For years, proponents of nuclear power expansion both in the US and around the world have been proclaiming the onset of a global “nuclear renaissance.” Faced with the dual-obstacles of growing worldwide energy demand and a stronger push for clean energy sources, the stage seemed set for a vibrant revival of the industry. Nuclear power’s 25 years of accident-free operation following the 1986 disaster at Chernobyl shed favorable light upon the industry, dulled anti-nuclear arguments, and brought noted environmentalists into the nuclear camp as they began to recognize the role nuclear power could play in promoting clean energy solutions.

The March 2011 failure at Japan’s Fukushima Daiichi reactor following a 9.0 magnitude earthquake and subsequent tsunami reignited the debate over nuclear energy and erased much of the goodwill that the nuclear industry had accumulated. Now, at least in the US, where images of Three Mile Island had finally faded, nuclear energy again finds its future in doubt. However, the Fukushima incident notwithstanding, the fundamental calculus driving the renewed push for nuclear power has not changed: in a carbon-conscious world with burgeoning electricity demands, nuclear power represents the only option for substantial and reliable baseload power generation.

In recent years, though the “renaissance” has yet to occur, thinking on the nuclear power development front has begun to shift away from traditional gigawatt-plus reactors and towards a new category of small modular reactors (SMRs). Boasting an unprecedented degree of reactor safety and multiple applications in the power-generation process, these reactors could revolutionize the nuclear power industry and contribute to US energy security while also reviving the flagging American nuclear industry. Though they have yet to be built and deployed, years of SMR research, including a two-decade experiment with the Experimental Breeder Reactor-II (EBR-II), a 20 MWe reactor at Argonne-West in Idaho, demonstrate the potential of such technology.

Nuclear vs. Nuclear: why go small?

As the EBR-II demonstrates, the concept of small reactors is not new, but has resurfaced recently. The United States Navy has successfully utilized small reactors to power many of its vessels for over fifty years, and the earliest power reactors placed on land in the US were mostly similar, though larger, iterations of the Navy’s reactors. Eventually, due to siting and licensing issues affecting economies of scale, reactor outputs were pushed ever higher to between 800 and 1200 MW and new reactors constructed today—such as the ones under construction at the Olkiuoto plant in Finland—approach as much as 1600 MW. In contrast, the International Atomic Energy Agency (IAEA) defines a small reactor as generating under 300 MW of power. On the surface, a move in this direction may appear to be a step backwards in development, however, amid concerns over issues including safety, proliferation risks, and cost, many in the industry are beginning to seriously examine the possible applications of widespread and distributed nuclear power from low-output reactors.

Promoting safer nuclear power

The debate over nuclear energy over the years has consistently revolved around the central question “Is nuclear power safe?” Certainly, the events at Fukushima illustrate that nuclear power can be unsafe, however, no energy source is without its own set of some inherent risks on the safety front—as last year’s oil spill in the Gulf of Mexico or the long-term environmental consequences of fossil fuel use demonstrate—and nuclear power's operating record remains significantly above that of other energy sources. Instead, accepting the role that nuclear energy plays in global electricity generation, especially in a clean-energy environment, a more pointed question to ask is "How can nuclear power be made safer?"

Although large reactors possess a stellar safety record throughout their history of operation, SMRs are able to take safety several steps further, in large part due to their small size. Due to simpler designs as a result of advancing technology and a heavy reliance on passive safety features, many problems plaguing larger and earlier generations of reactors are completely averted. Simpler designs mean less moving parts, less potential points of failure or accident, and fewer systems for operators to monitor. Additionally, small reactor designs incorporate passive safety mechanisms which rely on the laws of nature—such as gravity and convection—as opposed to human-built systems requiring external power to safeguard the reactor in the event of an accident, making the reactor inherently safer.

Furthermore, numerous small reactor concepts incorporate other elements—such as liquid sodium—as coolants instead of the pressurized water used in large reactors today. While sodium is a more efficient heat-transfer material, it is also able to cool the reactor core at normal atmospheric pressure, whereas water which must be pressurized at 100-150 times normal to prevent it boiling away. As an additional passive safety feature, sodium's boiling point is 575-750 degrees higher than the reactor's operating temperature, providing an immense natural heat sink in the event that the reactor overheats. Even should an accident occur, without a pressurized reactor no radiation would be released into the surrounding environment.

Even on the most basic level, small reactors provide a greater degree of security by merit of providing lower energy output and using less nuclear fuel. To make up for the loss in individual reactor generating capacity, small reactors are generally designed as scalable units, enabling the siting of multiple units in one location to rival the output capacity of a large nuclear plant. However, with each reactor housed independently and powering its own steam turbine, an accident affecting one reactor would be limited to that individual reactor.

Combating proliferation with US leadership

Reactor safety itself notwithstanding, many argue that the scattering of small reactors around the world would invariably lead to increased proliferation problems as nuclear technology and know-how disseminates around the world. Lost in the argument is the fact that this stance assumes that US decisions on advancing nuclear technology color the world as a whole. In reality, regardless of the US commitment to or abandonment of nuclear energy technology, many countries (notably China) are blazing ahead with research and construction, with 55 plants currently under construction around the world—though Fukushima may cause a temporary lull.

