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Next-Gen Reactors: How Nuclear Innovation Can Support Growth and a Healthy Climate

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The U.S. Supreme Court has put President Obama's Clean Power Plan on hold while lower courts review challenges to the regulation. The ruling is a setback to Obama's hopes of bypassing a hostile Republican majority in Congress and using his executive authority to require electric utilities to make big reductions in carbon emissions.

At last year's Paris climate summit, the administration pledged to make deep cuts in U.S. greenhouse gas emissions by 2025. With the Clean Power Plan (CPP) in limbo, Washington has no plausible mechanism for getting anywhere near those goals.[1]

In truth, however, the United States would fall well short of those goals even if the CPP survives legal challenges. For one thing, the rule covers the power sector, which accounts for only about 31 percent of U.S. emissions. What's more, the United States will have to put carbon reductions into overdrive, roughly doubling their current pace, to meet the administration's ambitious commitments in Paris.

The United States and developing countries like China and India will need more nuclear power to meet growing energy demand without loading more carbon into the earth's atmosphere.

Rather than put all of its climate protection eggs in the CPP basket, the White House clearly needs a broader strategy for making sure that America can do its part to slow down global warming. A key component of such a strategy must be expanding America's biggest source of zero-carbon energy: nuclear power.

Nuclear energy today accounts for nearly 11 percent of the world's electricity. Without it, the world would be producing an additional 2.5 billion metric tons of carbon dioxide per year.[2] Here at home, nuclear energy generates 19 percent of our electricity—fully 63 percent of all zero-carbon electricity in America.[3] The United States and developing countries like China and India will need more nuclear power to meet growing energy demand without loading more carbon into the earth's atmosphere. Yet we seem to be heading in the opposite direction—shutting down more nuclear capacity than we are adding.

U.S. nuclear companies intend to add five more reactors to the nation's fleet by 2020. In the meantime, however, they have announced plans to shut down three existing plants, and more may be in the offing. Why so many closures? One of the main reasons is the glut of cheap natural gas stemming from America's shale boom. Natural gas usually sets the price of electricity on the grid in much of the United States. Today, with natural gas is trading on the spot market at around two dollars per mBTU, nuclear-generated power is being priced out of electricity markets.[4]

Nuclear energy faces political headwinds as well. Many progressives and environmental activists remain reflexively opposed to expanding nuclear power, based on exaggerated fears about accidents and other safety risks. Green orthodoxy holds that the United States should make a swift transition to an economy powered solely by wind, solar and other renewable sources of energy. But renewables supply only about 7 percent of U.S. power now, and under any realistic projection will not be able to fully replace fossil fuels—let alone both fossil fuels *and* nuclear power—anytime soon.

Fortunately, the same sense of urgency about climate change that brought 188 countries to Paris last December seems to be eroding the anti-nuclear taboo here and in other countries. Public opinion has turned more favorable. And in a particularly promising development, climate-conscious entrepreneurs from Silicon Valley and other tech hubs have joined forces with nuclear scientists to develop a new generation of nuclear reactor technology.

New reactor designs hold tremendous potential to cut the costs of nuclear power, shrink the nuclear waste problem to more manageable proportions and operate more safely than traditional nuclear plants. Yet the U.S. government has done little to encourage and facilitate such innovation. For example, the Department of Energy (DOE) lacks a testing facility where nuclear entrepreneurs can experiment with new technologies and build new reactor prototypes. And the Nuclear Regulatory Commission (NRC), the industry's key regulator, lacks expertise in advanced reactor designs. The NRC is light-water reactor centric and needs to be modernized to permit efficient and timely licensing of advanced technologies.

Washington's failure to nurture next-generation reactors is driving nuclear entrepreneurs overseas. For example, TerraPower, created by Microsoft founder Bill Gates, is developing a liquid sodium-cooled fast reactor that uses depleted or natural uranium, and can burn spent fuel from old light water reactors. Citing the NRC's protracted and expensive licensing process, TerraPower has formed a joint venture with the China National Nuclear Corporation, a large state-owned enterprise, to build this "Traveling Wave Reactor" (TWR) in China within 15 years.

All of which raises some pertinent questions in this election year: Will the nation's political leaders allow the United States—which invented civilian nuclear energy after World War II—to forfeit leadership of this critical industry to geopolitical rivals like China and Russia? Are Republicans willing to make the public investments necessary to keep America in the forefront of nuclear innovation? Can Democrats rise above the knee-jerk hostility to nuclear energy of many in their base?

