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Combating Climate Change Through Nuclear Energy: Risks, Advantages, and Geopolitical Implications of Advanced Small Nuclear Reactors

Edward Jenner

Summary

Use of nuclear energy is likely to grow in the coming decades, in part to combat climate change. Increased deployment of nuclear energy will likely include use of advanced small reactors, which can facilitate decarbonization, increase nuclear safety, supplement gaps in renewable energy production, provide energy to low-demand communities, help desalinate water, and increase energy security. But there are also risks. Nuclear power, such as that produced by advanced small reactors, put nuclear material in more locations and use higher enrichment fuel for some reactor designs, both of which are security concerns. Moreover, while China and Russia already have operating advanced small reactors and are exploring using reactors aboard floating nuclear power plants, the U.S. will likely not have an operational advanced small reactor until the late 2020s. This brief explores the benefits and risks of advanced small nuclear reactors and describes strategies to mitigate these risks. The bottom line: advanced small nuclear reactors are a beneficial tool for reducing carbon emissions. But their safe deployment and use requires increasing nuclear security expertise and assessing both nuclear fuel and advanced small reactor needs. Moreover, nuclear newcomers need support to adopt nuclear norms and develop domestic nuclear regulatory bodies to lower the potential risks of nuclear energy while maximizing the potential benefits.

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The Potential for Nuclear Energy to Contribute to Decarbonization

Current efforts to lower global greenhouse gas emissions have the world on track for an average 2.7 degrees Celsius temperature rise this century,[1] nearly double the limit hoped for in the Paris Climate Accord. With a 1.0°C increase, climate change is already devastating—contributing to wildfires, crop failures, civil wars, mass human migration, and terrorism.[2] These effects are not projected to slow down, and may accelerate with higher temperatures.

To combat climate change, states are pursuing a wide array of strategies. These strategies can be broadly categorized as 1) efforts to limit the activities that produce emissions, 2) introducing new technologies that produce fewer or reduce emissions, and 3) using existing technologies in new ways to produce fewer or reduce emissions. The current global interest in nuclear energy is driven primarily by its potential to accomplish the first and third categories.

The first benefit of nuclear energy is that it is a zero process emission technology. This means that operating a nuclear reactor produces no carbon emissions, though carbon emissions are generated when nuclear facilities are built and decommissioned and when nuclear fuel is generated and handled.

Despite these implicit emissions costs, nuclear energy is one of the greener technologies from an emissions analysis—that is, it contributes fewer emissions than many of the alternatives.[3] Thus, utilizing nuclear energy limits the need for fossil fuels such as natural gas and coal, which produce roughly 100 hundred times more emissions per kilowatt-hour of electricity produced.

A second benefit of nuclear energy is its potential to decarbonize sectors that are otherwise hard to abate. One such example is powering aviation with hydrogen fuel. Hydrogen is a fuel carrier, meaning it is not obtained from nature but is produced from other sources of energy. Though this creates some energy losses, it allows a high-energy density fuel (hydrogen) to be produced with low emissions, depending on the production method.[4] If the method is renewable energy or nuclear (the latter of which can produce hydrogen more efficiently), aviation—and other sectors—can potentially operate as they are currently while using a fuel that generates fewer emissions.

Finally, nuclear energy can support the intermittency of renewables. Since renewable energy sources depend on variables outside our control—wind speed and sun exposure—nuclear energy can support a grid operating on renewables by supplementing their production.

1 United Nations Environment Programme (2021). "Emissions Gap Report 2021: The Heat Is On – A World of Climate Promises Not Yet Delivered." Nairobi. https://www.unep.org/resources/emissions-gap-report-2021.

2 "Climate change 'aggravating factor for terrorism': UN chief." *UN News*, (9 December 2021). https://news.un.org/en/story/2021/12/1107592.

3 United Nations Economic Commission for Europe. "Life Cycle Assessment of Electricity Generation Options." (2021).

4 National Renewable Energy Laboratory. "Hydrogen Basics." Department of Energy. https://www.nrel.gov/research/eds-hydrogen.html#:~:text=Hydrogen%20as%20an%20Energy%20Carrier,vapor%20as%20a%20by%2Dproduct.

