and South Africa are planning or studying the deployment of large nuclear reactor-powered desalination plants (the latter for industrial purposes).[56]

In 2018, Jordan's Atomic Energy Commission (JAEC) announced it would shift its attention from a single large nuclear reactor to SMRs, following an agreement between the JAEC and Saudi Arabia's nuclear agency (KA-CARE) to complete a feasibility study to construct two SMRs for desalinated water.[57] Also in 2018, Jordan signed MOUs with private sector SMR manufacturers from the United Kingdom, Russia, and the United States to construct SMRs.[58]

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[49] UNESCO, "Water and Climate Change: United Nations World Water Development Report 2020," 2021, 54.
[50] Ingersoll et al., "Integration of NuScale SMR With Desalination Technologies," ASME 2014 Small Modul. React. Symp., April 15, 2014.
[51] World Nuclear Association, "Nuclear Desalination," 2021.
[52] Ingersoll et al., "Integration of NuScale SMR With Desalination Technologies," ASME 2014 Small Modul. React. Symp., April 15, 2014, 1–2.
[53] Ghazaie et al., "Comparative Analysis of Hybrid Desalination Technologies Powered by SMR," January 2020, 5006.
[54] Studies were conducted in 2015, 2017, 2020, and 2021. Ghazaie et al., "Comparative Analysis of Hybrid Desalination Technologies Powered by SMR," January 2020, 5006.
[55] Ghazaie et al., "Comparative Analysis of Hybrid Desalination Technologies Powered by SMR," January 2020, 5006.
[56] World Nuclear Association, "Nuclear Desalination," 2021.
[57] World Nuclear Association, "Nuclear Power in Jordan," 2021.
[58] World Nuclear Association, "Nuclear Power in Jordan," 2021.

Hydrogen Generation

Hydrogen has long been studied as possible clean fuel source. Historically, hydrogen gas has been primarily used as a feedstock for the petrochemical industry (e.g., crude oil refinement, production of ammonia and methanol, etc.). But hydrogen can also be used as a cleaner fuel alternative—more specifically in fuel cells where it chemically reacts with oxygen producing electricity without generation pollutants or greenhouse gases.[59]. Access of hydrogen as a fuel will largely be determined by renewable sources because hydrogen generation involves the electrolysis of water which is an energy-intensive process.[60] . To date economies of scale has proven to be an obstacle for installation of hydrogen-based infrastructure, the future installation of SMRs may assist in the wider establishment of hydrogen production, which, like many designed SMRs, requires access to water.[61] The potential of using energy from SMRs to power industrial centers, particularly data centers, continue to be studied and discussed in the U.S. One announcement from August 2023 centered on the plan for the Surry Green Energy Center (SGEC) in Virginia. If SMRs are deployed at the site, the plan stands for it to occur within the decade, the thermal energy that the SMRs generate would support the electrolysis of water into hydrogen which in turn could fuel backup generators at the site.[62]

Country Profiles

As policymakers and regulators investigate and debate the feasibility of adopting and deploying SMR technology in domestic grids, several countries have emerged as likeliest to adopt such technologies. The countries highlighted in this section, the United States, United Kingdom, Russia, and China, have a variety of factors that will likely contribute to the adoption of SMRs, including domestic companies which design SMR technologies, regulatory changes to reduce the regulatory burden of SMR adoption, and policy priorities to reduce carbon emissions.

United States

The United States does not currently have any commercially operational SMRs, but the first SMR design was approved by the U.S. Nuclear Regulatory Commission (NRC) in September 2020.[63] There are a number of forces driving the continued development and eventual installation of SMRs, namely the fact that U.S.-based SMR manufacturers are already operating projects in dozens of international markets, the identification of several U.S. sites for the manufacture and launch SMRs for both commercial and research purposes, and ongoing work from national regulatory authorities to identify and address regulatory gaps in the SMR approval process.

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[59] The by-product of the reaction is water vapor. Hydrogen generates heat greater than 1,000˚C without emitting CO_2 when burned. International Renewable Energy Agency, *Geopolitics of the Energy Transformation*, 2022, 25.

[60] The Paris Climate Agreement has served as a rallying point as a target for net zero emission by the mid-21st century, and hydrogen has risen to the top as one of the best options for cutting emissions. International Renewable Energy Agency, *Geopolitics of the Energy Transformation*, 2022, 33, 65.

[61] International Renewable Energy Agency, *Geopolitics of the Energy Transformation*, 2022, 29,33.