Peter Thiel, a co-founder of PayPal, has issued a pointed challenge to President Obama, who supports nuclear energy as part of his "all-of-the-above" energy policy:

> Both the right's fear of government and the left's fear of technology have jointly stunted our nuclear energy policy, but on this issue liberals hold the balance of power. Speaking about climate change in 2013, President Obama said that our grandchildren will ask whether we did 'all that we could when we had the chance to deal with this problem.' So far, the answer would have to be no—unless he seizes this moment. Supporting nuclear power with more than words is the litmus test for seriousness about climate change. Like Nixon's going to China, this is something only Mr. Obama can do. If the president clears the path for a new atomic age, American scientists are ready to build it.[5]

As progressives, we believe nuclear innovation is potentially common ground in our polarized energy politics, since it will produce more economic growth and clean energy.

Fair enough, though we've heard very little on this subject from the Republicans running for their party's presidential nomination. No doubt that's because they don't accept the premise that American needs more nuclear energy to reduce our greenhouse gas emissions, since they don't believe those emissions are heating up the planet.

These ideological blind spots—GOP rejection of climate science and Democrats' tendency to overstate nuclear risks—threaten real damage to our economy and the environment. As progressives, we believe nuclear innovation is potentially common ground in our polarized energy politics, since it will produce more economic growth and clean energy.

This policy brief highlights the myriad benefits and improvements advanced reactor technology could bring to the clean energy sector, as well as the regulatory impediments to licensing these reactors. It also recommends ways to reduce the costs of design- and engineering-related delays. Part I briefly describes the main types of next generation nuclear reactor technology now being developed. Part II examines the economic, safety and environmental advantages of next gen technologies, and offers recommendations on how to keep the United States the global leader in nuclear technologies. Part III gives a brief history of U.S. nuclear reactor licensing and outlines proposals for the United States to maintain its global leadership in nuclear power.

An Industry Born in the USA

America invented civilian nuclear power in the years following World War II. In the 1950s, U.S. companies such as Westinghouse and General Electric created the most commonly used light water reactor (LWR) technology still in use around the world today. The fortunes of the commercial nuclear industry have sagged since the 1970s, amid rising public fears about its real and imagined hazards. Doubts about nuclear power peaked following the accident at 1979 Three Mile Island incident, which brought the industry's domestic expansion to a screeching halt. In the decades that followed, U.S. companies scaled back their nuclear divisions, and sold key assets to Japanese and other foreign companies.[6]

More recently however, public opinion has been trending back in a pro-nuclear direction. A solid majority (64 percent) of Americans now say they support nuclear energy.[7] The long hiatus, however, has left the United States in danger of forfeiting technological leadership, as other countries forge ahead in developing "next generation" nuclear reactors.

Leading nuclear startups such as Transatomic Power, TerraPower, Moltex Energy, and Terrestrial Energy aired their frustrations about U.S. regulatory roadblocks at a recent MIT workshop. Participants said it can take a decade or more, and hundreds of millions of dollars, just to get a license for a prototype reactor from the NRC. For example, Bill Gates' TerraPower in a joint venture with the China National Nuclear Corporation believe they can build a TWR in China within 15 years.

That is considerably less time than it would take if TerraPower were to do all of its testing and preliminary work in the United States. Moreover, the NRC has yet to finalize a regulatory licensing model for Generation IV reactor technology, prompting many companies to move experimental work to Russia, China, and South Korea.

Nuclear power, of course, is not the only U.S. industry paralyzed by regulatory sclerosis. A new report by Common Good documents the high costs of regulatory delay for large-scale infrastructure projects in general, including roads and ports, water systems and the electrical grid. It concludes that America's "approvals bureaucracy must be rebuilt, not tweaked" to reduce regulatory compliance costs and speed up licensing new projects.[8]

Similarly, a recent report by the U.S. General Accounting Office (GAO) found that reactor entrepreneurs confront daunting costs—between $1 and $2 billion—to develop and certify a new design. Even with a reactor design ready to submit to NRC, the licensing and construction can take nearly a decade or more before a reactor is operational.[9]

Now is the time for both political parties to act on deploying these promising nuclear reactor designs by promoting private and public partnerships to advance their deployment. This is what it took at the dawn of the nuclear power era, and is the same prescription that's needed today if the United States is to have a realistic shot at hitting its greenhouse gas reduction targets under the Paris accord. Yet polarization in Washington is blocking progress.

