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Advanced Reactors: Turning the Corner

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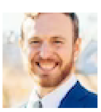

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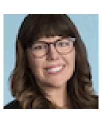

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Takeaways

A common misconception about advanced nuclear technologies is that they are largely conceptual and will not be commercialized in time to contribute to meeting near-term climate goals. However, a comprehensive look at global efforts to develop advanced nuclear reveals rapid progress towards commercialization and operation. For example, with numerous projects underway and multiple policies recently enacted to support advanced reactor development, the U.S. is well-positioned to be a global leader in this field. Several other countries are also boldly pushing forward with programs to develop, demonstrate, deploy, and commercialize advanced reactors—in some cases, the reactors are already being constructed or operated. To enable a pathway towards American leadership in advanced nuclear, the U.S. will need to redouble policy approaches supporting the development of advanced reactors, including strengthening public-private partnerships such as the Advanced Reactor Demonstration Program (ARDP), continuing modernization of its nuclear regulatory and licensing frameworks, ensuring robust supply of high-assay low-enriched uranium (HALEU) fuel, and exploring opportunities for federal procurement of advanced reactor technologies.

The next generation of nuclear reactors, collectively called "advanced reactors," are making substantial progress towards commercialization and are poised to offer new tools to provide clean energy. These advanced reactors are an evolution of either today's dominant reactor technology, light water reactors (LWRs), or non-LWR designs that have operated on an experimental and limited commercial basis since the 1960s but were never widely deployed. [1]

Today is a watershed moment in the advanced reactor space, with more than 30 commercial scale demonstrations of different designs in progress across the globe. These designs cut across technologies, sizes, and target applications. The timelines for these projects show that advanced nuclear energy can be operational in time to address the climate challenge, with commercial demonstrations in the 2020s, and then cost-reduction and large-scale rollout in the 2030s. These reactors are designed for mass production and to reduce construction risk through modularity, simplification of design, and a high-level of manufactured content. With shorter construction timeframes and lower construction risk, advanced reactors could quickly achieve cost reductions through technological learning.

Advanced Reactor Types, Sizes, and Applications

Technologies	Sizes	Applications
LWRs	Microreactors *(1-20 MWe)*	Electricity Production
Molten salt reactors	Small modular reactors *(20-300 MWe)*	Renewable Integration
High temperature gas reactors		Process Heat
Liquid metal reactors		Hydrogen and Ammonia Production
		Off-grid applications
		Desalination
		District Heat