[62] Proctor, “Hydrogen Production, SMRs Touted,” August 20, 2023.

[63] Nuclear Regulatory Commission, “NRC Approves First U.S. Small Modular Reactor Design,” September 2020.

Several U.S. SMR designers and manufacturers operate both domestically and internationally. In 2020, the International Atomic Energy Agency (IAEA) Department of Nuclear Energy identified SMR designs from 12 U.S.-headquartered firms, in addition to the Argonne National Laboratory (ANL) and the University of California, Berkeley.[64] Oregon-headquartered NuScale Power, one of the largest U.S. SMR manufacturers, has forged partnerships with government agencies and private sector firms to develop and implement its SMR technology in Japan, South Korea, Jordan, Ukraine, the Czech Republic, the United Kingdom, Romania, Poland, Kazakhstan, South Africa, Bulgaria, and Canada.[65] Maryland-headquartered X-energy has received support from Canada and the United Kingdom to develop and deploy its SMRs. X-energy has also received grant funding from the U.S. DOE's Advanced Reactor Demonstration Program (ARDP). Additionally, Florida-based Holtec International intends to replace some of its domestic decommissioned large reactors with its own 160 MW-designed SMRs.[66] For many of the American firms developing this new technology, the additional drive to adopt SMRs abroad provides many of these firms with potential commercial opportunities abroad.

Within the United States, two sites in Idaho and Tennessee have been identified and approved by SMR manufacturers and U.S. regulators for the installation of the first U.S. SMRs. In October 2020, DOE granted a cost-share award of $1.4 billion for the construction of twelve 60 MW SMRs at the Idaho National Laboratory near Idaho Falls, Idaho. It was to be constructed by NuScale in a partnership with the Utah Associated Municipal Power Systems (UAMPS).[67] However, three years later in 2023 NuScale announced the termination of the project, in part due to cost overages.[68] After the October 2020 DOE award the Tennessee Valley Authority announced it would collaborate with California-based Kairos Power in May 2021, on the construction of a 140 MW SMR at the East Tennessee Technology Park in Oak Ridge, Tennessee.[69]

The United States Nuclear Regulatory Commission (NRC), the lead U.S. regulatory agency in the nuclear sector, has identified a variety of regulatory issues in the United States that need to be resolved to smooth the approval process for the construction of future SMRs. Some matters have already been resolved, including containment performance metrics, licensing processes for reactor prototypes, licensing structure for multi-module facilities (important for scaling up SMRs, including the Idaho facility in construction), annual fees, use of probabilistic risk assessment in SMR licensing, and the appropriate requirements for operator staffing for SMR. However, ongoing areas of concern that need resolution remain, such as security and safeguard requirements, insurance and liability processing, emergency planning requirements, and siting policies for SMRs.[70]

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[64] Firms include NuScale, Holtec International, X-energy, Framatome, General Atomics, Westinghouse Electric, ThorCon, Flibe Energy, Kairos Power, Elysium Industries, OKLO Inc, and Ultra Safe Nuclear Corporation. International Atomic Energy Agency, *Advances in Small Modular Reactor Technology Developments*, September 2020, 7–9.
[65] NuScale Power, "Current Projects," 2021.
[66] X-energy, "Newsroom — X-Energy," 2021; Holtec International, "Holtec Strives to Make Nuclear Innovation Look Simple With SMR-160," 2021.
[67] Neutron Bytes, "DOE Awards UAMPS $1.355 Billion for NuScale SMR in Idaho," October 17, 2020; DOE, "Advanced Small Modular Reactors (SMRs)," 2020.
[68] Reuters, "NuScale Ends Utah Project," November 9, 2023.
[69] Neutron Bytes, "TVA to Collaborate with Kairos Power on 140 MWe SMR," *Neutron Bytes* (blog), May 10, 2021. See appendix for permitting status.
[70] Nuclear Regulatory Commission, "Small Modular Reactors (LWR Designs)," 2021.