Advanced Reactor Technology and the Future of Nuclear Power

Spurred by a fervent desire to combat climate change, U.S. high-tech entrepreneurs and venture capitalists are looking to reinvent the nuclear industry by betting on prototype technologies to replace the hulking plants of today with smaller, nimbler units that are safer and generate less waste. "I became a nuclear engineer because I am an environmentalist," says Leslie Dewan, the cofounder of Transatomic, a leading nuclear technology startup in Cambridge, Mass.[10]

In some respects, entrepreneurs like Dewan are taking America back to the dawn of nuclear power in the United States. Some of the technologies on today's drawing board, such as reactors using liquid metals, gases or molten salts as coolants, were actually pioneered in the late 1940s and early 1950s, as prototypes (Generation I) at U.S. government testing facilities whose mission was to develop and demonstrate peaceful uses of nuclear power. And they did. The first operational reactor was an experimental breeder reactor built at Idaho's Naval Proving Ground. A breeder reactor creates more fissile material than it consumes. At a time when America can't seem to find consensus on where to deposit spent fuels, improving on breeder reactor technology would point us toward a future where we'd have less waste or better yet, no waste to store.

Today's nuclear innovators are attempting to allay environmental concerns, and create nuclear technologies that address many of the problems associated with current reactors.

Most reactors in operation today are based on light water technology and use ordinary water as a coolant. These "Generation II" reactors were primarily constructed in the 1960s and 1970s. The four reactors currently under construction in the U.S. are known as "Generation III" or "III+" reactors, because they are light-water reactors, which offer simpler designs and more advanced safety features than their predecessors.

The entrepreneurs and scientists who are developing next generation nuclear reactors today are reminiscent of the early nuclear technology pioneers who accepted President Eisenhower's charge to transform the atom from a destructive to a constructive force for humanity. Today's nuclear innovators are attempting to allay environmental concerns, and create nuclear technologies that address many of the problems associated with current reactors.

Here are some of the Generation IV designs under development:

- Sodium Cooled Fast Reactors (SFR): This technology is cooled by liquid metal rather than water and can be fueled by the uranium and plutonium taken from light water reactor spent fuel. Developers include TerraPower, and Advanced Reactor Concepts.

- Gas Cooled Fast Reactors (GFR): This design circulates very high temperature helium through the reactor as coolant enabling a GFR to use fast neutrons to power a fission reaction which releases more of the energy in the fuel than today's light water reactors. Developers include General Atomics, and Hybrid Power Technologies.

- Lead Cooled Fast Reactors (LFR): Uses liquid lead as a coolant. LFRs are also able to use plutonium and uranium from spent fuel as its fuel. Developers include Gen4 Energy, LakeChime, and Westinghouse.

- Very High Temperature Reactors (VHTR): Unlike the other new reactor designs which use varying coolants, this technology is designed specifically to create high temperatures for industrial heat processes. Most large industrial processes needing heat rely on fossil fuels. The VHTR creates temperatures between 800 and 1000 degrees Celsius. This heat is then used to refine petrochemicals, produce hydrogen, and even desalinate water. Developers include X-Energy, Starcore Nuclear, and General Atomics.

- Molten Salt Reactors (MSR): This concept uses fluid fuel in the form of chloride salt or hot fluoride. Most reactors today use solid fuel. Its fluidity allows it to be both the fuel (producing heat) and the coolant (removing the heat and transporting to the power plant). Because the fuel is in fluid form it makes the reactor less expensive since fuel fabrication is not necessary. Transatomic Power has received funding to develop an MSR that consumes nuclear waste. If successful, this design would eliminate the need for long-term storage.

- Small modular reactors: Some developers have set their sights on deploying smaller and simpler light water technology commonly referred to as small modular reactors (SMR). These reactors would be built in factories as modular units and sent to the plant site for deployment, yielding significant cost reductions in construction and manufacturing. Vendors of these designs include NuScale, Holtec, and possibly mPower.

