Shultz-Stephenson Task Force on Energy Policy

Reinventing Nuclear Power Essay Series

Small Modular Reactors: A Call for Action

William J. Madia, Gary Vine & Regis Matzie

HOOVER INSTITUTION

SHULTZ-STEPHENSON TASK FORCE ON

Energy Policy

Reinventing Nuclear Power

Small Modular Reactors

A Call for Action

William J. Madia
Gary Vine
Regis Matzie

Hoover Institution Press
Stanford University
Stanford, California
2015

The Hoover Institution on War, Revolution and Peace, founded at Stanford University in 1919 by Herbert Hoover, who went on to become the thirty-first president of the United States, is an interdisciplinary research center for advanced study on domestic and international affairs. The views expressed in its publications are entirely those of the authors and do not necessarily reflect the views of the staff, officers, or Board of Overseers of the Hoover Institution.

www.hoover.org

Hoover Institution Press Publication

Hoover Institution at Leland Stanford Junior University, Stanford, California 94305-6010.

First printing 2015
21 20 19 18 17 16 15 7 6 5 4 3 2 1

Manufactured in the United States of America

This essay is part of the Hoover Institution Shultz-Stephenson Task Force on Energy Policy's Reinventing Nuclear Power project, edited by George P. Shultz and James O. Ellis Jr. Please see *http://www.hoover.org/reinventing-nuclear-power* for more information and related works.

The editors wish to acknowledge the constructive contributions made to this series by David Fedor.

Small Modular Reactors
A Call for Action

William J. Madia, Gary Vine, and Regis Matzie

Executive Summary

The US Small Modular Reactor (SMR) effort is at a critical juncture. Despite industry support and a successful start to the Department of Energy's Licensing Technical Support (LTS) program (that department's cost-sharing program for SMRs to support the development and licensing of two designs), the authors believe that widespread deployment of US-built SMRs will be difficult to achieve on the schedule needed to match potential domestic and global marketplace demand unless decisive action is taken now.

Various efforts have been undertaken to identify and prioritize the challenges to timely and widespread deployment, but little has been done to formulate effective strategies to overcome them. Further, these efforts have not been integrated across government and industry sectors. Also, some of the key lessons learned from the NP 2010 program (the Department of Energy [DOE] 2001–2011 program aimed at large Advanced Light Water Reactors [ALWRs]) do not appear to be incorporated in SMR strategies to date. In particular, a strong recommendation emerging from the NP 2010 program was to encourage nuclear utility engagement and market-driven decisions in all areas: technology selection, siting selection, and makeup of business teams. Utility engagement in SMRs has been limited and selective to date, in part because SMRs face significant headwinds today (as does commercial nuclear energy

in the United States generally) as a result of the current low domestic price of natural gas, the lack of a price for carbon emissions, and selectively favorable federal and state treatment of renewable energy sources. There has been progress in some areas: the Nuclear Energy Institute (NEI) has been instrumental in facilitating utility engagement in the area of generic SMR licensing issues, and the American Nuclear Society has also been engaged in SMR technical initiatives.

The challenges to successful widespread deployment of SMRs in the United States and globally are primarily economic in nature. These economic challenges include: (1) the high cost of completing the needed engineering, testing, and licensing to make SMRs market-ready; (2) the anticipated relatively high-capital cost of these new plants on a per-MWe (megawatt electrical) basis; (3) the lack of a design, construction, and operational track record for SMRs; (4) the future direction of domestic fossil energy supply and use, carbon pricing, and the export of US fossil resources, particularly natural gas; and (5) uncertainty in the Nuclear Regulatory Commission (NRC) licensing process for SMRs. These challenges are complex and interrelated, requiring an integrated government and industry response. With low natural gas prices today, the business case for SMRs is difficult to construct. However, natural gas prices are historically volatile, so pricing conditions could change.

Utilities are primarily concerned today about the impacts of the economic challenges to their US operating plants. Most utility executives are much more focused on addressing the challenges to today's plants (including the lack of long-term power purchase agreements and inadequate valuation of stable base-load capacity) than they are on impacts on future plants. This situation is compounded with understandably intense focus on stock prices and quarterly earnings, and insufficient focus on the long-term needs of the customer and the reliability of the national energy infrastructure. Longer term, utilities are greatly concerned about an over-reliance on a single fuel source.

Hence, SMR deployment faces a dilemma: unless some effort by industry and/or DOE is taken now to improve the future prospects for new nuclear plants, the option to deploy them when natural gas prices go up may be lost. SMRs provide another option for future nuclear generation. They are complementary to the large ALWRs being deployed today and expand opportunities for nuclear energy utilization in smaller markets in the future.

This paper seeks to show that a more proactive national strategy could make a difference and attract utility investment. A more proactive and integrated SMR strategy is called for now because SMRs represent potential strategic advantages for the United States. This paper postulates that there is an optimum time window for widespread deployment of SMRs in the next decade, which is likely to fade if foreign competition moves ahead of US designs, or if alternative sources of electricity are selected to replace retiring coal plants. US-designed SMRs have high export potential. However, this will only be realized if they are certified and commercialized in the United States, in parallel with (or ahead of) competing foreign designs that are being developed and licensed abroad, and if they are cost-competitive with respect to other zero or low-pollution options at the time of their deployment. Therefore, action is needed now to hit the window of opportunity in the mid-2020s.

A key lesson learned from the NP 2010 program was: "Development of business cases and, most importantly, a Roadmap of activities in the early phases of the NP 2010 program were essential." This recommendation, based on the "Near-Term Deployment (NTD) Roadmap" that formed the basis for NP 2010, should be extended to SMRs. This lesson parallels the recommendation of the Secretary of Energy Advisory Board (SEAB) subcommittee on SMRs, "that the Secretary of Energy charter an integrated government SMR strategy after there is more clarity concerning the many uncertainties surrounding the commercialization of SMRs."[1]

The case for preparing an integrated strategy or roadmap for SMR deployment (or a broader national energy strategy or nuclear energy strategy with SMRs embedded in it) is strong. Despite the strong headwinds

1. "A Strategic Framework for SMR Deployment," SMR SEAB subcommittee, February 24, 2012.

that face SMRs today, it is important to act now to organize, prepare, and, most importantly, implement an SMR roadmap. The alternative—waiting for market conditions to improve—could put the US competitive position, along with the attendant policy goals achievable with SMRs, at risk.[2] These national energy policy goals, discussed later in this paper, include geopolitical leadership, national security and electricity/grid security, economic strength/jobs, and environmental protection. The roadmap should provide an integrated plan of action aimed at widespread deployment of SMRs.

Government and industry generally agree that government should not fund research that industry can and should do on its own to advance nuclear technology. Government's role should be limited to high-risk/long-term research and development (R&D) in fields where industry is incapable of maintaining the level and length of investment needed to bring the product to market, as well as medium-term/medium-risk R&D where industry can and should provide a cost share in order to bring technologies to the point that industry can commercialize them on its own. It follows that a roadmap focused on commercialization should be led by industry—specifically by utility experts who represent the needs of future SMR owner/operators.

Introduction: What Are SMRs?

SMRs are generally defined as those nuclear reactors with an output capacity of 300 MWe or less. SMRs can utilize any viable coolant/moderator combination, including water-cooled, gas-cooled, liquid-metal cooled, or molten salt-cooled reactor concepts. They can utilize advanced fuel designs and configurations and other innovations. Historically, SMR concepts have been dominated by integral pressurized water reactors (PWRs),

2. There are risks associated with all electricity options now being deployed. Such risks have not deterred the prudent development of these technologies nor government and industry investment to advance them.

modular gas-cooled reactors, and modular sodium-cooled reactors. Most have sought to counterbalance the loss in economies of scale—due to their smaller power output per dollar cost of installed kilowatt-electric—through innovative construction technologies, including modular construction, factory fabrication, and shipment by rail of essentially complete "nuclear island" modules as well as portions of the balance of plant. The term "modular" refers to both the intended means of construction and the capability to add reactors to an SMR site in "modules"—additional power capacity added incrementally after the first reactor is built.

This "power scalability" feature of SMRs is important to utilities that do not want (or need) large (gigawatt-scale) nuclear plants for various reasons, e.g., financing, balance-sheet capacity, market demand, grid capacity, and infrastructure limitations. SMRs open up new markets for nuclear energy that heretofore have been closed to this option, such as replacing older coal-fired units and taking advantage of their existing site infrastructure. Desalination for arid areas such as the western and southwestern United States, the Middle East, and Africa is another potential application.

"Integral PWR" means that many of the components such as steam generators, coolant loops, and pumps are inside the main reactor vessel. This has a number of safety advantages, as discussed below, but also incurs innovation risks, since some operational aspects of this concept have yet to be demonstrated. Integral PWR concepts have been pursued over the last two to three decades, e.g., by Westinghouse (IRIS) and by Combustion Engineering (SIR). The DOE Near-Term Deployment Roadmap, published in 2001 as the basis for the NP 2010 program, evaluated five large ALWRs and three SMRs: the Westinghouse IRIS design (an integral PWR) and two gas-cooled reactor designs, the General Atomics GT-MHR (gas turbine modular helium reactor) and the Eskom (Electricity Supply Commission of South Africa) Pebble Bed reactor. SMR development proceeded through the last two decades, with federal support targeted at a range of advanced Generation IV (often referred to as GEN-IV) designs, including integral PWRs and the Next Generation Nuclear Plant—a high-temperature gas-cooled reactor concept capable of both electricity generation and hydrogen production for use as a transportation fuel and other industrial applications.[3]

Integral PWRs dominate the SMR options being considered today for near-term deployment because they involve relatively less technology risk and because they are the only SMR option that the NRC is prepared to review and license. A regulatory framework for licensing more advanced SMR concepts does not exist today, and only the initial, high-level approaches have been undertaken.

For these reasons, this paper is focused specifically on small, modular light water reactors (LWRs).[4] The nuclear industry, and nuclear utilities in particular, strongly support this preference for small LWRs and for an aggressive program strategy that encourages reliance on proven and previously licensed technology to the degree practical. Industry is acutely aware of the challenges facing NRC in reviewing innovative concepts and the commercial deployment risks associated with unproven reactor designs and/or fuels.

For the sake of simplicity, from here on the term SMR will be used to refer to small modular light water reactors.

Why SMRs Are Viable Today

Several motivations have driven the recent pursuit of SMRs. These features should, in theory, present attractive private sector investment opportunities:

- **Ability to finance the project; lower capital at risk.** The capital investment required for a large ALWR is in the range of $6 billion

3. See DOE web site, http://energy.gov/ne/nuclear-reactor-technologies/advanced-reactor-technologies.
4. As discussed later, a recent revision to the Utility Requirements Document prepared by the Electric Power Research Institute (EPRI) uses the term "smLWR" (for small modular Light Water Reactor) to differentiate from other coolant technologies.

to $10 billion, too large for the balance sheets of many smaller power companies to handle. SMRs are estimated to require one third or less of the capital requirements per SMR unit than for a large ALWR, thus allowing many smaller utilities to be able to finance these projects on their balance sheets.