Since Three Mile Island, the US share of the global nuclear energy trade has declined precipitously as talent and technology begin to concentrate in countries more committed to nuclear power. On the small reactor front, more than 20 countries are examining the technology and the IAEA estimates that 40-100 small reactors will be in operation by 2030. Without US leadership, new nations seek to acquire nuclear technology turn to countries other than the US who may not share a deep commitment to reactor safety and nonproliferation objectives. Strong US leadership globally on nonproliferation requires a vibrant American nuclear industry. This will enable the US to set and enforce standards on nuclear agreements, spent fuel reprocessing, and developing reactor technologies.

As to the small reactors themselves, the designs achieve a degree of proliferation-resistance unmatched by large reactors. Small enough to be fully buried underground in independent silos, the concrete surrounding the reactor vessels can be layered much thicker than the traditional domes that protect conventional reactors without collapsing. Coupled with these two levels of superior physical protection is the traditional security associated with reactors today. Most small reactors also are factory-sealed with a supply of fuel inside. Instead of refueling reactors onsite, SMRs are returned to the factory, intact, for removal of spent fuel and refueling. By closing off the fuel cycle, proliferation risks associated with the nuclear fuel running the reactors are mitigated and concerns over the widespread distribution of nuclear fuel allayed.

Economies of Scale Reversed?

Safety aside, one of the biggest issues associated with reactor construction is their enormous costs—often approaching up to $10 billion apiece. The outlay costs associated with building new reactors are so astronomical that few companies can afford the capital required to finance them. Additionally, during the construction of new reactors, a multi-year process, utilities face “single-shaft risk”—forced to tie up billions of dollars in a single plant with no return on investment until it is complete and operational. When this is coupled with the risks and difficulties classically associated with reactor construction, the resulting environment is not conducive to the sponsorship of new plants.

Conventional wisdom says that SMRs cannot be cost-competitive with large reactors due to the substantial economies of scale loss transitioning down from gigawatt-sized reactors to ones producing between 25MW and 300 MW, but, a closer examination may result in a different picture. To begin with, one of the primary benefits of SMRs is their modularity. Whereas conventional reactors are all custom-designed projects and subsequently often face massive cost overruns, SMRs are factory-constructed—in half the time of a large reactor—making outlay costs largely fixed. Moreover, due to their scalability, SMRs at a multi-unit site can come online as installed, rather than needing to wait for completion of the entire project, bringing a faster return on invested capital and allowing for capacity additions as demand increases over time.

Other indirect cost-saving measures further increase the fiscal viability of small nuclear reactors. Due to the immense power output of conventional reactors, they also require special high-power transmission lines. In contrast, small reactor output is low enough to use existing transmission lines without overloading them. This allows for small reactors to serve as “drop-in” replacements at existing old fossil fuel-based power plants, while utilizing the transmission lines, steam turbines, and other infrastructure already in place. In fact, the Tennessee Valley Authority (TVA) hopes to acquire two Babcock & Wilcox small reactors for use in this manner—perhaps precipitating a movement whereby numerous fossil fuel plants could be converted.

Lastly, and often ignored, is the ability of small reactors to bring a secure energy supply to locations detached from the grid. Small communities across Canada, Alaska, and other places have expressed immense interest in this opportunity. Additionally, the incorporation of small reactors may be put to productive use in energy-intensive operations including the chemical and plastics industries, oil refineries, and shale gas extraction. Doing so, especially in the fossil fuels industry would free up the immense amounts of oil and gas currently burned in the extraction and refining process. All told, small reactors possess numerous direct and indirect cost benefits which may alter thinking on the monetary competitiveness of the technology.

Nuclear vs. Alternatives: a realistic picture
When discussing the energy security contributions offered by small nuclear reactors, it is not enough to simply compare them with existing nuclear technology, but also to examine how they measure up against other electricity generation alternatives—renewable energy technologies and fossil fuels. Coal, natural gas, and oil currently account for 45%, 23% and 1% respectively of US electricity generation sources. Hydroelectric power accounts for 7%, and other renewable power sources for 4%. These ratios are critical to remember because idealistic visions of providing for US energy security are not as useful as realistic ones balancing the role played by fossil fuels, nuclear power, and renewable energy sources.

Limitations of renewables
Renewable energy technologies have made great strides forward during the last decade. In an increasingly carbon emissions and greenhouse gas (GHG) aware global commons, the appeal of solar, wind, and other alternative energy sources is strong, and many countries are moving to increase their renewable electricity generation. However, despite massive expansion on this front, renewable sources struggle to keep pace with increasing demand, to say nothing of decreasing the amount of energy obtained from other sources.

The continual problem with solar and wind power is that, lacking efficient energy storage mechanisms, it is difficult to contribute to baseload power demands. Due to the intermittent nature of their energy production, which often does not line up with peak demand usage, electricity grids can only handle a limited amount of renewable energy sources—a situation which Germany is now encountering. Simply put, nuclear power provides virtually carbon-free baseload power generation, and renewable options are unable to replicate this, especially not on the scale required by expanding global energy demands.