How Advanced Reactors Reduce Nuclear Risks

Generation IV designs have many potential advantages over light-water technology. They are able to burn used fuel, resulting in less waste that needs to be buried or otherwise stored safely. Crucially, most of the new advanced reactor designs lower the risk of nuclear proliferation; because they either produce less plutonium, or consume the plutonium they produce. And some new reactors can operate at very high temperatures, generating heat energy that can replace fossil fuels in industrial processes.[11]

Unfortunately, other countries have far more robust and ambitious research development and deployment programs. They appear on track to have commercially available advanced reactors for sale in the late 2020s and 2030s. For example, Russia is actively seeking to export its sodium-cooled fast reactor (BN-600) while continuing to further advance the technology at home by constructing a larger version (BN-800). In India, where thorium-bearing minerals are in abundance, they are developing advanced reactors which use thorium instead of uranium. One advantage to using thorium is it does not produce transuranic atoms like plutonium, americium, and curium, which are highly toxic and have long half-lives. China is sponsoring the world's broadest advanced reactor research and development effort, with aggressive programs aimed at demonstrating three reactor technologies including two variants of the molten salt reactor.[12]

These new designs are safer than traditional ones. Because sodium has a much higher boiling point than water, a sodium cooled fast reactor operates at normal atmospheric pressure. In contrast, light water reactors require water to be pressurized at 100-150 times normal to keep it from boiling away and exposing the reactor core. Most serious nuclear accidents have involved loss of water pressure, leaving the core uncovered. Additionally, the new designs have safety features that rely on laws of nature—especially gravity—rather than on engineered systems that require power to operate, equipment to function properly and operators to take correct actions in stressful emergency situations. This approach is called 'passive safety,' and is a major advantage that enables removing heat from the core without the need of electrical pumps

Another key advantage of advanced generation nuclear technology is lower costs. Because new designs use smaller, modular components that can be built in a factory and shipped directly to construction sites for assembly, construction costs are much lower. Light water reactors require large metal forgings, which have long lead times and are only produced by a small number of foreign suppliers.

The Breakthrough Institute highlights four ways that advanced nuclear technology can lower costs. First, they must incorporate safety features that obviate the need for expensive and redundant safety systems. Second, designs must in whole or in part be built modularly so that components of plants can be mass-produced and assembled, rather than fabricated at the construction site. Third, designs will need to be more efficient thermally such that they are able to generate more electricity from a smaller physical plant. Fourth, new designs must be able to use existing nuclear or industrial supply chains that do not require development or commercialization of new unproven materials and fuels.[13]

The United State lacks a swift, streamlined and predictable regulatory pathway for licensing advanced reactors.

Licensing and Construction of Nuclear Reactors in the United States

The private companies that are investing and developing these new reactors say the United States is lagging behind other leading nuclear countries in two critical areas: First, we need a national facility that would allow DOE to partner with private companies to test their concepts and demonstrate their feasibility under the auspices of federal regulators. Second, we lack a swift, streamlined and updated regulatory licensing regime more aligned with these new concepts.

The U.S. Nuclear Regulatory Commission (NRC) regulates reactors for commercial and research use, and licenses both power and non-power reactors (university research reactors).[14] The first step in obtaining a license is to demonstrate to the NRC that a proposed reactor can operate safely. This is a problem for domestic advanced reactor designs because the United States does not have the necessary facilities for testing all of the new models. TerraPower is doing its experimental work on its sodium cooled fast reactor prototype in Russia because it has facilities with a sodium cooled fast reactor where they can demonstrate its feasibility, while the United States doesn't have a facility they can use. Additionally, while the NRC is capable of reviewing and regulating an advanced reactor, it does not currently have regulations that are directly applicable to advanced technologies for either power or non-power applications (e.g., research).

At a U.S. House of Representatives Science Committee hearing in December 2014, Transatomic's Dr. Leslie Dewan proposed the establishment of a test-bed facility at a DOE National Laboratory where privately funded reactors could be constructed and operated under DOE authority:

> "Such a plan would require only clarification of the existing regulations, and it would make a universe of difference for advanced reactor designers. It could significantly reduce the cost and timeline of licensing an advanced reactor and give greater clarity to these numbers making it much more straightforward to raise private capital to fund them. In turn, the operating prototype facility would produce the mechanical, materials, and neutronics data necessary to license a commercial-scale facility under NRC guidelines."

Such a national facility would allow private companies to utilize the expertise at DOE which is critical in helping these new technologies develop from concept to marketplace. "DOE has safety oversight authority, unique capabilities, experts, and experimental facilities that could dramatically reduce the barriers, costs and delays involved in nuclear demonstrations," says Dr. Ashley Finan, senior project manager for Energy Innovation at the Clean Air Task Force in congressional testimony. "By controlling and defining many of the costs, the site would enable private investment in prototype reactors and pre-commercial projects. Not only could this unlock a great deal of private capital, it would enable U.S. innovators to move forward domestically, rather than turning to foreign partners."[15] Reps. Randy Weber (R-Texas) and Eddie Bernice Johnson (D-Texas) have introduced a bipartisan bill in the House of Representatives that directs the Department of Energy to establish a test facility that would allow for testing of advanced reactors and would be in operation no later than December 31, 2025. If enacted, this bill would enable the private sector to partner with the National laboratories to demonstrate novel concept reactors.[16] A similar bill was introduced in the Senate by Sen. Mike Crapo, and co-sponsored by two of the Senate's leading climate warriors, Sen. Sheldon Whitehouse of Rhode Island, and Sen. Cory Booker of New Jersey, and passed overwhelmingly with an 87–4 vote as an amendment to a larger energy reform bill which passed the Senate in April.