- **Extended option to use nuclear energy into a broader range of markets.** Because SMRs provide power in units of a few hundred MWe per module or less, they fit many electric grids better than large ALWRs. SMRs are ideally sized for replacing older coal units and for powering vital infrastructure that needs continuous reliable power in the event that the electric grid is interrupted, e.g., military bases or communication centers. They also can serve remote or isolated areas, e.g., islands or areas of lower population density, and global markets with smaller grids. SMR-powered water desalination is a potentially large global opportunity. Water desalination was the initial intended purpose for the South Korean SMART (System-integrated Modular Advanced ReacTor).
- **Shorter construction schedules.** This should result in less construction financing charges and provide for the possibility of an early revenue stream from the initial modules while other modules are being brought on line.
- **Factory fabrication of SMR modules.** This creates the potential for standardized mass production based on efficient design documentation, stabilized labor costs, higher quality control, and less on-site rework.
- **Simplified operations and maintenance (O&M).** Longer fueling cycles, reduced security forces, passive safety systems that do not have a myriad of active safety components, and reconfigured control room operation are crucial. (Both the reduced security and reconfigured control room attributes are speculative and heavily dependent on upcoming NRC decisions.)
- **Enhanced safety case.** Safety features from passive cooling and coolant inventory control (that do not require emergency AC power) and underground configuration are discussed below.

SMRs typically offer the following enhanced safety features:

- Enhanced physical protection and robustness against seismic events and external security threats because of design features, compact footprint, and below-grade siting
- Low core power density (lower fuel and clad temperatures than a typical PWR)
- Large coolant volume-to-core power ratio (longer margins for safety system response)
- No large pipes connected to reactor pressure vessel (RPV), eliminating large-break loss-of-coolant accidents
- Pipe penetrations that are small and generally positioned high on the RPV (increased amount of water in core after a hypothetical pipe break; reduced rate of energy release to containment from a hypothetical accident results in lower peak containment pressures)
- Depressurization of RPV by safety-grade system to allow gravity feed of secure water supply for passive inventory control
- Internal control rod drive mechanisms to eliminate rod ejection accidents
- Decay heat removal from reactor core by passive safety systems
- Natural circulation normal core cooling or use of many low head reactor coolant pumps to greatly reduce or eliminate traditional loss-of-flow accidents
- Smaller radioactive source term (because of small core size) and delayed potential radioactive release (because of longer coping time after an accident)

Note that the combination of these features establishes the technical justification for siting SMRs near electricity load centers, with the emergency planning zone at or near the plant site boundary.

From a national policy perspective, SMRs also offer potential strategic benefits:

- **Geopolitical influence**—An SMR export industry would afford greater leverage to achieve US nuclear safety and non-proliferation objectives, particularly in emerging countries that need small increments of electricity. US leadership could balance inroads being made in this area by Russian and Chinese nuclear power programs. Unless and until the United States has a comprehensive and viable international nuclear power strategy that acknowledges the realities of the global nuclear industry, our ability to influence the decisions of other nations with respect to their involvement in all aspects of the nuclear fuel cycle will be limited. A strong US SMR program would provide one element that would give the US government a greater voice in these critical discussions.

- **Economic growth**—Reliable nuclear power expansion provides a springboard for domestic economic growth and high-paying jobs throughout the United States.
- **Export expansion**—Early-to-market domestic SMRs have high export potential.
- **Advanced manufacturing**—SMRs are ideally positioned to support federal advanced manufacturing policy initiatives with a direct benefit in high-paying technical jobs.
- **Grid security**—SMRs are capable of providing reliable and secure electricity to critical national infrastructure, e.g., Department of Defense facilities, because of nuclear energy's high availability and lower vulnerability to cyberattacks and because SMRs are sized to better meet local needs if the grid is disrupted.
- **Environmental quality**—SMRs have the potential to provide significant reductions in greenhouse gas emissions, especially as the United States looks to replace several hundred smaller aging coal-fired power plants in the mid-2020 timeframe. Also, if proven viable, SMR-powered water desalination could have dramatic benefits to the global fresh water crisis.

Recent SMR History: A Candid Review

Based on growing industry interest in SMRs as a near-term clean energy power source, DOE issued a financial assistance Funding Opportunity Announcement (FOA) for a cost-shared industry partnership program in March 2012. The goal of the SMR Licensing Technical Support program is to promote the accelerated commercialization of SMR technologies that offer affordable, safe, secure, and robust sources of nuclear energy that can help meet the nation's economic, energy security, and greenhouse gas emission objectives. The LTS program is funded on a fifty-fifty cost-shared basis by DOE and industry participants, up to a maximum budget authority of $452 million over five years, which equates to a total estimated combined funding of $904 million. The program, as defined in 2012, would support the licensing by the Nuclear Regulatory Commission and first-of-a-kind (FOAK) engineering of SMRs. The LTS program was intended to fund up to two financial assistance cooperative agreements with SMR consortia, selected on a competitive basis. The licensing tasks within the scope of the 2012 FOA included: (1) review and approval of early site permits, design certifications, and combined licenses (often referred to as COLs) under the Part 52 licensing process (in Title 10 of the Code of Federal Regulations), or (2) environmental reviews, construction permits, and operating licenses under the older Part 50 licensing process.

The 2012 FOA sought SMR designs that could achieve NRC design certification and licensing to support plant deployment by 2022, a critical time for SMR deployment as discussed above. Although the FOA was open to both LWR and non-LWR technology options, the aggressive criteria and timeline for commercialization and deployment effectively limited successful proposals to designs based on LWR technology. Four light water SMR design teams applied: B&W (mPower), Westinghouse, NuScale, and Holtec.

On November 21, 2012, DOE announced that it had selected the mPower design by B&W to receive the first funding award under its SMR LTS program. B&W partnered with Bechtel International and the Tennessee Valley Authority (TVA) for this award. DOE agreed to support (within its capped budget of $452 million) up to half the cost of licensing the mPower design for deployment of up to four modules at TVA's Clinch River site near Oak Ridge, Tennessee.

DOE issued a second FOA on March 11, 2013, for an additional award (or potentially two awards) under the SMR LTS program. It strongly emphasized "new approaches and innovations in safety, operation, and economics." However, only design certification (neither the early site permit nor the COL) was within scope for the new FOA. Further, only Part 52 (not the older Part 50) was allowed as the licensing basis.

The second FOA allowed for a more relaxed project timetable supporting deployment "within 2+ years of a 2025 target date," instead of the required 2022 deployment date in the first FOA. The 2013 FOA also deemphasized factors contributing to timely deployment. The 2012 FOA required a licensing plan and a business plan; the 2013 FOA did not. The 2012 FOA required the applicant to address the state of its design for all key reactor systems by identifying a "technology readiness level"[5] and by providing evidence to substantiate these readiness levels. The 2013 FOA did not consider readiness levels. The 2013 merit review criteria ranked "new approaches and innovation" ahead of "potential for widespread deployment" and "extent to which domestic utilities or utility consortia have expressed interest, or provided an endorsement." Ranked even lower was, "An acceptable/realistic approach to completing design finalization for the selected SMR design following the certification, including FOAK engineering required, that is mature and is likely to result in commercialization." In addition, some of the 2013 selection criteria specified innovations that could result in additional costs without necessarily adding to safety.

On December 12, 2013, DOE announced that it had selected NuScale Power to receive the second funding award under its LTS program. NuScale's funding will be part of the total $452 million identified for the overall SMR LTS program for both the first and second procurements.

5. See DOE's "Technology Readiness Assessment Guide," DOE G413.3-4A, 9-15-2011.

In general, the commercial nuclear industry had a negative opinion regarding the DOE's fundamental change in direction, away from commercialization goals to innovation goals—not because of its influence on the selection process (the NuScale design is considered an excellent design concept) but because of its reduced emphasis on commercialization, its exclusion of project-specific engineering and licensing (early site permit and/or combined license) and resultant disincentive for utility engagement and investment, and its more relaxed deployment schedule. Focusing the program on reactor designs without the benefit of significant future customer engagement could eliminate potential sources of industry cost-sharing, reducing the probability of a plant order once NRC approves the design. Note how this new approach conflicts with a key lesson learned from the NP 2010 Program: "Utility-Led Consortium Approach: The utility-led consortium approach used on the COL Demonstration projects with utility partners and reactor vendors worked well and promoted the NRC's Design Centered Review approach."[6]

Less than two months after the December 2013 DOE announcement, Westinghouse announced that it had "reprioritized" staff devoted to SMR development and directed its efforts to the AP1000, the company's full-scale ALWR currently under construction in China and the United States. "The problem I have with SMRs is not the technology, it's not the deployment—it's that there are no customers," Danny Roderick, Westinghouse CEO, said. "The worst thing to do is get ahead of the market." Following these announcements, Ameren Missouri, Westinghouse's partner in developing the Westinghouse SMR for Ameren's Callaway site, said in a statement it is "stepping back and considering our alternatives."

6. "Nuclear Power 2010 Program: Combined Construction and Operating License & Design Certification Demonstration Projects: Lessons Learned Report," August 2012.

On April 14, 2014, B&W announced that it was reducing its spending on the mPower SMR project, having failed to find customers or investors. Its lead customer, TVA, had planned on building six units at its Clinch River site in Oak Ridge, Tennessee. B&W hoped to have secured a number of utility customers for its SMR, as well as investors keen to take a majority share in its development. B&W had been unsuccessful in these aims: "There was interest from customers and interest from investors, but none have signed on the dotted line." The result is that B&W decided to reduce its spending on mPower to a maximum of $15 million per year, and has begun negotiating with TVA and DOE to find a workable way to restructure and continue the project. B&W said it "continues to believe in the strength of the mPower technology," but without additional investors for the reactor, "the current development pace would be slowed."

The Energy Department has not indicated whether it is considering any additional awards or programmatic changes under the LTS program to address these happenings. It has the authority to do so under existing legislation.

The reasons these vendors slowed down their development of SMRs are generally hard to identify with any real precision. However, the authors speculate that there are a few reasons that likely contributed to the pullbacks. First, the financial requirement to design, certify, and engineer first-of-a-kind SMRs is estimated to be at least $1.5 billion. While the Energy Department LTS program provided much-needed funding support to these efforts, the remaining investment left to the vendors was substantial and required more than a ten-year payback timeline. Few publicly held companies could afford this level and length of investment. Also, with natural gas-generated energy dominating the near-term markets, few utilities have the ability to commit to long-term investments in nuclear power. Lastly, there is some regulatory uncertainty associated with SMRs. Key decisions regarding control room operations and emergency planning zone requirements have not been made since no vendor has put forward a license application that would cause NRC to resolve these questions.

Challenges Facing Commercialization and Deployment of SMRs

The authors have identified five hurdles to SMR commercialization success. These begin with a critical, if amorphous, hurdle labeled "implementing the vision" and are followed by: SMR economics, export and financing challenges, NRC licensing and regulatory challenges, and FOAK engineering and factory fabrication. Each is explored in depth below.

Challenge 1: *Implementing the Vision*

As noted above, some of the key lessons learned from the successful NP 2010 program have not been incorporated in SMR strategies to date. To its credit, there are many good aspects to the SMR strategy incorporated in the DOE's LTS program, particularly in the first FOA. DOE constructed its first FOA in March 2012 for the SMR LTS program with an intentional commitment to commercial success. It imposed formidable deadlines for successful completion of NRC licensing, and it established design goals and selection criteria aimed at encouraging strong utility industry participation in the program, via consortia committed to actual construction following successful licensing. These FOA conditions had the effect of encouraging SMR applicants to rely on proven technology, to the degree practical, and to partner with a willing utility. These factors all drove toward early commercial deployment.