Sequoyah nuclear power plant near Chattanooga, Tennessee. Photo: Photorush, CC BY-SA 3.0, via Wikimedia Commons

Growing Interest in the U.S. for Nuclear Power

The potential for nuclear energy to contribute to decarbonization has led to growing interest and approval for nuclear energy in the U.S. According to ecoAmerica, nuclear energy support has increased by 10 percent, from 49 percent in 2018 to 59 percent in 2021[5] (with support being described as "strongly support" or "somewhat support" nuclear power). Political stances have also shifted: Democratic support for nuclear energy has increased from 37 percent in 2018 to 60 percent in 2021, while Republican support persisted at the same rate of 64 percent over that time. Independents moved from 50 percent in favor in 2018 to 61 percent in 2021.

Many partner countries of the United States such as France, Japan, South Korea, and the United Kingdom are exploring advanced small modular nuclear reactors. Others such as Poland, Romania, South Korea, and Canada are pursuing partnering with the U.S. to develop or expand nuclear programs.

Risks and Challenges of Nuclear Energy

With growing support for nuclear energy in the United States, and the ability of nuclear energy to provide low-carbon electricity, it is likely that nuclear energy will play a more significant role in the U.S. energy mix in the near future. However, for all its advantages, nuclear energy is not flawless. Nuclear waste is radiological and thus an environmental concern for one million years, well beyond the current age of civilization. Severe errors in reactor and facility design, operation, or both can cause catastrophic failures such as Chernobyl or Fukushima. Nuclear material also inherently creates proliferation concerns, as it can be used (though not easily) for nuclear weapons development. And nuclear power plants are expensive—they cost billions as capital investments and take years to decades before turning a profit. The average time for a facility built in the U.S. to turn a profit is nearly a decade.

[5] ecoAmerica, "Energy Attitudes: Americans Support Clean Energy." American Climate Perspectives. 2021. https://ecoamerica.org/wp-content/uploads/2021/11/acps-2021_energy-attitudes-report.pdf.

The design of advanced small modular reactors (SMRs) aims to address these concerns. Many advanced SMR designs extensively use “passive safety” features, which can mitigate or stop an accident without operator intervention or application of an active system. Examples of these include convection cooling, reactor cooling pools, and fuel freeze plugs. Additionally, by utilizing a smaller reactor that can be built and assembled in a factory and then transported to the final location, build times and costs should (in theory) decrease compared to traditional reactors which have to be built on-site. Finally, SMRs’ modular design should allow them to be produced efficiently, en masse, making their productions comparatively cheaper than traditional reactors.

Small Modular Reactors—Benefits and Risks

Small modular reactors are not a novel idea. The concept of mass producing small nuclear reactors is decades old. Here, the term “advanced SMRs” is adopted from the International Atomic Energy Agency (IAEA), which defines “advanced” as either evolutionary designs that improve on existing designs with a strong emphasis on proven design features to minimize technological risk, or designs with radical changes in materials and/or fuels, operating conditions, or environments, and system configurations.[6] Advanced reactors are being designed, developed, and deployed for utilization of nuclear waste heat concurrent with electricity production. Thus SMRs, advanced reactors, and “advanced SMRs” are all unique terms.

There are many benefits to deployment and use of SMRs. Due to the small size of SMRs, they can fit into coal fire plants. Coal plants already contain electricity generation infrastructure such as steam turbines and grid connection. Thus there is interest in installing SMRs in retiring coal fire plants, which would allow SMRs to provide electricity without completely building a new power station.