Source: Pillsbury Winthrop Shaw Pittman

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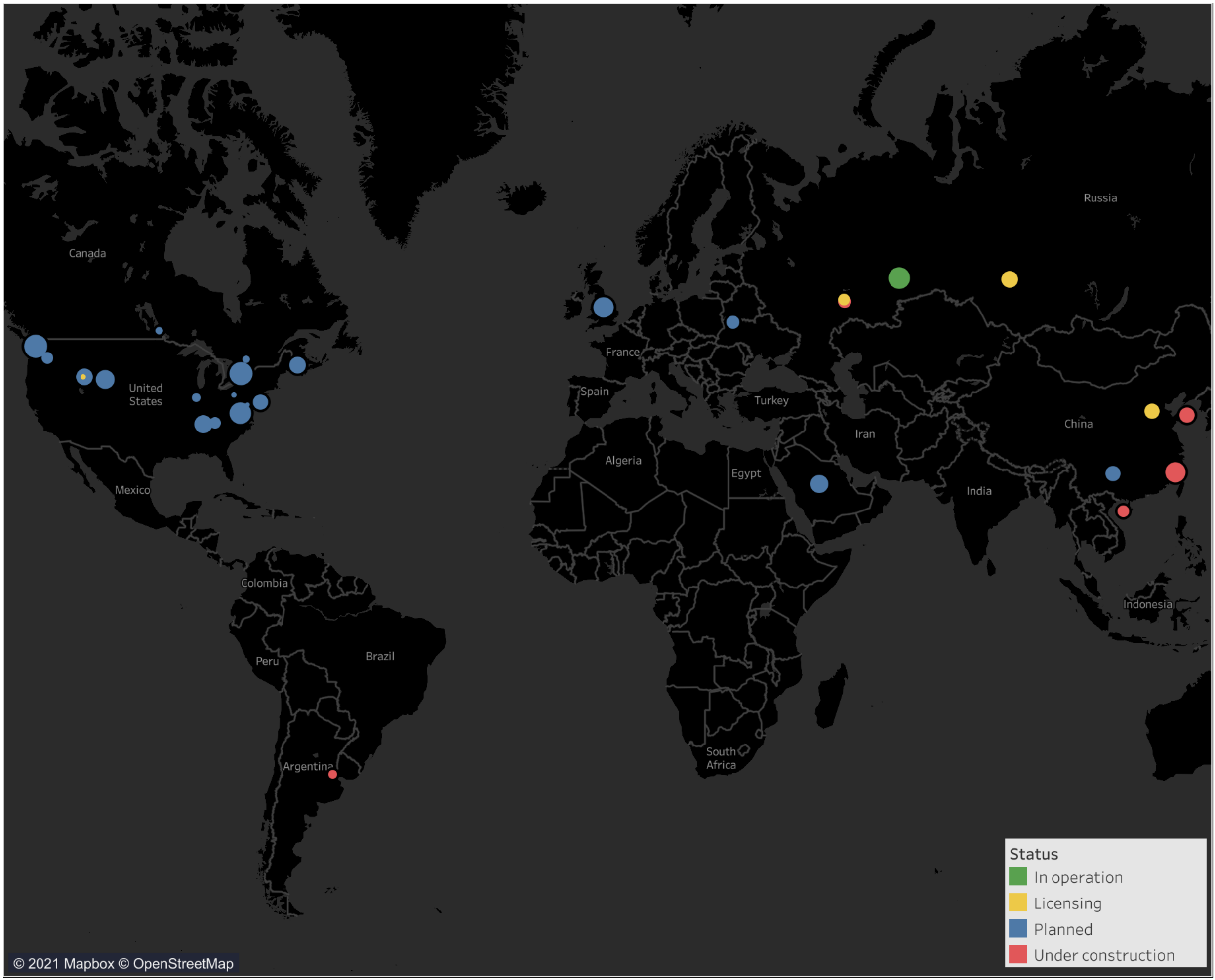
The interactive map below shows the technology types, locations, and estimated completion dates of projects underway globally. Details can also be viewed in this chart.

2021 Global Advanced Nuclear Demonstrations Map



United States

Last year marked monumental progress for advanced reactors across the United States. In May 2020, the Department of Energy (DOE) launched its Advanced Reactor Demonstration Program (ARDP) which as of FY2021 has awarded $480 million in appropriated funding for advanced reactor projects. The program has three different development and demonstration pathways:

- **Advanced Reactor Demonstrations:** Awards for two operating full-scale advanced reactors by 2027. The DOE will invest a total of $3.2 billion over seven years for the TerraPower/GE-Hitachi *Natrium* sodium fast reactor with a molten salt energy storage system, and the X-energy *Xe-100* HTGR, with matching investment from industry.

- **Risk Reduction Awards:** Awards to support reactors under development that can be licensed and deployed over the next 10 to 14 years. The DOE expects to invest approximately $600 million over seven years. The five awardees are:
  - Kairos Power *Hermes* reduced-scale test reactor, a precursor of the company's commercial fluoride salt-cooled high temperature reactor;
  - Westinghouse *eVinci*, a heat pipe microreactor;
  - BWXT *Advanced Nuclear Reactor*, a transportable microreactor;
  - Holtec *SMR-160*, a LWR reactor; and
  - Southern Company Services Inc. *Molten Chloride Reactor Experiment*, a precursor to TerraPower's *Molten Chloride Fast Reactor*.

The Advanced Reactor Concepts 2020 (ARC 20) awards are an additional pathway supported by DOE to advance designs with potential to commercialize in the mid-2030s. The awardees are ARC Clean Energy which is developing a seismically isolated advanced sodium-cooled reactor; General Atomics for its 50 MWe fast modular reactor conceptual design; and a Massachusetts Institute of Technology group working on a horizontal HTGR concept. DOE is expected to invest $56 million over four years.