United Kingdom

The UK government has made a commitment to expanding nuclear capacity, with one illustrative white paper from 2020 noting that "nuclear power provides a reliable source of low carbon electricity… [and the government will pursu[e] large-scale nuclear, whilst also looking to the future of the nuclear power in the UK through further investment in Small Modular Reactors and Advanced Modular Reactors."[71] In October 2021, UK Business Secretary Kwasi Kwarteng noted that nuclear power will be "part of the solution" in the government's effort to ensure the UK economy transitions to carbon neutrality by 2035.[72] As fuel costs continued to rise throughout 2022, the UK government also announced plans to accelerate nuclear power production to phase out Russian oil and coal by the conclusion of 2022, pledging an ultimate goal of Britain having 24 GW of nuclear power generation by 2050.[73]

As part of the UK's nuclear power generations, its government announced several proposals and funding projects to facilitate the adoption of both nuclear power (in a broader sense) and some projects/funding for SMR technology specifically. In 2020, the government announced a £385 million allocation to an Advanced Nuclear Fund to develop SMRs and to build advanced modular reactors in the UK.[74] UK Shearwater also announced plans to invest in an SMR-wind hybrid power plant with U.S.-based NuScale, the first in Europe.[75] In Wales there is consideration being given for the installation of a SMR to replace capacity that had been shut down in Anglesey.[76] For large reactors, a new nuclear facility with 3,200 MW of expected capacity, the Hinkley Point C station in Somerset, is expected to come online in 2026, with a similar capacity facility proposed in the Suffolk region.

The emerging UK SMR market is distinguished by its strong private sector interest in the deployment of SMRs for electricity generation. UK auto manufacturer Rolls Royce indicated in 2021 that it would invest millions in manufacturing and deploying self-designed SMRs. In late 2021 Rolls Royce announced it would manufacture SMRs with a generation capacity of 470 MW of power in its first UK project to provide baseload generation for the UK grid for 60 years. The Rolls Royce SMRs are also designed to source locally; according to the company, upwards of 80 percent of the component value of SMRs manufactured by Rolls-Royce will come from the UK supply chain.[77]

Russia

As stated above, as of March 2022 Russia has the only operational SMR installation globally.[78] To date, these two Russian SMRs represent the first and only SMRs to operate commercially, the first floating SMRs to operate, and the northernmost nuclear power stations in the world. In May 2020, these two 35 MW SMRs mounted aboard the barge *Akademik Lomonosov* began operations. The two reactors provide

[71] *Powering Our Net Zero Future*, December 2020, 16.
[72] Jessica Shankleman, Rachel Morison, "UK Plans Fossil Fuel-Free Power Grid," October 4, 2021.
[73] Emilio Casalicchio, "UK Banks on Nuclear," April 6, 2022.
[74] *Powering Our Net Zero Future*, December 2020, 50.
[75] Reuters, "Wylfa Hybrid Plan Shows How SMRs," January 26, 2021.
[76] Emilio Casalicchio, "UK Banks on Nuclear," April 6, 2022.
[77] Rolls-Royce, "Rolls-Royce Plc, Qatar Investment Authority," December 20, 2021; Rolls-Royce, "Small Modular Reactors," accessed November 14, 2022.
[78] World Nuclear Association, "First Small Modular Reactors Open a New World of Applications," December 19, 2019.

power to the town of Pevek in the Russian Arctic, and also provide the energy to desalinate seawater to provide fresh drinking water to the area daily.[79] These reactors reflect the growing role of nuclear power in the Arctic region; in September 2021, Russian Rosatom subsidiary Atomflot announced that four SMRs would be deployed in Baimskaya to power the mining of gold and copper in the Arctic.[80]

In addition to existing domestic SMR capacity, Russian companies maintain extensive investments in the design, manufacture, and deployment of SMR technology globally. Russian firms, led by Rosatom and NIKIET, have designed more than a dozen different SMRs, including land and sea-based water cooled SMRs (RITM-200, UNITHERM, VK-300, KARAT-45 and -100, RUTA-70, ELENA, KLT-40S, RITM-200M, ABV-6E, VBER-300, SHELF), gas cooled SMRs (GT-MHR, MHR-T, MHR-10), and fast neutron spectrum SMRs (BREST-OD-300, SVBR).[81] Russian firms have also announced co-investments to manufacture and deploy SMRs in the Philippines, Kyrgyzstan, Armenia, and the United Arab Emirates, among others, representing potential future competition in the global SMR market.[82]

China

China is currently the only country that has a commercially operational land based SMR. In December 2023 China's state media announced that commercial operations for the Shidaowan plant began operations, with an SMR, in the Shandong province.[83] Reports indicate that the SMR uses a modular design and is a 200 MW capacity unit and was developed by state-run utility Huaneng, Tsinghua University and China National Nuclear Corporation.[84]