Although the policy direction embedded in the initial March 2012 SMR FOA encouraged utility participation, it did so without a mechanism for market-driven technology selection, as was the case during the NP 2010 program. The NP 2010 program encouraged the formation of utility groups that had strong interest in a particular reactor technology. These groups helped the designers make specific design decisions that they felt would make the resulting designs more commercially attractive. These groups also provided strong unified voices to other stakeholders, including the DOE, Congress, and the NRC. The second SMR FOA moved even further away from utility engagement, favoring technology innovation, which in turn led to relaxed time-to-market emphasis and reduced commercialization potential. The revised SMR LTS program excluded all project-specific licensing and engineering work from its scope, discouraging utility engagement and investment.

Successful implementation of the vision for SMRs requires a change in direction—one that recognizes that NRC approval is not the end goal, but only a step along the way. Commercialization and widespread deployment of US-based SMR designs must be the ultimate goal. The private sector must complete the final steps toward that goal, but the federal government will have wasted significant resources with nothing to show for it if the LTS program is completed without establishing a clear pathway to commercialization.

Much more attention needs to be paid by the nuclear industry and the US government to the initial project structure and engineering work that will ensure SMR competitiveness, i.e., design engineering beyond that required for NRC approval, engineering to implement modular manufacturing and factory fabrication, construction engineering to assemble and erect the SMR at the plant site, and incentives for a "first mover" demonstration project(s).

Challenge 2: *SMR Economics*

Economic competitiveness is a significant challenge to SMR deployment, especially given today's low natural gas prices. Even if natural gas prices were higher, SMRs must overcome the disadvantage of poor economies of scale in order to compete with larger base load plants on a cost-per-kilowatt capacity basis.

One immediate issue is timing. SMRs are seen as a logical choice for replacing smaller retiring coal plants; however, the timing of this deployment strategy is problematic, due to accelerated retirements of older, smaller coal plants, driven by Environmental Protection Agency (EPA) actions. Roughly sixty gigawatts electrical (GWe) of coal capacity will be closed by 2016, driven by the EPA's mercury and air toxics standards rule. Furthermore, if EPA's proposed rule to regulate carbon dioxide emissions from existing plants survives legal challenge, another forty-five to fifty GWe of retirements could follow soon thereafter. Assuming this accelerated shutdown schedule, one potential response would be to replace these coal plants with easily available natural gas units. The remaining domestic fossil power generation fleet would then consist of relatively modern coal and natural gas power plants with a full suite of environmental controls that could operate for decades. A problem with this approach, however, is that without significant contributions from zero carbon power sources, longer-term carbon dioxide emissions reduction goals could not be met. Therefore, it is possible that if SMRs are commercially available in the near future, then companies that are committed to repowering old coal plants with SMRs could request an extension on coal decommissioning dates, making it possible for SMRs to fill this market niche, with rather dramatic impact on carbon emissions. This timing issue reinforces the point that action is needed now to take advantage of the limited window of opportunity for widespread SMR deployment in the United States.

The price of natural gas presents its own set of uncertainties. It is possible that various factors could cause gas prices to increase, such that by the time SMRs are ready to deploy they could be more competitive. None of these factors are imminent. But if they were to occur, the most significant would be: (1) pricing of greenhouse gas emissions through new policy actions; (2) new restrictive measures to address environmental risks from fracking-based shale gas development that dramatically alter the supply of domestic natural gas; and (3) widespread construction of liquefied natural gas terminals in the United States capable of exporting natural gas, which would drive competition for US natural gas supplies, which in turn might cause domestic natural gas prices to increase. However, these and other market factors affecting the relative costs of competing fuel supplies are largely outside the control of the power industry.

Predicting legislative actions that would affect SMR competitiveness is equally difficult. Carbon dioxide emission legislation could have a major impact on SMR competitiveness, but is unlikely to pass Congress in the near term. Further, most current federal and state energy incentives aimed at carbon-free technologies generally benefit renewable sources disproportionally to nuclear.[7] In fact, nuclear energy is often excluded from these incentives. Renewable portfolio standards (driven primarily by the states), clean energy standards, production tax credits, and loan guarantees often create an uneven playing field for new capacity. Some that do apply to large nuclear plants may not apply to SMRs. Rationalizing these incentives is not a current priority in Congress, nor are major changes anticipated at state levels.

Predicting the target range for SMR market competitiveness is problematic. Natural gas market fundamentals are volatile and uncertain, with most experts predicting low prices for an indefinite period. Estimates of increased coal power costs vary significantly as a result of unresolved or pending environmental regulatory actions and policies.

Uncertainty in SMR capital cost projections, given the lack of engineering detail achieved to date, further complicates the picture, especially for first movers. Reducing this uncertainty requires detailed design and reliable quotations from suppliers, as well as innovative strategies for first movers. FOAK plants will not be cost-competitive—a positive learning curve must enable later modules to become competitive. Ameliorating these capital cost concerns are the benefits of smaller plant size, which lower the amount of capital at risk. From the utility

---

7. The EPA's proposed existing power plant emission standards under Clean Air Act section 111(d) is an example, where all existing renewable power generation is included in state rate-setting formulas, but only a small portion of existing nuclear (the 6 percent considered "at risk") is similarly counted.

perspective, a modular plant could generate income from the first module deployed; by the time the fifth or sixth module is installed, a plant could become financially self-sustaining.

Much has been said about the benefits to SMRs from extended power purchase agreements with federal agencies (primarily the departments of Defense and Energy) to provide dedicated and secure power to military bases or national laboratory facilities. However, for this strategy to work, SMR economics need to be relatively competitive. If the cost differential is small, then the extra cost to these critical facilities could be justified, especially given growing concerns about power grid reliability and the vulnerability of the US grid to attack (either physical or cyber). Dedicated SMRs offer the capability to power facilities that are essential to national security, even if a major grid event were to occur. Opportunities for dedicated SMR deployments for federal sites are clearly limited but might be sufficient to kick-start initial deployment.

The need for urgent action is readily apparent when observing the rapid progress being made by overseas competitors of American SMRs. A few years ago, the United States had a clear lead in developing SMRs. That lead is evaporating.[8] Unless the United States implements a comprehensive SMR roadmap to address all challenges and opportunities, including aggressive initiatives aimed at driving down the "learning curve" discussed below, US-based SMR market competitiveness vis-à-vis international, state-sponsored competitors is at risk.

Further complicating US SMR competitiveness is the uniquely protracted licensing process in the United States for new reactor designs. New US reactor designs undergo a detailed and expensive NRC technical review and licensing process which, including the application process, historically has taken almost a decade to complete. Every new US reactor design in the last two decades has been approved and constructed

8. Note major progress on SMR designs by South Korea, Argentina, and Russia. China is a likely future competitor.

overseas before the first unit of that design achieved commercial operation in the United States. While US design certification is viewed globally as the gold standard, unless we find ways to complete the SMR licensing process in a timely manner, while not cutting any corners on safety, others will surely beat US vendors to global markets.

Challenge 3: *Export and Financing Challenges*

Another important lesson learned from NP 2010 was that a parallel program of financial incentives was essential to success: "NP 2010, in tandem with the EPACT-05 [Energy Policy Act of 2005] provisions, provided the impetus for reopening the option for nuclear energy in the U.S." The NP 2010 program and the EPACT-05 financial incentives, principally loan guarantees, were intended to work synergistically to facilitate private sector investment in enabling new nuclear energy plants—investment that would not have otherwise materialized or would have been delayed for many years. However, actual implementation turned out to be problematic. Based on a wrong input of return in the event of default, the Office of Management and Budget's calculation of the credit subsidy cost made it impossible for utilities in merchant markets to use loan guarantees. The only beneficiary thus far has been Southern Company's Vogtle units 3 and 4 project in Georgia, and that took an excessive amount of time to approve.

It is clear that the political climate does not exist today for large financial incentives for nuclear energy technologies. The SEAB subcommittee on SMRs examined options for federal incentives, including provision of a more level playing field, with consistent definitions for clean energy standards. This is important, because nuclear technology is often preferentially excluded from federal and/or state incentives, even when there is objective evidence that nuclear plants fully satisfy the requisite criteria. A comprehensive strategy is needed to correct this imbalance, but no consensus evaluation or integrated recommendations have been developed to date for federal and state policymakers.

In the United States, new plant construction is possible today in regulated markets, as evidenced by Westinghouse AP1000 projects under way in Georgia (Vogtle 3 and 4) and South Carolina (Virgil C. Summer units 2 and 3). These states have taken a long-term view toward providing incentives for base load construction to meet future load growth by allowing construction work in progress costs to be included in the customer rate base. Meanwhile, federal production tax credits and low interest rates along with potential federal loan guarantees make financing less costly. In deregulated or merchant markets, not all of these incentive mechanisms are available. Without specific incentives for new, large base-load capacity, incremental, low-capital-cost gas-fired capacity dominates.

Other formidable policy and administrative challenges face US designers in marketing their designs overseas. Even though US reactor technology represents the latest in safety design, global markets tend to prioritize economics and ease of contracting with potential reactor suppliers. Competing in the world nuclear energy market is therefore challenging for US suppliers who do not enjoy the same level of government support as do foreign suppliers. US suppliers are typically competing against state-owned enterprises or with nations where the government owns a majority share in the private companies, often heavily subsidized. These are the same headwinds the US nuclear enrichment industry faces with its international, state-sponsored competitors.

The recent debate over reauthorization of the US Export-Import Bank is noteworthy. The bank's charter was set to expire on September 30, 2014, with reauthorization in the House of Representatives in doubt. The Export-Import Bank provides essential support, both directly and indirectly, to US companies of all sizes that are investing overseas. In the nuclear business, no matter how big the private sector is, companies are cut out of the process without an export credit agency at the table—it is almost always mandatory in bid requirements to have national export credit agency funding options available. The nuclear industry (as well as many other industries, including the aircraft industry) undertook a major campaign to convince Congress that the Export-Import Bank is vital to its business. Authorization was ultimately extended, but only temporarily to June 2015.

Other obstacles to US leadership in nuclear energy markets overseas have been problems for years. But they are more important today as competition from non-US suppliers of nuclear technology increases, for two main reasons.

First, the US export control regime is costly to navigate. Approvals in the United States can take years instead of the months required elsewhere. American firms often suffer from fragmented government oversight in this arena, with multiple federal agencies involved. The NEI has urged Washington to improve coordination and integration among the many government agencies with a role in US nuclear technology export policy: the departments of State, Energy, and Commerce; the NRC; and the Export-Import Bank. In 2013, the Obama administration created a position in the National Security Council to drive greater integration, which is beginning to pay dividends, particularly for large-value contract opportunities where greater US government attention is paid. Continued effort to streamline various agency processes remains to be accomplished.

Second, the lack of a global nuclear liability regime is a significant problem for SMR designers as it is with any nuclear export opportunities today. This situation complicates commercial arrangements and also means that, in the event of a nuclear incident, claims for damages would be the subject of protracted and complicated litigation in the courts of many countries against multiple potential defendants with no guarantee of recovery. This situation is inhibiting US reactor sales today to India, for example.

The International Trade Administration (an arm of the Department of Commerce) has highlighted these problems in a 2011 report[9] with a number of policy and industry recommendations.

9. "The Commercial Outlook for U.S. Small Modular Reactors," International Trade Administration, US Department of Commerce, February 2011.

Challenge 4: *NRC Licensing and Regulatory Challenges*

As stated earlier, the NRC review and eventual certification of SMR designs is an absolutely essential step to deployment. In this endeavor, the DOE LTS program for SMRs is critical. Without US government financial and inter-agency support, the industry could not successfully license and deploy SMRs—the risks and resource requirements are too formidable.