Congress also passed the Energy Act of 2020, tucked in the end-of-year omnibus bill, which included a monumental $6.6 billion in authorized funding for advanced nuclear energy. The bill authorized not only ARDP funding for the next five years, but also a program to support the commercial availability of domestic High-Assay Low-Enriched Uranium (HALEU), which is used in the composition of fuel for most advanced reactors and is necessary for large-scale deployment. Furthermore, the Energy Act of 2020 authorized programs focused on nuclear integrated energy systems, which are important to demonstrate nuclear technologies for non-electric applications such as hydrogen production, process heat, or desalination. While Congress will still need to appropriate funds toward these programs, the authorizations provide useful direction for DOE and a strong signal that advanced reactors are a bipartisan priority on Capitol Hill.

Key elements of the funding authorized for advanced nuclear in the Energy Act of 2020 are summarized below:

Authorized Funding for Advanced Nuclear *(Energy Act of 2020)*

Program/Subject Area	Authorization
ARDP	$2.14 billion *over the next 5 years*
HALEU Fuel Availability Program	$174 million *over the next 5 years*
Advanced Fuels Research	$625 million *over the next 5 years*
Advanced Reactor Technology Research	$275 million
Nuclear Integrated Systems Research	$160 million
Nuclear Fuel Cycle Research and Development	$300 million *over the next 5 years*
University Nuclear Research	$100 million *over the next 5 years*

Source: Energy Act of 2020, https://rules.house.gov/sites/democrats.rules.house.gov/files/BILLS-116HR133SA-RCP-116-68.pdf

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So far, multiple ARDP awardees have announced demonstration sites in Richland, Washington; Oak Ridge, Tennessee; at a retiring coal plant in Wyoming; and at the Idaho National Laboratory.

In parallel to commercial demonstrations, the U.S. Department of Defense (DoD) is pursuing Project Pele, which has the objective to design, build, and demonstrate a prototype mobile nuclear reactor by 2024. In March 2021, DoD announced it had selected BWX Technologies, Inc. and X-energy to complete the final design for their mobile nuclear reactor prototypes. After completing their final design in 2022, DoD may select one company to build their prototype and anticipates full power testing of the reactor by the end of 2023, and outdoor mobile testing at a DOE installation in 2024.

There were also significant advanced reactor licensing milestones in 2020. NuScale is working with the Utah Associated Municipal Power Systems (UAMPS) on the Carbon Free Power Project (CFPP) and received the first design certification for a small modular reactor (SMR) from the Nuclear Regulatory Commission (NRC) in August 2020. The CFPP will be located at the Idaho National Lab (INL) and is expected to start operation in 2029. In 2020, DOE awarded up to $1.4 billion to support development of the project.

Oklo also submitted the first combined license application for an advanced reactor to the NRC. Oklo's *Aurora Powerhouse*, a microreactor non-LWR design, is also to be constructed at the INL site and is expected to come online between 2023 and 2025.

Canada

In December 2020, the Government of Canada, together with key stakeholders across the country, launched Canada's SMR Action Plan. The Action Plan builds on the 2018 SMR Roadmap effort led by the Department of Natural Resources Canada (NRCAN) and was informed through engagement with Canadian territories, provinces, indigenous peoples and communities, utilities, vendors, and national laboratories. Canada's SMR Action Plan puts forth over 50 recommendations in areas key to SMR development, demonstration, and deployment and seeks to establish concrete targets based on stakeholder concerns.

Canada's first advanced reactor project is Global First Power's 15 MWt commercial demonstration of the Ultra Safe Nuclear Corporation *Micro Modular Reactor*, an HTGR microreactor at Canadian Nuclear Laboratories' (CNL) Chalk River site. The project is part of CNL's program for the construction and operation of SMRs at CNL-managed sites, with four companies engaged in various stages of that program. The lead developer, Global First Power, is a joint venture between Ontario Power Generation (OPG) and developer Ultra Safe Nuclear Corporation. Global First Power has engaged in licensing and environmental assessment processes with commercial deployment planned in 2025.

