A Strategic Framework for SMR Deployment

February 24, 2012

Introduction

A strategy for the successful deployment of small modular reactors (SMRs) must consider what the goals of deployment would entail, the challenges to achieving these goals and the approach to overcome those challenges. This paper will attempt to offer a framework for addressing these important issues at the outset of the program. The deployment of SMRs will be realized by private power companies making the decision to purchase and operate SMRs from private vendors. The government role is to set national priorities for clean energy and national security and create incentives to achieve them. The policy tools the government may choose to use to advance this technology in support of these national objectives will evolve as SMRs advance through the commercialization process. This strategic framework identifies four phases to this process and indicated policies that may be appropriate at each stage.

Goals for SMR Deployment

We put forward two overarching goals that dictate the pace and scale of a successful deployment. (1) The first SMRs will be built in the United States. This will enhance the opportunity to establish U.S. leadership in these technologies, ensuring that these new reactors conform to U.S. standards for safety and nonproliferation. Building the first SMRs in the U.S. will confer economic benefits by establishing a domestic supply chain that will be a source of stable employment and an engine for ongoing innovation in the industry. (2) Deploy upwards of 50 GW of SMR power plants in the U.S. to replace old, small coal-fired plants currently in operation as part of the broader market for baseload electricity. Deployment at this scale would make a significant contribution to the Nation's clean energy goals and the expected pressure to retire old coal plants provides a sizeable market opportunity for reactor vendors. This pace would likely entail multiple vendors operating multiple factories to meet demand.

These two goals require a strategy that can accelerate the commercialization of U.S. SMRs and address the challenges that can impede this technology from making a significant contribution to the Nation's energy objectives, both environmental and economic.

The Challenges to SMR Deployment

The challenges that could hamper the commercialization of SMRs could be enumerated at length, but for the purpose of laying out a high-level strategic framework, we will address two of the critical questions at the outset of the program. First, can these reactors be licensed in a timely fashion? Second, can SMRs produce electricity at costs that are attractive to potential power producers?

Licensing

The licensing challenge for new nuclear power systems is not unique to SMRs. The Generation III and III+ reactor designs now being pursued in the U.S. have undergone years of analysis and review at a cost measured in hundreds of millions of dollars even though these are essentially improved versions of well-understood light water reactor (LWR) technology that is employed at every reactor in the country. Even the proposed SMRs that use uranium fuel and water cooling will face additional scrutiny for the design and operational characteristics that are novel compared to their larger cousins. These unique and largely unstudied characteristics, from a regulatory perspective, include the integration of primary system components into the reactor pressure vessel, the passive recirculation modes with low coolant flows under operating and accident conditions, and the potential operation of multiple reactor modules from a single control room. For SMRs that are designed to use different fuels or coolants, the licensing challenges will be more daunting as the Nuclear Regulatory Commission (NRC) does not have staff with equivalent expertise in non-light water systems. Building a staff with this expertise and making the appropriate adjustments to the regulatory framework to address the unique operational and safety aspects of advanced reactors and fuel is likely to take years.

The NRC is currently taking steps to try to address some of the potential policy, licensing, and key technical issues that will impact the certification and licensing of both near-term and more advanced SMRs. The NRC has issued a series of papers focused on issues such as: siting SMRs, security requirements, operator staffing for multi-module facilities, and the defense-in-depth philosophy for advanced reactors.[1] These papers are the basis for engaging industry and others to explore the potential regulatory impacts of SMR design features and characteristics.

The potential barrier that licensing could pose to the commercial development of SMRs puts it at the forefront of strategic issues. Phase 1 of the strategic framework is focused directly on this challenge. Assuming this can be overcome, the next issue is to understand the potential for SMRs to compete in the marketplace. To assess this challenge, a quick review of the basic SMR business model may be useful.