NEI and NRC have been working for several years on a number of generic licensing issues applicable to future SMR designs. Significant progress has been made on the following:

- security and safeguards requirements
- insurance and liability (i.e., Price-Anderson Act provisions)
- decommissioning funding
- licensing feasibility (modularity)
- emergency planning requirements
- annual fees (commensurate with smaller size)
- pre-application engagement
- control room staffing and site staffing
- multi-module licensing

Additional generic work is also needed on SMR radiological source term assumptions (mechanistic source term and the treatment of modular plants), post-Fukushima requirements, and various environmental issues.

Design-specific licensing is another matter. SMRs are often described as smaller versions of existing LWR technology. In fact, no one has licensed and operated a commercial integral PWR.[10] Integral PWRs lack an operating experience basis to predict transient and accident performance, and must therefore rely on testing and computer models to predict how they will respond. Incorporation of pressurizers and steam generators inside reactor vessels is imposing challenges, affecting how the plant operates. For example, switching the flow regime inside steam

10. Integral PWR technology was used on two shipboard reactors in the 1960s: the NS Savannah (US) and the Otto-Hahn (German); both were cargo vessels.

generators (boiling inside the tubes instead of on the outside of the tubes as is currently done for large PWRs) has never been demonstrated successfully in the history of commercial nuclear power. New regulatory guidance will need to be developed for situations where existing guidance is not adequate. SMRs employ innovative design features to varying degrees (compared to GEN-III and GEN-III+ reactors), with no experience base. Some of these innovative features will require single-effects and/or integrated-effects testing, potentially requiring design-specific test facilities. Work on design-specific safety issues and transient analysis modeling by modern computer codes is in its early stages.

SMRs face another disadvantage relative to the prior larger designs: unlike ALWRs, these SMR designs have not yet undergone any equivalent screening against consistent utility requirements. This situation introduces the possibility of an uneven playing field among competing SMR designs because of subtle differences in design assumptions that are not obvious to individual utilities, the Energy Department, or the Nuclear Regulatory Commission. It also introduces the possibility of unnecessary regulatory instability as a result of differences in safety margins among competing designs, combined with the NRC's natural tendency to drive any differences in approach to conform to the most restrictive applicant. Fortunately, the Electric Power Research Institute (EPRI) is completing work on a revision to its ALWR Utility Requirements Document to address a number of key issues for SMRs. The Department of Energy has supported this effort on a fifty-fifty cost-share basis. The revision was released in December 2014 and includes a number of generic standards for SMRs, such as:

- Design margin, e.g., quantitative fuel thermal margin requirements
- Design life, design availability requirements, planned and forced outage rates
- Load following and load rejection requirements and transient coping requirements[11]

11. For example, ALWRs are required by utilities to be able to ride out all anticipated transients (turbine trip, loss of feedwater, loss of offsite power, etc.) without

- Probabilistic risk assessment targets (core damage frequency and consequence limits)
- Preference for increased automation of plant operations
- Spent fuel storage capacity
- Maintainability standards, refueling outage duration targets, and equipment replaceability
- Economic targets for capital cost, O&M cost, and fuel cost
- Seismic design based on a generic plant siting envelope approach

The NRC in August 2012 issued a comprehensive report to Congress on advanced reactor licensing that discusses SMR licensing issues in detail, along with R&D needs and human resource and facility requirements.[12]

Challenge 5: *First-of-a-Kind Engineering and Factory Fabrication*

The amount of engineering required for implementation of a new FOAK reactor plant design is very large, when including the preliminary design, the detailed design, the design for manufacture, and the construction engineering. Typically this takes over a decade to accomplish and between $500 million and $1 billion, not including licensing costs. For perspective, the four US integral PWR SMR designs had less detailed engineering completed as they competed for DOE LTS funding than was already done on the AP1000 and ESBWR (GE-Hitachi's Economic Simplified Boiling Water Reactor) at the beginning of the NP 2010

---

activating emergency core cooling systems, lifting either primary or secondary safety valves, or activating complex control systems (e.g., power-operated relief valves). This drove the designers of PWRs to make both their pressurizers and steam generators much larger, so as to provide greater surge volume on the primary and secondary sides, respectively. It is not clear that all SMR designs could conform to such a requirement.

12. "Report to Congress: Advanced Reactor Licensing," Nuclear Regulatory Commission, August 2012, http://pbadupws.nrc.gov/docs/ML1215/ML12153A014.pdf.

program.[13] DOE and industry should therefore expect that any program to deploy SMRs would take at least as much time and resources as the NP 2010 program. In fact, it is very likely that the currently planned limits to the SMR LTS program ($452 million over five years) will not be sufficient to complete the job. Even if industry funds the program well in excess of its 50 percent requirement, the five-year limit on DOE participation is clearly problematic.

A much higher level of design completion is required beyond that which enables NRC approval before a reactor can be ordered and built. FOAK engineering is essential to developing a credible cost and schedule estimate—a prerequisite to utility planning and investment decisions. Design completion, including site-specific COL engineering and FOAK engineering, were essential elements of the cost-shared NP 2010 program, but are marginalized in the SMR LTS program.

In the long term, the promise of SMR economic competitiveness and widespread deployment is often viewed as dependent on modular construction and factory fabrication on a very large scale, requiring enhanced manufacturing techniques and extensive infrastructure development. Large investments in factories to manufacture modules will be required to achieve the needed economies and quality control of production. Recent experience with factory fabrication of large modules for ALWRs at Chicago Bridge & Iron's Lake Charles facility in Louisiana demonstrates that the promise of vastly increased quality control is not a given—it must be inculcated. The development of detailed work procedures, implementation of approved quality programs, and significant training of the workforce in the use of these procedures and quality programs is necessary to obtain the benefits of factory fabrication.

It is quite possible for SMRs to experience a major learning curve benefit from driving costs down as a result of strategies discussed in this paper, including advanced manufacturing technologies, factory

13. Note that these two 1,000 MWe+ designs benefited greatly from the prior formal NRC review of predecessor designs: the 600 MWe AP600 and the 600 MWe SBWR. AP1000 and ESBWR were scaled-up versions.

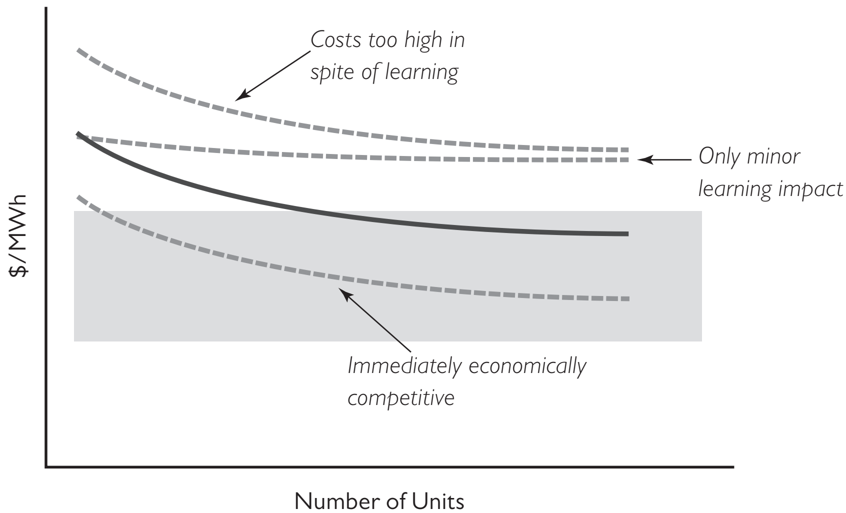


FIGURE 1. Uncertainties in economic evolution
Source: SMR SEAB Subcommittee, "A Strategic Framework for SMR Deployment," February 2012, Office of Nuclear Energy web site, http://energy.gov/ne/downloads/strategic-framework-smr-deployment.

fabrication for "nth-of-a-kind" subsequent units in relation to FOAK units, and streamlined licensing processes. The SEAB subcommittee on SMRs studied this learning curve issue in depth.[14] Although the magnitude of this learning curve is uncertain, there is compelling reason to believe that an aggressive plan of action could influence this learning curve in a major way. Figure 1, taken from the SMR subcommittee's strategic framework,[15] portrays this effect. The solid line displays the benefits of a highly effective learning curve. The near-flat dashed curve ("only minor learning impact") displays the status quo.

14. "Economic Aspects of Small Modular Reactors," SMR SEAB subcommittee, March 1, 2012. See also, "A Strategic Framework for SMR Deployment." This analysis is based in part on a report by Robert Rosner and Steven Goldberg, "Small Modular Reactors—Key to Future Nuclear Power Generation in the U.S.," Energy Policy Institute at Chicago, November 2011.

15. "A Strategic Framework for SMR Deployment."

We believe that realization of these “highly effective” learning curve benefits will be challenging. The costs of the “nuclear island” (the reactor unit, its safety systems, and surrounding structures), which are the primary focus of modular construction and factory fabrication, represent less than half of total plant costs. Therefore, achieving large learning curve benefits will require major innovative approaches to address the full breadth of cost reduction opportunities for the remaining majority of the plant costs. This includes the entire supply chain and factory infrastructure spectrum. Near term, there is an adequate supply chain to start up the SMR economy using existing infrastructure, but much more will be needed to support widespread deployment.

Strategies to Improve Economic Competitiveness and Facilitate Widespread Deployment

Strategy 1: *Critical Role of Factory Fabrication, Modular Construction, and Advanced Manufacturing*

Factory fabrication and modular construction on a large scale are both essential to achieving the learning curve improvements discussed above. They will enable much shorter construction times, reducing the time-to-market cycle that will enable the financing benefits of multiple unit construction on an SMR site, such that a specific SMR design fabricated at a central factory could become financially self-sustaining after five or six units are completed. Efficient design documentation that can more easily incorporate lessons learned from the fabrication of prior modules will expedite this learning curve benefit.

Much of the work needed to implement factory fabrication and modular construction can proceed based on existing technology. However, there is a role for advanced, state-of-the-art manufacturing technologies, some of which may require further R&D. Innovation strategies are discussed next.

The President's Council of Advisors on Science and Technology (PCAST) published two compelling reports in 2011 and 2012 that call for a major all-sectors advanced manufacturing initiative, to include a nationwide strategic plan and the creation of sector-specific technology roadmaps. The focus of the PCAST reports was on US competitiveness and the imperative to reverse the trend away from declining US leadership in manufacturing. As US leadership in manufacturing declines, other nations are investing heavily in advancing their manufacturing leadership.[16] This situation is pervasive throughout all business sectors in the United States, and it is affecting the nuclear industry. For example, the United States no longer manufactures ultra-large metal components such as large forgings, pressure vessels, and steam generators. The United States currently retains a viable supply chain for other high-value nuclear components, but non-US suppliers are increasingly competitive.

Government and industry generally agree that government should not fund research that industry can and should do on its own to advance nuclear technology. Government's role should be limited to high-risk/long-term R&D that industry cannot invest in, as well as medium-term/medium-risk research, development, and demonstration that industry would cost-share, in order to bring it to the point that industry can commercialize the technology on its own. This principle is visualized in figure 2, the "valley of death" graphic from the 2012 PCAST report. The curve at the far left represents government's important role in high-risk, long-term R&D. The gap in the middle represents what happens when government and industry fail to work together and share the risks and responsibilities to co-sponsor these high-risk technologies through the "valley of death" so they can be commercialized by industry.

The 2012 PCAST report calls for a phased approach. Phase I would create an overall all-sectors strategic plan for advanced manufacturing;

16. "Report to the President on Ensuring American Leadership in Advanced Manufacturing," President's Council of Advisors on Science and Technology, June 2011.