In addition to sites where entrepreneurs can demonstrate "proof of concept," swifter NRC review and licensing is imperative. The NRC has deep expertise with light water reactors, but it lacks well-established guidelines and rules for reviewing and approving advanced designs. Investors, not surprisingly, are reluctant to make big bets on new technologies in the absence of a certain path for regulatory approval. A RAND report on obstacles to deploying advanced reactors in the United States found that, "In the face of institutional dysfunction, regulatory uncertainty, and unpredictable economic prospects for nuclear energy, industry is understandably reluctant to invest again in new technologies."[17] So that new designs don't languish in bureaucratic limbo an updated nuclear regulatory process is necessary to provide applicants with clarity, well-timed feedback, and integrity.

Dewan estimates that at its current rate of development it would take the NRC 20 years at a minimum to refine such a process. At that torpid pace, U.S.-based companies will fall hopelessly behind in the race to develop next generation nuclear technology. Furthermore, there's a great deal of uncertainty in how much regulatory approval will cost a company hoping to commercialize its design. Estimates for the costs of licensing just a prototype reactor through the NRC range from $200 million to $500 million. A commercial license would cost significantly more, though no one seems to have reliable estimates as to how much more.

Without more nuclear power, the United States won't be able to reconcile the twin imperatives of economic growth and climate protection.

How should the NRC streamline its regulatory procedures for advanced nuclear reactors? One idea, suggested by Finan, is to adopt a "test-then-license" approach akin to the approval process for new drugs from the FDA. "The current NRC certification process is 'all or nothing,' without interim levels of approval or acceptance."[18] That makes it a crapshoot for investors. In contrast, the FDA has a staged review structure for drug manufacturers with opportunity for feedback and a schedule that has finality. Under this process, investors and manufacturers are keenly aware of the status of the application and whether the application passes regulatory standards. This is a safety versus efficacy situation where if safety evaluations are equally or more rigorous during the phase trials and efficacy is maintained without costing more, the regulation is workable for the private investor and companies.

Change at the NRC won't happen by itself. Congress needs to step in with clear mandates to the commission, and offer the resources it needs to carry them out. In the recently enacted omnibus spending bill, Congress appropriated over $900 million to the NRC for its annual budget, and did not include additional funding for advanced reactor design certification and licensing. Instead, the NRC is downsizing even as U.S. scientists and entrepreneurs rush to bring advanced reactors to market. At an NRC presentation last February on Project AIM 2020, the agency's internal strategic plan, they project that the number of new reactors seeking licenses will be "down significantly" by 2020.[19]

Conclusion

Nuclear energy should play a larger role in America's transition to a low-carbon economy. Without more nuclear power, the United States won't be able to reconcile the twin imperatives of economic growth and climate protection. What's more, innovations in next-gen technology create a striking opportunity to revive U.S. leadership in civilian nuclear energy. This will be an economic boon for America, generating good jobs and tremendous export opportunities, while also reducing greenhouse gas emissions. Environmentalists often claim that there's no conflict between the demands of economic growth and sustainability. They are right—so long as we use the tools available to us to sustain growth while reducing the amount of carbon we pump into the atmosphere. Next-gen nuclear energy is such a tool, and progressives should embrace it.

Endnotes

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6 Although we *support* the development of next generation nuclear technologies, PPI continues to support current light-water reactor technologies. Despite the constant criticism of nuclear power the industry does have a very strong operational safety record. According to the World Nuclear Association, there have been three major reactor accidents in the history of civil nuclear power—Three Mile Island, Chernobyl and Fukushima. One was contained without harm to anyone, the next involved an intense fire without containment, and the third vigorously tested the containment, allowing some release of radioactivity in the surrounding area. These represent the only major accidents to have occurred in over 16,000 cumulative reactor-years of commercial nuclear power operation in 33 countries.

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About PPI

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