Cost Competitiveness

The deployment premise for SMR power plants is that factory-fabricated reactor and building modules will be shipped directly to the power plant site and installed with relative ease compared to the challenge of building a large reactor on-site. These SMR power plants can be sized to meet the requirements of the utility, but the expectation is a facility that would produce up to 600 MW of electricity in configurations that range from a single reactor (300 MW or less) to a dozen smaller ones operated as a single power plant. The fundamental question when considering the economic potential of SMRs is whether the economic gains from factory fabrication of standardized nuclear reactors can sufficiently counteract the economies of scale that have traditionally driven nuclear reactors to larger sizes.[2]

The SMR approach is to try to reduce costs by building these complex reactors in controlled settings with dedicated machinery and an experienced workforce rather than at the plant site. While it is unlikely that the first SMR units will be competitive with larger units, the expectation

---

[1] NRC, *Security Regulatory Framework for Certifying, Approving, and Licensing Small Modular Nuclear Reactors*, SECY-11-0184, December 29, 2011; NRC, *Development of an Emergency Planning and Preparedness Framework for Small Modular Reactors,* SECY-11-0152, October 28, 2011; NRC, *Staff Assessment of Selected Small Modular Reactor Issues Identified in SECY-10-0034,* SECY-11-0112, August 12, 2011; NRC, *License Structure for Multi-Module Facilities Related to Small Modular Nuclear Power Reactors,* SECY-11-0079, June 12, 2011; NRC, *Operator Staffing for Small or Multi-Module Nuclear Power Plant Facilities,* SECY-11-0098, July 22, 2011.

[2] While SMR cost will obviously be important to potential purchasers, there are other factors that will be considered by these firms. The lower up-front cost of an SMR power plant may be a much better fit for the balance sheet of power producing companies, the companies may seek a diversified portfolio of generating technologies to minimize exposure to fuel price shocks, and the potential to expand capacity by adding modules to an SMR plant may all be significant factors as part of an SMR business case. 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.

is that a factory workforce that has the opportunity to repeat operations will maximize the potential for improvements through learning. These learning effects have been consistently realized in large manufacturing operations including U.S. nuclear navy construction programs. There are potential additional gains to be made in establishing standardized factory fabrication, including improved product quality and minimization of regulatory impacts through the conduct of in-factory inspections.

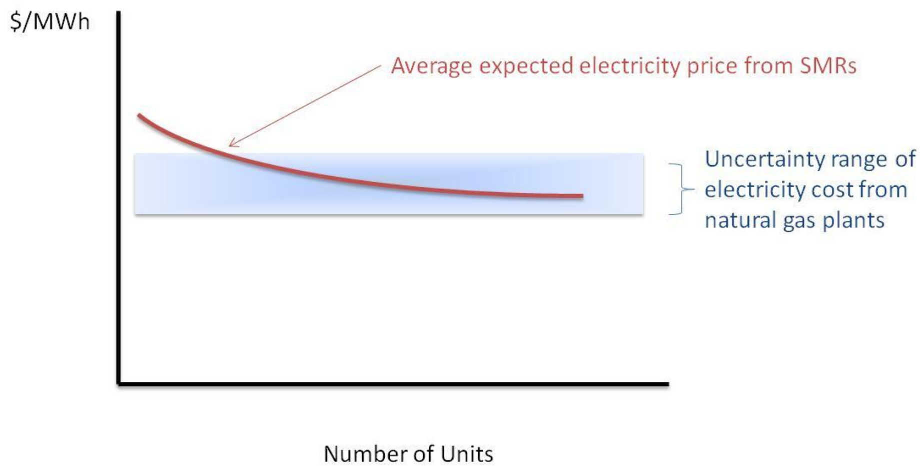

Figure 1 – Expected Evolution of SMR Economic Competitiveness

Figure 1 notionally depicts the expected evolution of the economic competitiveness of SMRs compared to electricity produced from natural gas power plants. There are two salient aspects of the figure that will shape the strategic approach. First, the downward curve of the cost of SMR electricity is a reflection of the expected improvements through learning. Second, the SMR electricity cost does not begin in the competitive range but does reach it as more units are built and learning effects are realized. These two characteristics indicate the need for a strategy that can lead to a sufficient level of construction to allow SMRs to be considered as an economically viable, clean energy option by power companies.

Four Phases to Commercial Deployment

Accomplishing these goals will require a multi-phased deployment from licensing through full-scale production and a strategy that adjusts along those stages. We lay out four phases each with a distinct goal but different policy tools may be appropriate for achieving those goals.