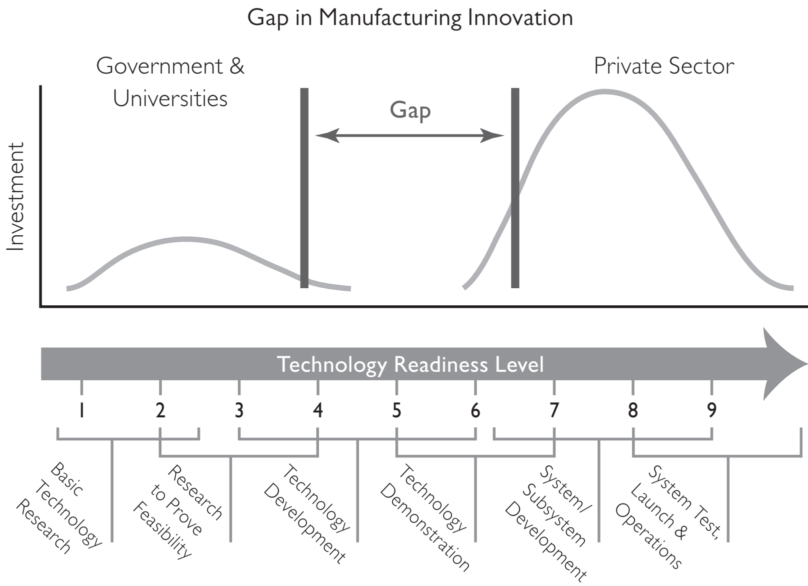


FIGURE 2. Gap in manufacturing innovation
Source: President's Council of Advisors on Science and Technology, "Report to the President on Capturing Domestic Competitive Advantage in Advanced Manufacturing," July 2012, White House web site, https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast_amp_steering_committee_report_final_july_27_2012.pdf.

phase II would create individual technology roadmaps; phase III would create and manage programs. In addition, PCAST states: "Wherever possible, it is critical that a co-funded model be used wherein both industry and government contribute. For mature industries, consortia should create and manage the programs."

Within DOE, the responsibility for coordinating advanced manufacturing is assigned to DOE's Office of Energy Efficiency and Renewable Energy (EERE). "As part of the Administration's effort to spark a renaissance in American manufacturing, the Energy Department announced in June 2012 that it will invest more than $54 million in thirteen projects to develop innovative technologies and materials for the industrial sector. This investment will help to provide American manufacturers with the cutting-edge tools, techniques, and processes they need to compete successfully in the global marketplace."[17] These thirteen projects are being managed by the Energy Department's Advanced Manufacturing Office, operated by EERE. None of these projects support nuclear energy or new nuclear energy plants. SMRs are well positioned to support federal advanced manufacturing policy initiatives with a direct benefit in high-paying technical jobs. However, no Advanced Manufacturing Office funds have been made available for SMRs to date.

Advanced manufacturing technologies combined with factory fabrication, sufficient to allow shipping completed modules and sub-modules to construction sites, is central to the SMR business case. Repetitive and high-volume, high-quality production of all SMR components (e.g., nuclear island, turbine-generator sets, balance of plant) to achieve the steep learning curve described in the SMR subcommittee reports could lead to major cost and schedule reductions. Breakthroughs in technologies that lower the cost of construction of SMRs should work hand-in-hand with high volumes of series production (including international sales) to realize this learning curve benefit.

Recognizing this, DOE's Office of Nuclear Energy developed an "Advanced Methods for Manufacturing Technology (AMM) Roadmap for the Nuclear Energy Sector," as recommended by PCAST. This AMM Roadmap was completed by an industry team of experts in September 2012, but was never implemented. It included project management and resourcing arrangements for DOE and industry.

From the AMM Roadmap executive summary:

> *The stakes for the US in manufacturing are huge. Not only is a strong manufacturing base essential to the success of US reactor designs currently competing in global markets, but the success of the SMR Initiative depends heavily on the ability of the US to deliver on the SMR's expected advantages—the capability to manufacture major SMR modules and components in a factory setting, dramatically reducing the amount of*

17. See DOE-EERE web site, http://www1.eere.energy.gov/manufacturing.

costly on-site construction required—thereby enabling these smaller designs, which lack the "economies of scale" of their larger ALWR counterparts, to be economically viable. "Modular construction" has been proven in shipbuilding and other industries, and is being exploited to a limited degree in modern ALWR construction.[18] *It must expand dramatically for SMRs to deliver their full potential as economic competitors in US and global markets. Most important, reducing the cost of construction here in the US for both ALWRs and SMRs will result in cheaper electricity for American families and businesses.*

The future of the SMR Initiative depends heavily on our ability to reduce the cost and schedule for new nuclear construction. We must make fabrication and manufacture of nuclear power plants faster and cheaper, with equal or better reliability than the current state-of-the-art in power plant construction. Efforts to date to both define the strategy and identify the most promising technologies that can achieve these goals suggest that innovation in new, advanced manufacturing methods is critical to success.

Note that the AMM Roadmap defines advanced manufacturing very broadly, to include technologies that can be applied at both the factory and the construction site. It includes advanced engineering tools and processes, advanced project management and configuration management tools, and advanced inspection tools. Advances and efficiencies in lifting and transporting heavy modules will also be important. More specifics on the AMM Roadmap for the nuclear sector are provided in appendix A.

Also note that factory fabrication on a large scale of complex reactor plant modules is not easy. Quality controls are absolutely essential. Early experience with AP1000 reactor modules fabricated in an industrial facility hundreds of miles from the plant site, as well as on-site fit-up

18. Note that the AP1000 has greatly advanced modular construction techniques; SMRs have the potential for even greater advances, based on further technology innovation as well as the smaller size of the plants.

experience, suggests that the learning curve effect is real, but that project management and quality controls can be improved.

Finally, much can be learned from foreign competition. The United States should learn from what other countries have been doing in this regard in their new reactor programs, especially Russia, China, and South Korea, and then deploy proven techniques in the United States.

Strategy 2: *Facilitating Demonstration Projects*

The Energy Department and industry have made a concerted effort recently to identify regions of the country with a high concentration of critical Defense and/or Energy Department facilities that require extraordinary levels of electricity reliability and resistance to grid failure, even under cyberattack scenarios. A few such regions have been identified. Cognizant federal facility and local leaders have been contacted and briefed on the advantages that an SMR could offer their region. More information will be needed, and more progress toward licensing and design completion will be necessary before decisions are possible.

Strategic siting of SMRs in support of critical national infrastructure raises important policy questions. It is reasonable to expect that federal agencies would support SMR projects, and be willing to pay a premium from a national security perspective. But how much of a premium is appropriate for this added protection? Would legislation be required? How would ownership issues be handled?

Complicating this initiative is President Obama's recent Executive Order 13514 to all executive branch agencies, requiring them to obtain 20 percent of their electricity from renewable energy sources by 2020. This order was a component of the administration's Climate Action Plan, intended to reduce America's carbon emissions. Nuclear energy was, however, excluded by the order.[19]

19. Note that a recently released executive order on Planning for Federal Sustainability in the Next Decade (March 2015) mentions SMRs, but

Nuclear energy represents the majority of carbon-free electricity produced in the United States, and the administration has acknowledged its role in achieving meaningful global reductions in carbon dioxide emissions. We therefore believe that American climate action plans should include nuclear energy. Not doing so complicates the DOE initiative to identify federal sites willing to consider SMRs.

The December 2013 letter from NEI to President Obama on this matter is attached as appendix B.

Strategy 3: *Improved Licensing Process*

Opportunities for streamlining licensing processes need to be explored. Reducing licensing and construction times can have a major impact on plant cost by reducing the carried construction interest from plant order to commercial operation. Some streamlining opportunities were identified during NP 2010 licensing of ALWR designs, all of which can be applied to SMRs as "lessons learned." In addition, the NRC has directed its staff[20] to expand the use of risk insights and other efficiencies, such as resolving key technical and policy issues early in the SMR licensing process. The new risk-informed approach to SMR licensing has not been developed fully, and is thus an important area for the Energy Department and industry to explore and to provide suggestions to the NRC.

As discussed above, a number of generic issues, mostly of a policy or programmatic nature, are already being addressed by NEI and NRC. These issues should be ranked systematically based on their importance and their likelihood to reduce cost and schedule of construction and/or cost of plant operations. Rankings should also consider risk of resolution vs. non-resolution and urgency (e.g., when in the licensing process should each issue be resolved). Those issues with the greatest potential

---

differentiates between renewable energy goals and alternative energy goals. It is too early to determine whether this order could benefit SMRs.

20. Staff Requirements Memorandum on SECY-11-0024, "Use of Risk Insights to Enhance the Safety Focus of Small Modular Reactor Reviews," May 11, 2011.

to delay SMR licensing, or to positively affect the SMR business case (if resolved successfully), should be given top priority.

Learning and applying the lessons from the NP 2010 program to the SMR LTS program is critical. Some of these lessons are technical or programmatic in nature, such as choices regarding the form and content of licensing submittals, the sequence of environmental reviews in relation to reactor systems reviews, and the potential for new or changing technical requirements (e.g., seismic and flooding requirements). Other lessons learned are managerial in nature, such as effective communications and data exchange provisions and efficient meeting and conference call protocols for resolution of issues. DOE lessons-learned documents are available to applicants to assist in these areas.

The Department of Energy's Office of Nuclear Energy (DOE-NE) and industry should carefully examine the options available for SMR licensing and select the pathway that is most likely to achieve ultimate success, setting the stage for multiple standardized SMR deployments to follow. In contrast to NP 2010, SMR licensing needs to consider two fundamentally different options: the "new" licensing process, Part 52, created in 1989 to resolve problems in the prior Part 50 process, or potential use of the older Part 50 for reasons unique to FOAK SMRs.

DOE, industry, and NRC have been discussing the merits of Part 50 versus Part 52 for SMR licensing for over a decade, dating back to the earlier SMR designs discussed above. There are differing industry opinions as to whether the Part 50 or the Part 52 approach is better suited for licensing the first advanced reactors. A consensus exists that the second and subsequent reactor units should be licensed under Part 52. The question that lacks consensus is, "Should the first unit (or the first unit of each unique SMR design) be licensed under Part 50 or Part 52?" A Part 50 demonstration of the first unit would in effect be a prototype demonstration, followed by design certification and multiple COLs under Part 52 for all units to follow. The Part 50 demonstration of the first unit would involve obtaining a construction permit from NRC that could be based on less design information than is required for design certification or COL under Part 52. This would be followed by construction and development of sufficient additional design information for ultimate approval by NRC of an operating license. The use of Part 50 does allow the construction phase of the project to proceed at an earlier date, but with the risk that subsequent design changes (e.g., determined during the detailed design, manufacturing engineering, or construction engineering) might require construction rework and schedule extension.

Part 52 was the clear choice for GEN-III+ designs because of their maturity, near-complete coverage by existing technical regulations, and NRC staff familiarity. However, SMRs lack operating experience and detailed applicable regulatory guidance, and thus might be more likely to consider using Part 50. The more immature the design, the more likely that Part 52 would be a difficult option for a FOAK plant.