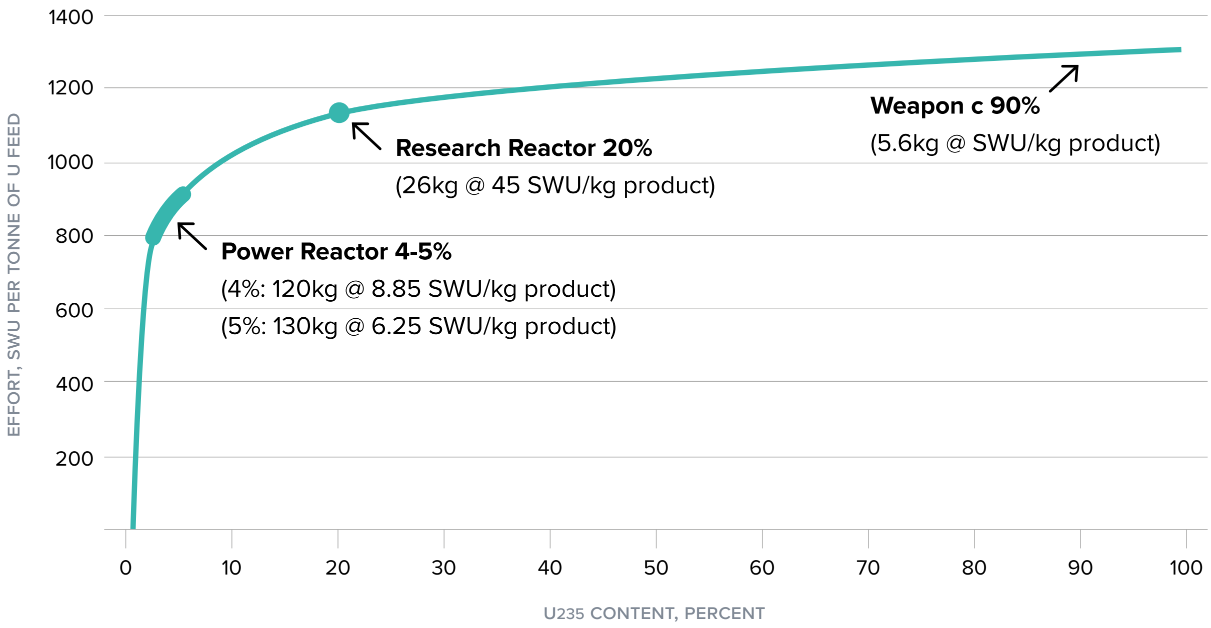
Smaller nuclear reactors can also operate aboard floating nuclear power plants (FNPP). The U.S. built one of the first FNPPs in the 1960s to power infrastructure at the Panama Canal. An attractive facet of floating nuclear power plants is they are immune to the effects of earthquakes and tsunamis. If the facility is staged offshore in deep enough water, earthquakes and tsunamis would not pose a risk to the facility. Alternatively, if the facility can detach readily from its onshore connections, it could move to deeper waters in the event of an oncoming tsunami. The ability to insulate from these risks can make a nuclear power plant safer and cheaper as significant safety infrastructure is not required.

However, use of SMRs also implies risk. For some SMR designs, the reactors are to be fueled with High Assay Low Enriched Uranium (HALUE), which is between 5 percent and 20 percent enrichment, contrary to standard nuclear power plants, which generally operate below 5 percent enrichment. This is a safeguards and security concern because work required to enrich uranium is not linear, and therefore, 20 percent enriched uranium is significantly closer to weapons-grade uranium than 5 percent, as shown in Figure 1. Countries using SMRs with HALEU fuel (or sub-state actors looking to steal nuclear material) will have a lower barrier to pursue nuclear weapons compared to traditional nuclear power plants. There are some mitigating factors. SMRs, for example, can be designed to have sealed reactor cores, but the concern is nonetheless significant.

[6] Advanced Reactors Information System, IAEA. https://aris.iaea.org/.

FIGURE 1

Uranium Enrichment vs Energy Consumption, provided by the World Nuclear Association.[7]



The increasingly tense geopolitical context, shaped by Russia's war in Ukraine and rising competition between the U.S. and China, is another area of concern. Russia, the only exporter of HALEU fuel, has shown its willingness to use energy dependence for coercive leverage. For this reason, the U.S. is exploring producing HALEU domestically.[8] But currently, Russia and China are ahead of the U.S. in this technology. Russia and China are currently pursuing utilizing advanced SMRs aboard FNPPs. Russia has deployed the first advanced SMR aboard an FNPP, the *Akademik Lomonosov*, in the Artic where it provides electricity to a local mining community. The FNPP was preferable to a land-based facility because of the difficulty of moving a nuclear reactor over the Tundra, building the necessary containment vessel, and supporting safety infrastructure in frozen earth. Russia has been exploring providing FNPPs to potential nuclear customers, one of which may be Brazil. China is also interested in FNPPs, but more so to utilize themselves rather than export. China has built artificial islands in the South China Sea, and hopes to power installations on these islands with FNPPs. China also has an operational advanced SMR, but has not yet deployed one aboard an FNPP. The U.S. is yet to build an advanced SMR.