The island province of Hainan, China's southernmost province, has historically struggled with the provision of electricity from mainland China due to its remoteness. In recognition of this challenge, China's National Nuclear Corporation (CNNC) announced in 2019 that Hainan would be the first location in which an SMR would be installed for commercial use. The island of 10 million residents currently has two operational nuclear reactors (Changjiang 1 and 2), with a combined capacity of 1300 MW, and an additional two 1000 MW reactors (Changjiang 3 and 4) are under construction. Furthermore, one Chinese-designed SMR with a net power capacity of 100 MW referred to as Changjiang 5, is currently being constructed. Changjiang 5 is a pressurized water reactor and is designed to be a proof-of-concept project to feed into existing nuclear capacity on the island, but unlike the other Changjiang reactors it will be installed underground—this feature is in the design of many of the new SMRs as it provides an added safety component. Construction of the Changjiang 5 SMR began July 2021 and is expected to be operational by the mid-2020s. It is likely to be one of the first commercial SMRs to be operational on land.[85]

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[79] Chatzis, "Small Reactors, Great Potential," October 22, 2020.
[80] Construction began September 2022. Dalton, "Russia / Construction Begins in China of First Floating Reactor," September 1, 2022. World Nuclear News, "SMRs to Power Arctic Development," September 3, 2021.
[81] International Atomic Energy Agency, *Advances in Small Modular Reactor Technology Developments*, September 2020, 57–81, 111–31, 149–137.
[82] Nuclear Engineering International, "Rosatom Signs Agreements in Dubai," January 4, 2022.
[83] Reuters, "China Starts Up World's First Fourth-Generation Nuclear Reactor," December 8, 2023.
[84] Reuters, "China Starts Up World's First Fourth-Generation Nuclear Reactor," December 8, 2023
[85] World Nuclear News, "China Starts Construction of Demonstration SMR," July 13, 2021.

In addition to the construction of the Hainan SMR, the CNNC has announced other SMRs to be built across China. Agreements in Shangrao and Ganzhou are expected to add further SMR capacity (using the same design as the Hainan reactor, an ACP100), in addition to potentially further capacity in Hunan and Jilin. Floating reactors, similar to the SMRs in the Russian Arctic, may also be considered to support China's shipbuilding industry.[86] China's nuclear reactor industry includes research universities, private sector firms, and state-run SOEs, similar to Russia. The Chinese nuclear industry has designed in a variety of SMRs, including water cooled reactors (ACP100, CAP200, DHR400, HAPPY200), gas cooled reactors (HTR-PM, HTR-10), and molten salt reactors (smTMSR-400).[87]

Challenges to adoption

There are currently several challenges to the adoption of SMRs ranging from public perception to economic viability. This section will briefly explore some of the larger challenges identified by industry experts as representing the most significant barriers to entry: regulatory gaps in the approval and deployment of SMRs in a variety of jurisdictions and policy uncertainty.

Regulatory Gaps

Several industry representatives, as well as the regulatory agencies themselves, have identified regulatory gaps in the approval process for SMR technology. As nuclear reactor technology is extremely complex and often requires regulatory input from a variety of stakeholders, the approval of large nuclear reactors can be a multi-year (and in some cases decades' long) process.[88] The lengthiness of the process has historically impacted both investment in nuclear power and interest in adoption of nuclear technology.[89] Additionally, SMRs have faced similar regulatory hurdles to those first faced by the nuclear industry decades ago. Additionally, SMR have the burden of presenting new technology for approval (in essence starting approval processes from scratch).[90] As a result, SMRs face both the ongoing challenges in many markets of approval for the siting and deployment of nuclear reactors, as well as regulatory challenges (and in some cases regulatory gaps) for the deployment of what is in essence treated as a "new" technology.

Outside the United States, other countries have also identified regulatory gaps which may hinder their adoption and deployment of SMRs. In Canada, a 2018 report from the SMR Roadmap Regulatory Readiness Working Group noted several potentially unnecessary regulatory requirements for SMRs that are typical for large nuclear reactors but not for SMRs. The report noted that SMR designs could render some regulations unnecessary or obsolete, in particular certain staff training requirements, emergency preparedness, security requirements, and liability policies.[91] One Canadian expert also noted that the