OPG is also seeking to build a grid-size SMR at its Darlington site for which it already holds a Site Preparation License, granted by the Canadian Nuclear Safety Commission (CNSC). OPG is advancing engineering and design work with three developers: the GE-Hitachi *BWRX-300*, the Terrestrial Energy *iMSR*, and the X-energy *Xe-100*. OPG aims for connecting the first unit to the grid as early as 2028.

New Brunswick Power (NBP) is another Canadian utility seeking to advance a new generation of reactors. NBP is working with two developers – Moltex and ARC Nuclear Canada Inc. – to license and construct advanced reactors at its Point Lepreau site by the late 2020s.

In the province of Manitoba, the remote community of Pinawa has agreed to demonstrate the benefits of SMRs to an off-grid community and/or mining organization. Pinawa hosts the CNL-managed Whiteshell Laboratories, a nuclear research and development site that is currently being decommissioned.

United Kingdom

In the UK, advanced nuclear was included in the Prime Minister's ten point plan for a green industrial revolution released in November 2020. Specifically, the UK Government will invest £215 million (~$300 million) into SMRs through the Low Cost Nuclear (LCN) program from 2021 onwards. The investment will be made into the UK SMR design, a 440 MWe modular Pressurized Water Reactor designed with factory-manufactured components that will be transported to site for assembly and installation. The design is being developed and deployed by the UK SMR consortium, which is led by Rolls Royce and includes Assystem, Atkins, BAM Nuttall, Jacobs, Laing O'Rourke, the National Nuclear Laboratory, the Nuclear AMRC, and TWI.

Russia

In December 2019, the *Akademik Lomonosov*, the world's first floating commercial SMR, was connected to the grid. The two 35 MWe KLT-40C reactors aboard are based on technology used on Russian icebreakers and are supplying power to the remote Chaun-Bilibino network in Russia's Far East. Rosatom announced in December 2020 that the first commercial RITM-200 50 MWe reactor, an evolution of the KLC-40C and currently used in Russia's newest icebreakers, will be constructed in the Republic of Sakha (also known as Yakutia) in Siberia. Site work will begin this year and operation is targeted for 2028.

Russia also has significant experience with fast reactor deployment, with two operating commercial scale fast reactors at Beloyarsk NPP – the BN-600 sodium-cooled fast breeder reactor (in operation since 1980) and the BN-800 with a different fuel composition (in operation since 2016). Rosatom increasingly sees fast reactors as the future of the Russian nuclear industry with one of its key priorities being the Proryv (Breakthrough) project, which seeks to demonstrate a closed fuel cycle with improved uranium efficiency and reduced waste accumulation.

A key component of the Proryv project is the MBIR, a 150 MWt multi-loop sodium-cooled fast reactor capable of testing lead, lead-bismuth, and gas coolants that will run on mixed-oxide (MOX) fuel. The reactor is under construction at the Research Institute of Atomic Reactors (RIAR) site in Dimitrovgrad and is scheduled for operation in late 2021. RIAR will construct a pyrochemical reprocessing facility at the same site to close the fuel cycle, and the overall project aligns with the International Atomic Energy Agency's International Project on Innovative Nuclear Reactors and Fuel Cycles and will be open to foreign collaboration.

Another component of the Proryv project is the BREST OD-300, a fast neutron lead-cooled reactor sited in Seversk, Tomsk region. Site preparation work began in 2020, and the reactor is scheduled to come online in 2026.

Finally, the SVBR-100, a lead-bismuth reactor design based on reactors that were used on Russian submarines, is planned for demonstration at the Dimitrovgrad site. AKME-engineering, a 50/50 joint venture between Rosatom and Siberian energy company Irkutskenergo, obtained a site license for the project.

China

The speedy development of fourth generation reactors has been a key part of China's last two five-year plans and is likely to remain a top strategic priority.