As great power competition between the three countries intensifies, there is concern that China and Russia will gain leverage and influence through nuclear exports with U.S. partner countries. Though Russia and China have exported nuclear technology to many countries, including U.S. partners, in the past, the increase in global interest in nuclear technology means these exports could become more significant.

[7] http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx.

[8] "U.S. Department of Energy Seeks Input on Creation of HALEU Availability Program." December 14, 2021. https://www.energy.gov/ne/articles/us-department-energy-seeks-input-creation-haleu-availability-program.

Policy Recommendations

How can the U.S. harness the promise of nuclear energy to combat climate change, and specifically the potential of advanced small nuclear reactors, while mitigating potential security risks? The following four recommendations provide a pathway for capitalizing on the benefits of nuclear energy while addressing the risks associated with energy in the current geopolitical context. These recommendations are by no means exhaustive but rather a starting point for an issue that will likely require significant study as advanced SMRs and FNPPs are deployed globally.

1) Sponsor Counterterrorism Training for Commercial Entities and States Engaged in the Nuclear Fuel Cycle

The IAEA has built counterterrorism training facilities around the world that educate personnel in nuclear security, and are critical for states pursuing nuclear energy and nuclear sciences. These facilities provide the ideal platform for scaling up expertise in nuclear security among commercial entities involved in the nuclear fuel cycle, nuclear science research institutions, and states pursuing nuclear energy, such as advanced reactors. The U.S. should lead this effort by collaborating with the IAEA and sponsoring personnel tasked with physical security to train at such facilities. For more information on nuclear security, the IAEA describes establishing nuclear security through training centers in IAEA TECDOC-1734.[9] On SMRs specifically, Williams, et. al provides a technical evaluation of security (along with safeguards and safety).[10]

2) Assess the Nuclear Fuel Cycle and Nuclear Power Needs of the U.S. and Partner Countries

Increased nuclear energy use will increase the need for nuclear fuel cycle services, of which Russia and China are major contributors. Though the U.S. is already assessing its need for HALEU fuel[11] and testing a pilot plant, the U.S. does not have a complete nuclear fuel cycle. If the U.S. and partner countries are forced to rely on Russia or China for certain fuel cycle steps, that could increase the influence or leverage Russia or China may have. The U.S. and its partners need to determine what their nuclear energy goals are, and subsequently the fuel cycle requirements for those goals. If the capacity of the U.S., partner countries, and neutral third parties cannot meet future demand, the U.S. should work with partner countries to expand their capabilities. The U.S. has capabilities in several, but not all, steps in the nuclear fuel cycle, as do some U.S. partners such as France, Canada, Germany, Japan, and South Korea. To ensure all needs are met without creating oversupply, it may be worthwhile to coordinate between countries on which steps and to what extent countries would expand.

3) Encourage International Nuclear Safety, Security, and Safeguards Norms

The U.S. should promote norms for nuclear newcomers. Several international treaties exist to cooperatively address nuclear safety, spent fuel management, and nuclear accidents mitigation. With advanced SMRs, and especially FNPPs, it is imperative countries adopt these international norms.

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[9] IAEA, *Establishing and Operating a National Nuclear Security Support Centre*. 2020.

[10] Williams, et. al, "System Studies for Global Nuclear Assurance & Security: 3S Risk Analysis for Small Modular Reactors." Prepared by Sandia National Laboratories. October 2018.

[11] Dixon, *et. al*, "Estimated HALEU Requirements for Advanced Reactors to Support a Net-Zero Emissions Economy by 2050." Idaho National Laboratory, December 2021.