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[86] World Nuclear News, "China Starts Construction of Demonstration SMR," July 13, 2021.
[87] International Atomic Energy Agency, *Advances in Small Modular Reactor Technology Developments*, September 2020, 2–4.
[88] See e.g., DOE Loan Program Office, "Pathways to Commercial Liftoff: Advanced Nuclear," 2023.
[89] See: Bowen, Ochu, Glynn, "The Uncertain Costs of New Nuclear Reactors," December 2023.
[90] GAO, "NRC Needs to Take Additional Actions to Prepare to License Advanced Reactors," July 2023; Bowen, Ochu, Glynn, "The Uncertain Costs of New Nuclear Reactors," December 2023.
[91] Regulatory Readiness Working Group, "Canadian SMR Roadmap," August 1, 2018, ii.

licensing process could be disproportionately impactful on the deployment of SMRs, that "design certification, construction and operation license costs are not necessarily less than for large reactors."[92]

Policy Uncertainty

From a policy perspective, countries' varying levels of commitment to nuclear power also affect the future of SMRs. In recent years, some nuclear power generating countries have announced a reduction or cessation of their nuclear power generation (e.g., Germany, Belgium, Japan).[93] The delicate balance between initial large upfront investment prior to the construction of nuclear power plants and expectations of eventual electricity demand years later can be complicated by these unexpected policy developments. The nuclear regulatory approval process can in some cases take decades, and even fast regulatory approval, construction, and deployment can take 10 years or more.[94] Domestic policy developments or policy uncertainty can further hinder investment in nuclear technology if it alters the conditions in which a potential nuclear reactor would operate. In the past decade, for example, Germany and Belgium shifted from being large nuclear power producers to shuttering or planning to wind down nearly all of their nuclear power production.[95] Conversely, during the same period Turkey, Bangladesh, the United Arab Emirates, and Belarus began construction of their first nuclear power plants.[96]

The constant policy uncertainty as it pertains to nuclear energy broadly can limit future investment in the SMR sector. Although the time it takes to construct an SMR is likely significantly shorter than constructing a large nuclear reactor—policy changes and uncertainty can affect investment decisions (particularly with a newer technology) and a SMR plant construction may never commence. As one industry observer noted, "on the one hand, investment to develop and deploy SMRs requires a secured market and demand for the product, but on the other, one cannot secure the market without funding to develop and demonstrate, or even to do the necessary research or build test facilities that may be required for licensing."[97] Further, it can be difficult to further measure benefits (or detriments) of deploying the technology because there are not enough SMRs online to study and draw conclusions from.[98] The market risk may curb investment in future SMR development and the nuclear sector broadly, adding another lengthy chapter to the era of nuclear energy.

Looking Forward

While SMRs have the potential to be the answer to a number of clean energy and technology related questions there is still much that needs to be overcome before SMRs become integrated into the infrastructure. Addressing these hurdles requires continued concerted efforts from governments, regulatory bodies, industry stakeholders and the public. This will involve continued research,

[92] World Nuclear Association, "Small Nuclear Reactors," 2021.
[93] World Nuclear Association, "Country Profiles," accessed November 14, 2022; Statista, "Nuclear Power Plants by Country 2021," 2021.
[94] Between 1981 and 2019, the median construction time for a new nuclear reactor varies from between 84 and 117 months (8-10 years). Statista, "Median Construction Time for Nuclear Reactors 2019," 2020.
[95] World Nuclear Association, "Country Profiles," accessed November 14, 2022.
[96] World Nuclear Association, "Country Profiles," accessed November 14, 2022.
[97] Chatzis, "Small Reactors, Great Potential," October 22, 2020.
[98] Shwartz, "Small Modular Reactors Produce High Levels of Nuclear Waste," May 30, 2022.

collaborative initiatives, regulatory reforms and public engagement. Some notable events and announcements as it relates to SMRs are highlighted below.

- In July 2022, the European Parliament voted in favor of EU rules labelling nuclear energy as "green."[99] Mairead McGuinness, EU Commissioner for Financial Services, Financial Stability, and Market Union, called the classification change a "pragmatic proposal…needed for our energy transition."[100] In addition to helping the EU move towards its carbon zero climate goals, the change is also aimed at diversifying EU energy sources and reducing dependency on imported Russian gas.[101]
- The U.S. Inflation Reduction Act of 2022 (IRA22) also includes provisions to incentivize investment in nuclear energy. Among them are zero-emission nuclear power production tax credits for existing nuclear plants, technology-neutral tax credits for investments in new zero-carbon power plants, and funding for nuclear energy plant and infrastructure projects at the Department of Energy National Laboratories.[102]
- Also in 2022 at the UN Climate Change Conference (COP27) John Kerry, U.S. Special Presidential Envoy for Climate, announced Project Phoenix which has the specific goal of accelerating the clean energy transition by "supporting feasibility studies and providing technical assistance to support the pursuit of the conversion of coal-fired power plants to reliable and safe zero-carbon small modular reactor (SMR) nuclear energy generation."[103]
- In an August 2023 keynote speech on promoting nuclear nonproliferation for the peaceful use of nuclear energy Ambassador Jenkins, U.S. under secretary for arms control and international security, re-emphasized how SMRs play a "critical role in decarbonizing hard-to-abate sectors beyond electricity, such as industrial process heat, clean hydrogen production, and water desalination" and "have advanced safety features.".[104]
- More broadly during the COP28 meeting in December 2023 nuclear power, including SMRs, was reportedly subject to "unprecedented" attention with nearly two dozen countries signing a declaration to triple nuclear energy by 2050. SMRs have been a focus as a way to help achieve the goal set forth in this declaration.