China's progress in demonstrating advanced reactor technologies is best marked by the HTR-PM, featuring two 100 MWe high temperature pebble bed reactors under construction at the Shidao Bay NPP. The HTR-PM began hot functional testing in January 2021 and is scheduled to come online later in 2021. The plant is a scaled-up version of the HTR-10, a 10 MWt prototype reactor at Tsinghua University which has been in operation since 2003. Eighteen additional HTR-PM units are proposed for the Shidao Bay site. China is also proposing a scaled-up version of the plant, the HTR-PM600, with a single large turbine rated at 650 MWe driven by six HTR-PM reactor units.

China is also in the process of demonstrating small LWRs and China National Nuclear Corporation (CNNC) is building the ACP-100, a 125 MWe SMR, at the Changjiang NPP which is targeted for operation in 2026. The ACP-100 is designed for a variety of applications such as thermal unit replacement, urban district heating, marine applications, and on military bases. The 200 MWe NHR-II is another LWR SMR in development and is being sited in the Hebei province in northern China to provide district heating as well as industrial steam.

Finally, CNNC is constructing the Xiapu fast reactor demonstration project in the Fujian province. The two-reactor project is comprised of CFP-600 sodium-cooled pool-type fast neutron reactors, with operations planned for 2023-2025. Research conducted at these reactors aims to support China's plan to achieve a closed nuclear fuel cycle.

Argentina

Argentina has previously exported research reactors to Australia, Peru, Algeria, and Egypt and is leveraging those successes to demonstrate and commercialize an SMR. The CAREM-25 is a small PWR that is under construction at the Atucha Nuclear Power Plant with operation planned for 2024. The reactor is intended to be a prototype with scaled-up units targeted for export.

Ukraine

In 2019, Ukraine's national nuclear operator, NAEK Energoatom, Ukraine's State Scientific and Technology Center (SSTC), and Holtec International entered into a consortium partnership to deploy Holtec's *SMR-160* in Ukraine and establish a manufacturing hub for the modules in the country. Six *SMR-160* units are planned to be operational by 2030 at the country's Rivne nuclear site and Energoatom is considering deploying additional SMR-160 units to complement renewables. Holtec has a long-standing relationship with Energoatom; the company has worked since 2005 to design, license, construct, and commission a central spent fuel storage facility in Ukraine and also provides spent fuel storage and transportation services to Energoatom.

Saudi Arabia

The use of SMRs for power, desalination, and thermal applications is part of the Saudi National Atomic Energy Project (SNAEP), approved by the government in 2017. Saudi Arabia's King Abdullah City for Atomic and Renewable Energy (K.A.CARE) has focused on two technologies, the Korean 100 MWe *SMART* reactor, an integral-type LWR, and the Chinese HTGR. Saudi Arabia is looking to not only build SMRs in the Kingdom, but also to own the IP for the technologies for export to the global market. K.A.CARE and its potential Korean partners have cooperated since 2015 on the *SMART* reactor and in 2019, an organization led by Korea Atomic Energy Research Institute (KAERI) completed engineering works and produced a Preliminary Safety Analysis Report (PSAR) for the design. In 2020, K.A.CARE and South Korea's Ministry of Science and ICT (MSIT) signed a contract to establish a joint entity to commercialize and construct the *SMART* in Saudi Arabia, with the first unit planned for 2026.

Conclusion

With multiple countries considering nuclear reactors as a method of providing low-carbon energy, it is important to understand the broader global landscape of advanced reactor development. End-user countries will be interested in the suite of technologies that can address their specific needs, and supplier countries that can provide a competitive product will have a significant market advantage. Specifically for the U.S., it is important to note that advanced reactor RD&D efforts are not occurring in a vacuum, and that progress in advanced reactor development in other countries should elicit commensurate increases in funding, policy support, and programs that have facilitated significant achievements by the American advanced nuclear industry so far.

TOPICS

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ENDNOTES

1. Historical advanced reactors include high-temperature gas-cooled reactor (HTGR) pilots in the United States, United Kingdom, Germany, and China as well as the BN 350 sodium cooled reactor in Kazakhstan.