4) Promote Autonomy in Regulatory Bodies for Nuclear Newcomers

Nuclear energy oversight requires autonomy and insulation from political influences. Without it, there is potential for unsafe or unsecure development of nuclear projects to meet political demands. The U.S. should assist nuclear newcomers to develop regulatory and oversight bodies to ensure autonomous nuclear energy production follows best practices. The U.S. can cooperate with the IAEA to utilize several existing initiatives that were developed for exactly this situation. The International Regulatory Development Partnership (IRDP), for example, a component of the U.S. Nuclear Regulatory Commission, supports development of autonomous regulatory institutions. The IAEA's Comprehensive Capacity-Building Initiative for System of Accounting for and Control of Nuclear Material and Safeguards Implementation (COMPASS), oversees material accountancy and safeguards for nuclear newcomers, which complements the IRDP. The IAEA also has the Integrated Regulatory Review Service (IRRS) which can review and support regulatory bodies, such as one developed with the IRDP. The U.S. should coordinate with the IAEA to utilize these initiatives to support nuclear newcomers. The United Arab Emirates (UAE) is a recent newcomer country that has not only adopted nuclear norms, as suggested in recommendation three, but also incorporated suggested best practices for developing a nuclear regulatory body. More on the UAE's success as a nuclear newcomer is described by "Nuclear Newcomer Countries – The Path of the United Arab Emirates[12]" in *Nuclear Law – The Global Debate*,[13] a series of essays compiled by the IAEA.

Conclusion

Given the significant potential of nuclear energy to contribute to achieving net-zero emissions, it should be no surprise that in 2021 the U.S. Department of Energy (DOE) spent a record $1.3 billion to support the nuclear reactor fleet and advance nuclear energy research. Along with the Bipartisan Infrastructure Bill, signed by the Biden administration in late 2021, the DOE will continue to support advanced nuclear energy research in the coming years. For example, the DOE is supporting a pilot enrichment plant with advanced centrifuges in Piketon, Ohio to provide HALUE fuel for advanced reactors and prove commercial viability. At Palo Verde Nuclear Generating Station in Phoenix, Arizona, the DOE and PNW Hydrogen, LLC are collaborating to produce hydrogen from waste heat supplied by nuclear energy. Advanced reactor demonstrations are underway by both Terrapower and X-energy, on target for production before the end of the decade.

Nuclear energy is poised to decarbonize significant parts of the energy grid globally and in the United States. The U.S. can facilitate the industry's growth in the next few years by increasing counterterrorism training, potentially providing nuclear fuel cycle needs to allies and other partner countries, encouraging international nuclear security norms, and supporting development of autonomous nuclear regulatory bodies. Further, the U.S. has poised itself to successfully do this, as it has an established and successful history of nuclear security and safeguards. Pursuing these recommendations will support the continued success of nuclear energy and thus support decarbonization and climate goals.

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[12] AlKaabi, H., "Nuclear Newcomer Countries – The Path of the United Arab Emirates," in *Nuclear Law, the Global Debate*. IAEA, 2022.

[13] IAEA, *Nuclear Law*, the Global Debate. IAEA, 2022.

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Author

Edward Jenner is a Postdoctoral Fellow in Technology and International Security at the UC Institute on Global Conflict and Cooperation (IGCC) in Washington, D.C. At this fellowship, Edward has focused on nuclear issues and their impact on great power competition. Prior to this fellowship, Edward was a Stanton Nuclear Security Fellow at Texas A&M, where he collaborated with Matthew Fuhrmann and Craig Marianno on research studying supply-side nuclear proliferation. Edward was also a senior nuclear reactor operator and assistant reactor supervisor at the University of California, Irvine. Edward received his Ph.D. in chemical engineering from UC Irvine. Edward's primary research interest is nuclear energy and related nuclear issues. He seeks to understand how nuclear energy may abate climate change, and how effects of climate change and great power competition may impact nuclear proliferation through nuclear energy. He is also interested in related issues such as small modular reactors, floating nuclear power plants, nuclear fuel reprocessing, and climate change disinformation.

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9500 Gilman Drive # 0518, La Jolla, CA 92093-0518