However, despite incentives and interest worldwide SMR's prospects remain questionable, and reports indicate that SMRs are unlikely to be more widely deployed before 2030 according to the World Nuclear

[99] Abnett, "EU Parliament Backs Labelling Gas and Nuclear Investments as Green," July 2022.
[100] European Commission, "EU Taxonomy: Vote by EP on Complementary Delegated Act," July 2022.
[101] European Commission, "EU Taxonomy: Vote by EP on Complementary Delegated Act," July 2022.
[102] Huff, Kathryn, "Inflation Reduction Act Keeps Momentum Building for Nuclear Power," September 2022
[103] State, "Project Phoenix," September 7, 2023.
[104] During this speech Ambassador Jenkins also highlighted the Foundational Infrastructure for the Responsible Use of Small Modular Reactor Technology (FIRST) program, established in 2021, which is summarized as "an effort to promote innovation, bring clean technologies to scale, and build unprecedented global cooperation to confront the climate crisis, under the highest standards of safety, security, and nonproliferation." Jenkins, "Response to Climate Change and Energy Security: Opportunities and Challenges for SMRs." August 2, 2023.

industry—as of January 2024 no commercial SMRs are currently under construction in the western world.[105]

[105] Chu, "COP28 Shines Spotlight on Nuclear Power," December 7, 2023. See also table in appendix which shows that as of the end of 2023 at least four advanced reactor demonstration (not commercial) plants were on the books with DOE funding or NRC license applications in the U.S.

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Appendix

Table A.1 Number of operable nuclear power reactors worldwide as of May 2023, by country

Country	Number of Operational Reactors
United States	93
France	56
China	55
Russia	37
Japan	33
South Korea	25
India	22
Canada	19
Ukraine	15
United Kingdom	9
Spain	7
Belgium	5
Sweden	6
Czechia	6
Pakistan	6
Finland	5
Slovakia	5
Switzerland	4
Hungary	4
Argentina	3
Germany	3
Taiwan	3
Mexico	2
Bulgaria	2
Romania	2
United Arab Emirates	3
Brazil	2
South Africa	2
Slovenia	1
Belarus	1
Armenia	1
Iran	1
Netherlands	1

Source: Statista, "Statistics on Global Nuclear Energy," accessed March 20, 2023.

Table A.2 Examples of SMR Demonstration Plants with DOE Funding or NRC License Applications

Reactor Designer	Technology	Reactor Power (electric)	Plant Owner	DOE Funding	Plant Location	NRC Licensing Status
Terra Power	Sodium-cooled fast reactor	345 MW	PacificCorp	Up to $1.6 billion	Kemmerer, WY	Pre-application activities
X-energy	High-temperature gas-cooled reactor	80 MW	Energy Northwest	Up to $1.2 billion	Seadrift, TX	Pre-application activities
Kairos	Fluoride-salt-cooled high-temperature reactor	35 MW	Kairos	Up to $303 million	Oak Ridge, TN	Construction Permit applications submitted 9/29/2021 And 7/14/2023
Abilene Christian University	Molten salt research reactor	1 MW	Abilene Christian University		Abilene, TX	Construction permit application submitted 8/12/2022

Source: Adapted from https://crsreports.congress.gov/product/pdf/R/R42853; Thomas, "Efforts to Transform US Nuclear Industry Entering Full Bloom," September 21, 2022.

Note: Abilene Christian University Reactor is backed by private funding. Not listed is the NuScale/UAMPS project, as stated in the U.S. country profile section, the project was terminated on November 8, 2023. The shuttering of the project has been attributed, in part, to ballooning costs.