Note that B&W intends to use Part 50 to license its mPower SMR design—a design based largely on proven technology.[21]

Several considerations will influence the decision to license SMRs under Part 50 versus Part 52, including the applicant's assessment of the process for making changes during construction under Part 52 and the not-fully-tested inspections, tests, analyses, and acceptance criteria (ITAAC) process. Both these areas were identified in the NRC's 2014 self-assessment of post-COL performance. The industry and NRC are applying lessons learned from the lead Part 52 projects at Plant Vogtle and V.C. Summer to effect improvements in the plant change process, ITAAC process, and other areas for future Part 52 licensees. SMRs provide an opportunity to extend these improvements beyond that achieved for the larger plants. For example, expanding the ITAAC process into the manufacturing facility will help complete these milestones earlier in the process and reduce ITAAC risks in the field. Having retooled its

21. Also note that B&W and TVA recognize the disadvantages of the Part 50 approach—namely, the uncertainty in licensing the second reactor. To counteract this, they plan to develop and request NRC review of the Part 52 certification in tandem with the Part 50 review, so that the two licenses are essentially the same in content. TVA would not likely begin construction until the design certification approval was assured. This reduces the significant schedule advantage of the construction permit/operating license approach.

processes to review applications under Part 52, another factor in an SMR applicant's decision to license under Part 50 versus Part 52 may be the NRC staff's readiness to review applications for construction permits and operating licenses.

Strategy 4: *Facilitating Standardization*

Standardization of designs, construction technologies, licensing strategies, and plant operations (once in commercial operation) has tremendous cost-saving potential. Much has already been done in this area. For example, each SMR vendor is committed to standardizing its fleet of SMRs in both design and licensing. NEI and NRC are working to resolve common policy issues on a generic basis so those resolutions can apply to all future SMRs. However, additional opportunities for standardization exist that have not materialized. In the licensing space, opportunity remains to standardize the resolution of technical issues that can apply to multiple SMR designs. The Utility Requirements Document recently released by the Electric Power Research Institute should make a significant contribution here. In addition, there are opportunities to conduct generic R&D aimed at resolution of open technical and licensing issues, as well as construction issues, which could apply to multiple SMR designs. The AMM Roadmap should help develop common construction and fabrication cost-saving strategies. Another opportunity for common R&D relates to testing requirements to satisfy regulatory or code-based issues of a generic nature. A common test facility could serve the needs of multiple SMRs for such issues. Also note the following relevant discussion from the AMM Roadmap:

> *NRC expects approval by appropriate codes and standards bodies as a prerequisite to its regulatory approval. DOE and the AMM Working Group recognize that the development of technology is only the first step in providing industry with implementable usable processes and products. The high degree of regulation in the nuclear industry requires that processes or products used in nuclear plant construction be approved*

by codes and standards setting bodies that develop their requirements through consensus based rules. AMM recognizes the need for its technology developments to meet the requirements of these rules. All R&D must consider how it will develop acceptance by these bodies. DOE interfaces with NRC both directly and via the Nuclear Energy Standards Coordination Collaborative (NESCC).

The NESCC is a joint initiative of the American National Standards Institute (ANSI) and the National Institute for Standards and Technology (NIST), to identify and respond to current needs of the nuclear industry. NIST is an arm of the Department of Commerce. NESCC was formed in 2009 by ANSI and NIST to facilitate and coordinate the timely identification, development, and revision of standards for the design, operation, development, licensing, and deployment of nuclear power plants. Standards for other nuclear technologies, including advanced reactor concepts, are also addressed. NESCC is open to all stakeholders, government, legislative, and regulatory bodies, industry, standards developing organizations, certification organizations, and other interested parties. DOE-NE co-chairs its meetings.

Clearly, efforts by the Department of Energy, the Nuclear Regulatory Commission, the AMM Working Group, EPRI, the Nuclear Energy Institute, and other organizations in this important forum, especially focused on generic code and regulatory issues, will benefit all SMR designers and represent a further advantage to standardization efforts. Further, with the potential for even longer extended operating cycles for SMRs, advance work is needed on codes, standards, and regulations that could inhibit the use of longer cycles, such as periodic maintenance and testing requirements.

Major lessons were learned during NP 2010 regarding the benefits of standardized licensing processes for plants of the same design, especially during the COL phase. All applicants seeking a combined license using a specific design were organized in design-centered working groups where common issues were identified and resolved a single time for the "reference COL application" and for all subsequent COL applications for that design. This process should be followed for SMRs.[22]

Strategies that could reduce plant staffing requirements are also important to cost control. Some key opportunities in this area are already being evaluated by NEI and NRC, particularly related to security requirements.

Further, a major effort and creative thinking about designing a streamlined and standardized operating organization for SMRs will pay dividends. Staffing represents about 80 percent of a nuclear plant's O&M cost and could be a deciding factor in competing with other types of energy sources. Some work on this has already started, especially when staffing requirements are dictated by regulation. For example, NEI is working with NRC on options to address control room staffing and security requirements for SMRs. Optimizing the operating organization also includes reviewing maintenance and engineering functions, where state-of-the-art technology can be applied during the design phase, including computerization, automated and passive security measures, digital controls, materials that have minimal non-destructive examination requirements, and access to equipment for testing and maintenance. The ratio between contracted and permanent staffing can be optimized by exploiting opportunities for rotating maintenance crews among SMR modules. This would allow the same utility staff to repeatedly perform maintenance operations, gaining efficiencies and maintaining quality through standardization. High-cost contract staff, which often has rotational assignments or turnover, can be avoided, resulting in O&M savings.

The now completed SMR Utility Requirements Document will increase the degree of standardization in technical and operational areas and add efficiency and stability to the regulatory process for all issues identified and resolved generically. These utility requirements address issues beyond the licensing scope of SMR designs and should enable further cost reductions, since the utility executives who advise and approve

22. The process can be followed for mPower under the first FOA, but not the second FOA, which does not allow for COL applications.

these requirements are focused on the economic as well as the safety performance of the designs. Utilities tend to manage cost impact decisions on a life-cycle cost basis—that is, they seek to reduce the overall life-cycle costs of a plant, not merely the initial construction costs. For example, utilities will seek to build into SMR designs certain features that improve maintainability, such as adequate laydown space for repairs, built-in inspectability for structures, systems, and components, and equipment diagnostics.

Other Strategies to Reduce SMR Costs

Other strategies beyond advanced manufacturing, R&D demonstration, improvements in licensing, and standardization can be used to reduce the cost and schedule for SMR deployment. For example, several design features that are advertised by some SMR designers as adding significant safety or environmental benefits should be reexamined to make sure the benefits warrant the added cost. Cooling water system design is a prime example of this situation. Dry cooling was encouraged by the second FOA, but this capability adds to both capital and operating costs, and it could reduce nuclear safety margins.[23] Another example is underground siting. Burying reactors below grade adds significantly to cost and schedule. An objective review of this policy might determine that partial embedment (in contrast to full embedment) might afford the same benefits at reduced cost. Other technologies that could help reduce cost include greater use of digital instrumentation and controls, computerized seismic design, use of HTPE (polymer) piping for underground applications, and advanced concrete technology.

The policy recommendations provided in the International Trade Association (Department of Commerce) report discussed above, related primarily to obstacles to international markets for SMRs, should be

23. “Tradeoffs Between Once-Through Cooling and Closed-Cycle Cooling for Nuclear Power Plants,” EPRI-TR-1025006, June 2012. See pages 2-14 to 2-18.

addressed in the SMR roadmap, solutions to which would afford significant cost and schedule benefits.

If SMR siting on department of Defense or Energy sites becomes a feasible strategy, then the SMR roadmap should facilitate interface requirements for such sites, including means to reduce costs.

Further, financial incentives need to be analyzed in greater detail. Which of the Energy Policy Act of 2005 incentives in existence today apply to SMRs—e.g., does the production tax credit ($18/megawatt hour) apply to SMRs or only large ALWRs? If not, does Congress need to extend this incentive? Are new incentives needed? Can SMRs be included in a federal clean energy standard, if one is implemented? Can SMRs be included in states' renewable portfolio standards, which today have significant impacts on utility supply decisions? The SMR subcommittee reports discuss various options in some detail.

The Nuclear Energy Advisory Committee subcommittee on reactor technologies recently reviewed the issue of federal and state impacts on the competitiveness of nuclear energy from the perspective of current plant closures. They considered the impacts of various market defects[24] on both currently operating plants and future LWRs under construction or planned, including SMRs. Initial recommendations were focused on current plants, including a call for an interagency task force at the federal level to help promote regional and state policy that would influence public utility commissions and the load-serving entities to create electricity markets that take into account key attributes, such as fuel source diversity, electric supply reliability, and environmental sustainability. The subcommittee felt that the federal government could influence states' inclusion of nuclear power as a new plant option by the policies and regulations that it sets via the Federal Energy Regulatory

24. Competitive electricity markets are not producing price signals sufficient to stimulate investment in new generating capacity, with the exception of gas-fired plants, or to support continued operation of existing capacity. Prices are being suppressed in various ways, including the unintended consequences of state and federal mandates and subsidies (e.g., renewable portfolio standards) as well as actions by the regional transmission organizations.

Commission and the EPA. It was felt that if the federal government were to move in a more supportive way relative to nuclear power, then the states would follow suit.

The Overarching Strategy: Developing a Government-Industry Roadmap for SMRs

Provision for a roadmap was a key lesson learned from NP 2010: "Development of business cases and, most importantly, a roadmap of activities in the early phases of the NP 2010 program were essential."[25] This lesson parallels the recommendation of the SEAB subcommittee on SMRs, "that the Secretary of Energy charter an integrated government SMR strategy after there is more clarity concerning the many uncertainties surrounding the commercialization of SMRs."[26]

The development and implementation of an SMR roadmap is needed now because US initiatives are not keeping up with market realities and are drifting away from commercialization-focused, market-driven decision-making. Assessments by the SEAB SMR subcommittee and others agree that widespread deployment of SMRs will require an integrated government-industry strategy for success. There are actions that DOE and industry can take now to reduce the cost and schedule of building SMRs, to accelerate the learning curve, and to further promote widespread deployment. SMR strategies today are focused almost exclusively on licensing, overlooking other critical factors in the SMR business case.

> *SMRs have the potential to make significant contributions to meet national priorities for clean energy and national security. Realizing this potential will require overcoming challenges to commercialization including licensing of new reactor technologies and presenting an economic case*

---

25. "Nuclear Power 2010 Program: Combined Construction and Operating License & Design Certification."

26. "A Strategic Framework for SMR Deployment."

> *that will lead to widespread adoption by power producers. A four-phased framework beginning with licensing and progressing through first movers, early adopters and eventual full-scale factory production helps to identify which challenges might appear throughout the development process and identify possible government policies that may be suitable in support of advancing the Nation's interest.*[27]

The primary goal of the proposed SMR roadmap should be to greatly increase the prospects for widespread deployment of SMRs in the United States and overseas markets. The roadmap should be proactive, seeking aggressive and creative strategies for widespread SMR deployment. A window of opportunity exists with "old-coal" replacement as a primary mission for SMRs that cannot wait for a decade-long reactor development program. Further, growing international competition in SMR designs dictates an aggressive American program aimed at achieving US superiority by being first-to-market.

The SMR roadmap should be based on a thorough assessment of the barriers to successful widespread deployment. The assessment should be comprehensive and include technical, policy, economic, and environmental barriers. It should rank them to the extent needed to prioritize actions to resolve them. The SMR subcommittee emphasized the need for an *integrated* strategy. This suggests a roadmap that is both comprehensive in scope and complete in terms of meeting *both* industry and government needs.