Small nuclear reactors, however, like renewable sources, can provide enhanced, distributed, and localized power generation. As the US moves towards embracing smart grid technologies, power production at this level becomes a critical piece of the puzzle. Especially since renewable sources, due to sprawl, are of limited utility near crowded population centers, small reactors may in fact prove instrumental to enabling the smart grid to become a reality.

Pursuing a carbon-free world
Realistically speaking, a world without nuclear power is not a world full of increased renewable usage, but rather, of fossil fuels instead. The 2007 Japanese Kashiwazaki-Kariwa nuclear outage is an excellent example of this, as is Germany's post-Fukushima decision to shutter its nuclear plants, which, despite immense development of renewable options, will result in a heavier reliance on coal-based power as its reactors are retired, leading to a 4% increase in annual carbon emissions. On the global level, without nuclear power, carbon dioxide emissions

from electricity generation would rise nearly 20% from nine to eleven billion tons per year. When examined in conjunction with the fact that an estimated 300,000 people per year die as a result of energy-based pollutants, the appeal of nuclear power expansion grows further.

As the world copes simultaneously with burgeoning power demand and the need for clean energy, nuclear power remains the one consistently viable option on the table. With this in mind, it becomes even more imperative to make nuclear energy as safe as possible, as quickly as possible—a capacity which SMRs can fill with their high degree of safety and security. Additionally, due to their modular nature, SMRs can be quickly constructed and deployed widely. While this is not to say that small reactors should supplant large ones, the US would benefit from diversification and expansion of the nation's nuclear energy portfolio.

Path forward: Department of Defense as first-mover

Problematically, despite the immense energy security benefits that would accompany the wide-scale adoption of small modular reactors in the US, with a difficult regulatory environment, anti-nuclear lobbying groups, skeptical public opinion, and of course the recent Fukushima accident, the nuclear industry faces a tough road in the battle for new reactors. While President Obama and Energy Secretary Chu have demonstrated support for nuclear advancement on the SMR front, progress will prove difficult. However, a potential route exists by which small reactors may more easily become a reality: the US military.

The US Navy has successfully managed, without accident, over 500 small reactors on-board its ships and submarines throughout 50 years of nuclear operations. At the same time, serious concern exists, highlighted by the Defense Science Board Task Force in 2008, that US military bases are tied to, and almost entirely dependent upon, the fragile civilian electrical grid for 99% of its electricity consumption. To protect military bases' power supplies and the nation's military assets housed on these domestic installations, the Board recommended a strategy of "islanding" the energy supplies for military installations, thus ensuring their security and availability in a crisis or conflict that disrupts the nation's grid or energy supplies.

DOD has sought to achieve this through decreased energy consumption and renewable technologies placed on bases, but these endeavors will not go nearly far enough in achieving the department's objectives. However, by placing small reactors on domestic US military bases, DOD could solve its own energy security quandary—providing assured supplies of secure and constant energy both to bases and possibly the surrounding civilian areas as well. Concerns over reactor safety and security are alleviated by the security already present on installations and the military's long history of successfully operating nuclear reactors without incident.

Unlike reactors on-board ships, small reactors housed on domestic bases would undoubtedly be subject to Nuclear Regulatory Commission (NRC) regulation and certification, however, with strong military backing, adoption of the reactors may prove significantly easier than would otherwise be possible. Additionally, as the reactors become integrated on military facilities, general fears over the use and expansion of nuclear power will ease, creating inroads for widespread adoption of the technology at the private utility level. Finally, and perhaps most importantly, action by DOD as a "first mover" on small reactor technology will preserve America's badly struggling and nearly extinct nuclear energy industry. The US possesses a wealth of knowledge and technological expertise on SMRs and has an opportunity to take a leading role in its adoption worldwide. With the domestic nuclear industry largely dormant for three decades, the US is at risk of losing its position as the global leader in the international nuclear energy market. If the current trend continues, the US will reach a point in the future where it is forced to import nuclear technologies from other countries—a point echoed by Secretary Chu in his push for nuclear power expansion. Action by the military to install reactors on domestic bases will guarantee the short-term survival of the US nuclear industry and will work to solidify long-term support for nuclear energy.

Conclusions
In the end, small modular reactors present a viable path forward for both the expansion of nuclear power in the US and also for enhanced US energy security. Offering highly safe, secure, and proliferation-resistant designs, SMRs have the potential to bring carbon-free baseload distributed power across the United States. Small reactors measure up with, and even exceed, large nuclear reactors on questions of safety and possibly on the financial (cost) front as well. SMRs carry many of the benefits of both large-scale nuclear energy generation and renewable energy technologies. At the same time, they can reduce US dependence on fossil fuels for electricity production—moving the US ahead on carbon dioxide and GHG reduction goals and setting a global example. While domestic hurdles within the nuclear regulatory environment domestically have proven nearly impossible to overcome since Three Mile Island, military adoption of small reactors on its bases would provide energy security for the nation's military forces and may create the inroads necessary to advance the technology broadly and eventually lead to their wide-scale adoption.

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