The roadmap should serve as a strategic plan. It should contain schedules, near-term milestones, and specific accountabilities to industry and government stakeholders to complete milestones successfully and on schedule. These milestones should include technical and programmatic objectives as well as financial, institutional, policy, and public/policymaker communications objectives. This paper attempts to create the vision and lay the groundwork for an SMR roadmap without encroaching on the responsibilities of the team that must be assembled

---

27. Ibid.

to develop it. Hence, the strategies listed above and the direction and scope articulated below are *suggestions* by the authors. The roadmap team must chart its own course.

The SMR roadmap should be technology-neutral, but focused on integral PWRs. It should address the needs of *all* potentially near-term deployable SMR designs, i.e., those based on LWR technology. It should not be limited to supporting the two SMR designs selected for funding under the LTS program. Utilities desire and benefit from competition among reactor designers; a number of utilities were supportive of the two SMR designs not selected by DOE, both of which have significant market potential.

The SMR roadmap should articulate a candid assessment of nuclear energy's path forward and show how actions by DOE and industry can encourage widespread deployment. It should articulate a realistic and objective plan for success. It should aggressively and proactively seek opportunities, large and small, to improve SMR economics. It should investigate all success paths, thinking logically and creatively.

The SMR roadmap's assessment of market conditions should include analysis of alternative scenarios that help illuminate the types of actions that might be needed. In particular, economic assessments should include various natural gas price scenarios and various new environmental regulations and their impacts on both coal and natural gas pricing, as well as likely timing for retirements of existing assets. Renewables impacts should be included in the assessment as well. The roadmap scenarios should recognize that the window of opportunity to replace retiring coal plants is probably five to ten years away, not fifteen to twenty. Can SMRs be ready for a massive construction program that early? If not, what strategies could still allow for some penetration into this market? The SMR subcommittee envisioned deploying upward of fifty gigawatts of SMR power plants in the United States to replace old, small coal-fired plants currently in operation. This might be achieved in the 2040 timeframe, when a mature factory-based industry could achieve a total output on the order of fifty SMRs per year. How credible are these goals, and what supporting technologies and infrastructure would be needed to achieve them? What build rate could be achieved by 2025, assuming significant coal retirements still remain for SMRs to backfill? Where are the market opportunities overseas? What is the timing of these market needs?

Note that NP 2010 needed a roadmap back in 2001 to get going. The SMR situation is different. The SMR LTS program was launched successfully; what is needed today are comprehensive strategies that reach far beyond the LTS program to achieve widespread commercialization. This must include greater attention to US and global market needs, greater attention to NP 2010 lessons learned, greater attention to the SMR business case, and greater attention to FOAK engineering.

Engaging senior industry executives and experts in this process is essential to success. This will identify those critical elements of a strategy that are essential to successful deployment from the perspective of investors who will own and operate these facilities. It will bring a wealth of operating experience to the process, enabling further refinements in design and construction to assure consistent safety, reliability, and performance standards for all SMRs. This consistency in market expectations for SMRs will be aided by the revision to the Utility Requirements Document, with specific provisions for small modular LWRs, further assuring market-based apples-to-apples comparisons of competing designs and greater regulatory stability.

An SMR roadmap effort must be led primarily by industry, and specifically by utility experts with in-depth understanding of electricity markets, new plant design and licensing issues, and legislation. The roadmap could be "chartered" by either industry or government, specifically DOE.

One model for a utility-led but DOE-chartered roadmap was the Near-Term Deployment (NTD) Roadmap, prepared in 2001. The NTD group reported to the appropriate Nuclear Energy Advisory Committee subcommittee of that era, and was chaired by two senior utility executives and staffed largely by industry experts, with modest university and laboratory representation. The NTD group met with individual reactor designers to obtain input on barriers to progress and recommended solutions. It also sought out sufficient information on individual designs and associated business and licensing plans to evaluate commercial deployment potential. The group evaluated all the obstacles to widespread deployment, and then proposed a comprehensive set of recommendations to resolve them.

The best model for a utility-led and industry-chartered roadmap was the "Nuclear Power Oversight Committee Strategic Plan for Building New Nuclear Power Plants" first published in 1990 and updated annually for almost a decade, setting the stage for NRC design certification of ALWRs. The committee transitioned in 1994 to an ad hoc committee reporting directly to the NEI executive committee. It worked closely with a utility-led and EPRI-staffed Advanced Reactor Corporation, responsible for completing FOAK engineering for two selected ALWR designs on a cost-shared basis with DOE. These efforts were early precursors to the NP 2010 program.

Whether chartered by industry or by DOE, the roadmap should rely on or engage key industry stakeholders to better address market needs. These include NEI's SMR Working Group and NEI's SMR Licensing Task Force. These also include the EPRI Advanced Nuclear Technology Steering Committee and the American Nuclear Society SMR Special Committee. Key utility leaders on these committees are prime candidates to lead the SMR roadmap committee, with attention paid to selecting individuals with no apparent conflicts of interest linked to any single SMR design.

Summary: Proposed Scope and Content of SMR Roadmap

The roadmap effort should be led by utility executives and focused on widespread commercialization, incorporating lessons learned from NP 2010. It should be nuclear technology-neutral, addressing the needs of all near-term deployable SMR designs. Specifically, it should target all four of the initial integral PWR competing designs and seek engagement by proponents of all four. It should include the following:

- Thorough assessment of market conditions, including pros and cons of SMRs relative to competing technologies, global markets, evolving factors (environmental requirements, fossil fuel availability, and costs) that could affect SMR competitiveness, with evaluation of various scenarios.
- Thorough assessment of barriers to widespread deployment, including projected capital and life-cycle costs, economies of scale considerations, availability of financing, licensing hurdles, barriers to export (policy, regulatory, and institutional), infrastructure shortcomings, and nuclear fuel cycle policies, addressing, in a comprehensive way, barriers to global deployment.
- Assessment of individual SMR designs and their capabilities to address these barriers, including associated timelines, business plans, licensing plans, costs, and resource requirements.
- Thorough assessment of policy and financial incentives for SMR deployment, focusing on those incentives that provide maximum benefit at lowest cost to taxpayers, including (but not limited to) loan guarantees, power purchase agreements, construction work in progress (primarily a state issue), and tax credits, resolving the current problems with DOE's loan guarantee program and conducting similar assessment of possible in-country incentives for global markets.
- Thorough assessment of means to improve prospects for widespread deployment, including:
  - Means to accelerate and exploit the learning curve, including advanced manufacturing, factory fabrication, and computerized design.
  - Means to support needed investments in infrastructure, including but not limited to investment tax credits for manufacturing facilities, and actions from the studies by PCAST of US competitiveness in manufacturing.

- Means to engage future owner/operators in program decisions, technology assessments, and user-defined design and operational requirements. Means to maximize private sector investment in SMRs, including cost-sharing of LTS program costs and first-of-a-kind engineering costs.
- Timely resolution of licensing issues (including both generic policy issues and design-specific technical issues) and opportunities to streamline the licensing process, e.g., through a more risk-informed process.
- Specific opportunities to enhance standardization to reduce costs and enhance stability.
- Resolution of barriers to global deployment, including resolution of US export control issues and nuclear liability issues in certain countries.
- Specific actions by the administration or Congress, including policy leadership and legislation. These actions include (but are not limited to) recommendations from the above assessment of policy and financial incentives, addressing fuel cycle issues.

- Schedules, milestones, and specific accountabilities assigned to industry and government stakeholders.

Large-scale deployment of SMRs offers many potential strategic advantages to the United States. We believe the time to act is now.

Visit Hoover's Reinventing Nuclear Power project online to view a companion slide deck with diagrams and specifications for five SMR designs from mPower, NuScale, Holtec, Westinghouse, and KAERI: *http://www.hoover.org/reinventing-nuclear-power.*

Appendix A: DOE-NE-Specific Actions on Advanced Manufacturing

The AMM initiative, if implemented, would be expected to provide the following benefits:

- Reduce cost and schedule for new nuclear construction and make fabrication and manufacture of nuclear plant structures and components faster and cheaper, with equal or better reliability.
- Restore the US position as a manufacturer and constructor of nuclear power plant designs both domestically and worldwide.

From the AMM Roadmap executive summary:

The future of the SMR Initiative depends heavily on our ability to reduce the cost and schedule *for new nuclear construction. We must make fabrication and manufacture of nuclear power plants faster and cheaper, with equal or better reliability than the current state-of-the-art in power plant construction. Efforts to date to both define the strategy and identify the most promising technologies that can achieve these goals suggest that* innovation *in new,* advanced *manufacturing methods is critical to success.*

It is with this understanding and foresight that the DOE's "Nuclear Energy R&D Roadmap," published in April 2010, articulated its new reactor technology goal with economics *in mind.*

> ***R&D Objective 2: "Develop improvements in the*** **affordability of new reactors** ***to enable nuclear energy to help meet the Administration's energy security and climate change goals."***

The AMM Roadmap identifies the most important generic AMM technologies that should be pursued initially. These AMM technologies are grouped in seven areas or "bins":

- factory and field fabrication
- welding and additive manufacturing
- heavy section manufacturing

- concrete
- coatings and cladding
- advanced configuration management
- lessons learned, tech transfer

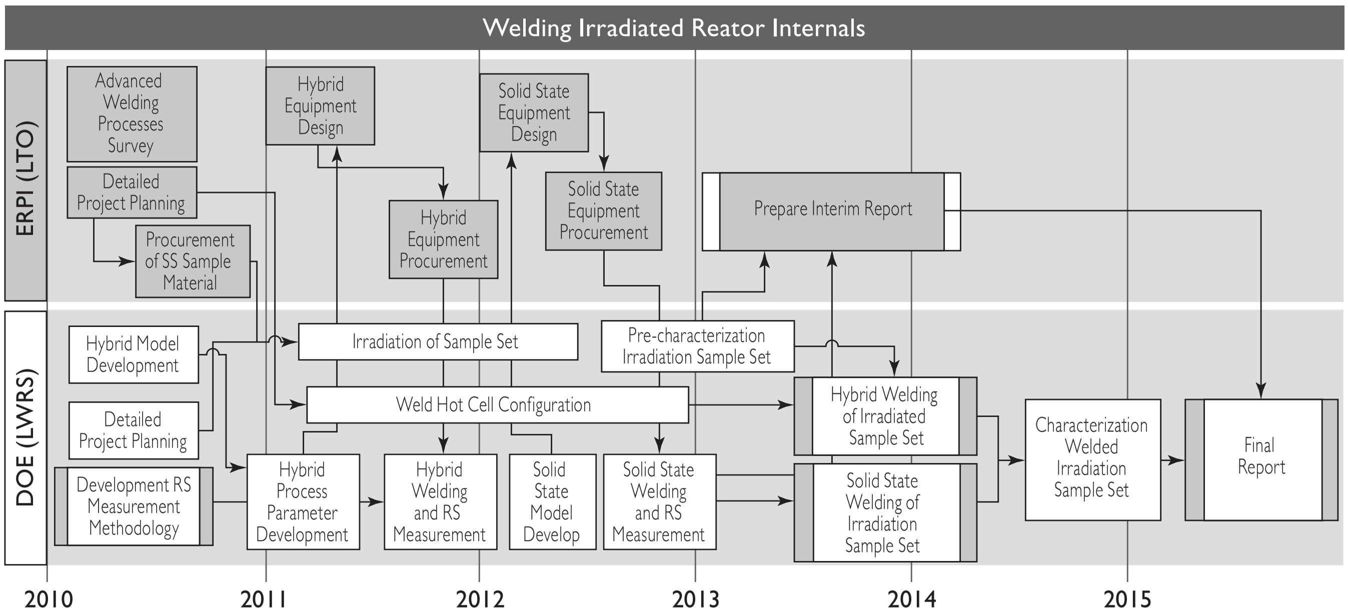
The above generic R&D categories were intended to be supplemented using additional market assessments by the AMM Working Group, working closely with the SMR vendors. This would allow incorporation of design-specific technology development and demonstration tasks for their designs, as well as expedited code approval for use by SMRs of technologies that have been developed but not yet approved for use. (See above discussion of NESCC activities under "Strategy 4, Facilitating Standardization.")

Each of these seven technology areas should be managed as an aggressive, highly directed program, guided by industry experts who identify those projects with the greatest potential to help all SMRs.

An example of how the R&D for each of these technology areas could be organized is shown in appendix figure 1, which displays how the DOE-NE LWR sustainability program manages welding R&D. Note how thoroughly integrated the DOE and industry (EPRI) programs are and how the R&D agenda is highly directed toward specific technology objectives.

The AMM Roadmap was completed in September 2012, but has not been published and implemented. It was prepared by the AMM Working Group under the direction of DOE-NE-72 (Office of Light Water Reactor Technologies).[28] It was then transferred to the new NE-4 organization (Office of Innovative Nuclear Research, under the deputy assistant secretary for science and technology innovation). All Nuclear Energy

28. The AMM Working Group chartered by DOE represents a broad segment of reactor system vendors, manufacturers, engineer/constructors, and R&D organizations, with technical expertise and direct end-user market experience and perspectives in manufacturing. Examples include representatives of shipyards with expertise in modular construction, Edison Welding Institute, and EPRI. All SMR vendors are represented.



APPENDIX FIGURE 1. Welding irradiated reactor internals

Process flow outline of cooperative research and development efforts between the Department of Energy and the Electric Power Research Institute.

Source: J. T. Busby, "Light Water Reactor Sustainability Program: Materials Aging and Degradation Technical Program Plan," September 2012, US Department of Energy, http://www.energy.gov/sites/prod/files/LWRS_Materials_Aging%26_Degradation_Technical_Program_Plan_September2012.pdf

University Program R&D was consolidated into NE-4 with this transition, along with the cross-cutting R&D programs identified collectively as Nuclear Energy Enabling Technologies (NEET). The "Crosscutting Technology Development" component of NEET is broken into five subprograms:

- reactor materials
- advanced sensors and instrumentation
- advanced methods for manufacturing
- proliferation and terrorism risk assessment
- nuclear energy advanced modeling simulation

Note that R&D results that are needed urgently to support near-term industry needs are being managed elsewhere for four of these five areas, most notably by DOE's Light Water Reactor Sustainability program. That allows NE-4 to focus NEET on longer-term research with primary reliance on university and laboratory researchers. AMM is the lone exception. Generic AMM R&D of an urgent nature is not being conducted anywhere in DOE-NE.

The AMM component of the NEET budget has been funded quite modestly since 2010. This slow start for such a strategically vital initiative is unfortunate, since the AMM program is the only DOE program that directly and explicitly addresses the "affordability" goal in the DOE-NE R&D roadmap (and thus is uniquely capable of contributing to the success of the SMR LTS program). From the AMM Roadmap:

> *Federal funding to the AMM Program should be stable, predictable, and sustained for five years or more, at a total annual funding level that reflects what industry can reasonably be expected to support with its matching funds. This level is yet to be defined, but is probably in the range of $10M/year to $20M/year over five years.*
>
> *100% of DOE-NE funding to AMM projects is currently allocated to proposer-driven R&D. The percentage of directed R&D, cost-shared by industry, should be increased to at least 50% by FY2014, using the*

"co-funded model" recommended by PCAST. This percentage should continue to increase subsequently, approaching 80% of total DOE investment in AMM.

Note that this type of highly directed program is not possible using the NE-4 management model, which relies primarily on proposer-driven projects by university teams, which may or may not mesh with the highest priority R&D needs to enable cost-competitive new reactor construction.

Experience gained from the AMM Working Group interactions with individual SMR designers suggests these designers are focused intently on NRC review and approval of their designs, not on manufacturing methods. They are not resourced or capable of conducting the R&D necessary to exploit the wide range of opportunities afforded by advanced manufacturing technologies. The conclusion of the AMM Working Group was that a generic initiative was needed to support all SMR designers.

Transitioning the program back to NE-72 would re-establish the essential close coupling between the SMR LTS program and the AMM program under common leadership. It would expedite the full implementation of the AMM Roadmap, vastly improving the chances for timely commercialization of SMRs. In addition, EPRI should be encouraged to address this critical need within its advanced reactor R&D program; and DOE and EPRI should reconsider the option to collaborate and cost-share this work.

Appendix B: NEI letter to President Obama

MARVIN S. FERTEL
President and Chief Executive Officer

1201 F Street, NW, Suite 1100
Washington, DC 20004
P: 202.739.8125
msf@nei.org
nei.org

NUCLEAR ENERGY INSTITUTE

December 12, 2013

President Barack Obama
The White House
1600 Pennsylvania Avenue, N.W.
Washington, D.C. 20500

Dear Mr. President:

On behalf of the U.S. nuclear energy industry, I am writing to express our concern about your recent order to all Executive Branch agencies requiring them to obtain 20 percent of their electricity from renewable energy sources by 2020. This order was a component of your Administration's Climate Action Plan, published last June, and is intended to reduce America's carbon emissions.

We understand your Climate Action Plan to be a broad-based commitment to reduce carbon emissions – taking advantage of all energy sources – not just a mandate to promote only renewable energy. As you and others in your Administration have often said, nuclear energy can, and must, play a major role in any credible national plan to reduce carbon emissions and we believe it should be included in any Presidential mandate to federal agencies on procurement of carbon-free electricity.

America's 100 nuclear power plants represent 64 percent of the carbon-free electricity produced in the United States and dwarf the emissions prevented by all other energy sources. These plants are the only source of low-carbon electricity that can operate reliably around the clock. Relative to the sources of electricity that would have been used in their absence, America's nuclear power plants in 2012 prevented the emission of 570 million metric tons of CO_2, equivalent to taking 110 million cars off the road. In the absence of nuclear energy, the U.S. electric sector's carbon footprint would have been 26 percent larger. All credible analyses of this issue – by the Environmental Protection Agency, the Energy Information Administration and independent international institutions like the Intergovernmental Panel on Climate Change and the International Energy Agency – have demonstrated unequivocally that the United States and the world cannot achieve meaningful reductions in carbon emissions without preservation of our existing nuclear energy assets and large-scale construction of new nuclear power plants.

Given these facts, it is extremely disappointing that the mandate to federal agencies did not include instructions to procure electricity from nuclear power plants as part of the federal government's initiative to reduce carbon emissions. While renewable energy sources should be part of the mix of low-carbon sources, intermittent energy resources must always be backed up, typically by natural gas-fired electric generating capacity.

Your Administration has recognized the strategic importance of U.S. leadership globally to meet our non-proliferation, safety and environmental goals, and is advocating the export of U.S. nuclear technology, services and operational expertise. The Administration has also supported the public-private partnership to develop small modular reactors, and has worked with U.S. industry to conduct the necessary R&D to extend the life of our nation's 100 operating reactors. You have also recognized the critical role of our independent regulator, the Nuclear Regulatory Commission, and have nominated highly qualified, objective and experienced individuals to serve as commissioners. Given this record, we believe failure to include nuclear energy in your mandate for procurement of carbon-free electricity by federal facilities is a missed leadership opportunity, and one that would be embraced by consumers. Eight-five percent of Americans believe that nuclear energy should play a similar or expanded role in America's electricity portfolio in the next 10 years.

The companies that operate America's 100 nuclear power plants are part of a larger electric power sector that embraces and practices an energy policy based on diversity of technology and fuel supply. We regard this approach as one of the core strengths of the U.S. electricity supply system. All resources – natural gas, advanced nuclear, renewables, efficiency, hydro and advanced coal – can and must play a role in meeting America's electricity needs. You have expressed similar views in your public statements, which is why we expected this philosophy would be reflected broadly in the Administration's policies.

Thank you in advance for considering these comments. I would be pleased to discuss these matters further with your staff.

Sincerely,

Marvin S. Fertel

List of Acronyms

ALWR	Advanced Light Water Reactor
AMM	Advanced Methods for Manufacturing
ANSI	American National Standards Institute
COL	Combined (Operating) License
DOE	Department of Energy
DOE-NE	Department of Energy Office of Nuclear Energy
EERE	Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
EPACT-05	Energy Policy Act of 2005
EPRI	Electric Power Research Institute
FOA	Funding Opportunity Announcement
FOAK	First-of-a-Kind
GW	Gigawatt
GWe	Gigawatt electrical
ITAAC	Inspections, Tests, Analyses and Inspection Criteria
LTS	Licensing Technical Support
LWR	Light Water Reactor
MWe	Megawatt electrical
NEET	Nuclear Energy Enabling Technologies
NEI	Nuclear Energy Institute
NESCC	Nuclear Energy Standards Coordination Collaborative
NIST	National Institute for Standards and Technology
NRC	Nuclear Regulatory Commission
NTD	Near-Term Deployment
O&M	Operations and Maintenance
PCAST	President's Council of Advisors on Science and Technology
PWR	Pressurized water reactor
R&D	Research and Development
RPV	Reactor Pressure Vessel
SEAB	Secretary of Energy Advisory Board
SMR	Small Modular Reactor
TVA	Tennessee Valley Authority

About the Authors

Bill Madia is currently chairman of the Board of Overseers and vice president for the SLAC National Accelerator Laboratory at Stanford University. He retired from Battelle Memorial Institute in 2007 after a 33-year career. His last position at Battelle was executive vice president for mergers and acquisitions. Prior to that, he was responsible for Battelle's $4 billion, 15,000-person laboratory operations business.

Regis Matzie is a consultant to the international nuclear industry and works extensively with the US Department of Energy. He was formerly senior vice president and chief technology officer of Westinghouse Electric Company. His 35-year career has dealt with the development of advanced commercial nuclear systems and fuel cycles. He is a graduate of the US Naval Academy and retired as a captain in the naval reserves.

Gary Vine is a nuclear energy consultant working with Longenecker & Associates on a wide range of projects, primarily for the US Department of Energy. He served in various positions at the Electric Power Research Institute from 1981–2008, including program manager for the Advanced Light Water Reactor program and executive director of federal and industry activities. He holds a bachelor of science degree from the US Naval Academy and a master's degree from the US Naval Postgraduate School.

HOOVER INSTITUTION

SHULTZ-STEPHENSON TASK FORCE ON

Energy Policy

The Hoover Institution's Shultz-Stephenson Task Force on Energy Policy addresses energy policy in the United States and its effects on our domestic and international political priorities, particularly our national security.

As a result of volatile and rising energy prices and increasing global concern about climate change, two related and compelling issues—threats to national security and adverse effects of energy usage on global climate—have emerged as key adjuncts to America's energy policy; the task force will explore these subjects in detail. The task force's goals are to gather comprehensive information on current scientific and technological developments, survey the contingent policy actions, and offer a range of prescriptive policies to address our varied energy challenges. The task force will focus on public policy at all levels, from individual to global. It will then recommend policy initiatives, large and small, that can be undertaken to the advantage of both private enterprises and governments acting individually and in concert.

Contact for the Shultz-Stephenson
Task Force on Energy Policy:
Jeremy Carl, *Research Fellow*
(650) 723-2136
carljc@stanford.edu