Phase 1 – Near-term Certification and Licensing

The first phase of the strategy is to address the licensing challenge described above. The goal for this phase is to complete SMR designs, see those designs certified by the NRC and have projects licensed to build and operate these reactors. Following the request of the Administration and approval from Congress, DOE has an emerging program to accelerate this certification and licensing effort. The five-year $452 million program will provide financial risk mitigation for the costs of working through the NRC review and approval process for up to two SMR designs and associated operating licenses. The successful conclusion of this phase should result in reactor designs that are of sufficient maturity to both meet the safety requirements of the NRC and serve as a solid basis for commercial contracting and cost estimation.

Phase 2 – Construction of the First Movers

While phase 1 is necessary to provide the initial momentum toward the widespread commercial deployment of SMRs, it may not be sufficient. If the first-of-a-kind SMR power plants produce electricity at costs higher than available alternatives, the market demand for the new technology may not materialize. Widespread deployment of SMRs implies commercial competitiveness; reaching the state of competitiveness may require incentives for market or non-market actors to bear the costs of learning. Phase 2 of the strategic framework is to encourage the construction of the first-of-a-kind SMR plants. These first movers will likely not have the benefit of full factory production as the manufacturing processes will be established through repetition. In fact, it is most likely that the components and modules fabricated for these first plants will be done on specification as prototype parts.

The government is well-suited to be the first purchaser of electricity from SMR power plants. Executive Order 13514 establishes ambitious greenhouse-gas reduction goals for Federal agencies[3] that could translate into a premium for clean energy that the government is willing to bear but is not currently valued by the private sector. The President's Council of Advisors for Science and Technology has called attention to the potential leverage that the government has to use its purchasing power to advance technologies that can support clean energy objectives.[4] A specific policy tool that would be applicable for such first movers would be for the government installations, such as DOE labs or military bases, to enter into power purchase agreements (PPA) with those local utilities that are willing to own and operate SMRs. The output from these SMR power plants would need to be at a price that would enable the utility to make the capital investment for the project. It is too early to discern how such PPAs should be structured but one could see a tradeoff with a high power price for a small number of reactors on one end or a smaller premium spread out over the certainty of a large number of orders on the other. It should be noted that there are specific restrictions limiting the length of PPAs with government facilities, and these limitations may need to be addressed in order to make these arrangements practical. Should it make sense for private entities in favorable markets to act as first movers, the policy tools identified in phase 3 may be appropriate.

Phase 3 – Early Adopters Leading to Factories

Once the first reactors have been built, the focus shifts to phase 3 – inducing early adopters in the private sector to fill an order book that will be sufficient to warrant the capital investment to establish a fully-configured, fully-staffed SMR factory that will begin working down the learning curve to lower the overall costs. This phase will see the industry transition from building the first units to developing the capability to produce SMRs at a sustained rate. As this transition takes place, suppliers would be expected to leverage existing, excess factory capacity from realms such as the U.S. naval shipbuilding industry. The vision is that by 2030, the industry will have built on the order of twenty units and dedicated factories will be in place leading to the final phase of the commercialization process.

The expectation is that this wave of orders will move beyond government purchases to those by private companies for electricity production in favorable markets. PPAs for government sites

---

[3] *Executive Order 13514 – Federal Leadership in Environmental, Energy, and Economic Performance*, published in the Federal Register October 8, 2009.

[4] President's Council of Advisors on Science and Technology, *Report to the President on accelerating the Pace and Change in Energy Technologies Through and Integrated Federal Energy Policy,* November 2010.

beyond the first movers will likely provide a subset of these early adopters. For utilities looking to sell electricity their broad customer base, government policies may be an important element of the deployment strategy by providing incentives for these companies. Policies to spur early adopters could include credits for the production of electricity from early SMRs, offsetting investment challenges through tax credits or some form of loan guarantee. Policies intended to spur manufacturing could be applicable to the investment decisions for building SMR factories. Wider-reaching proposals such as government corporations to demonstrate new energy technologies may provide additional opportunities for alleviating constraints, as well. This range of policy tools would almost certainly require broad Congressional support and action.

Phase 4 – Sustained Factory Production of SMRs

As initial factories are improved and expanded and new ones are built, the mature industry could result in a total output on the order of 50 SMRs per year by 2040 or sooner. This account presumes that most of the deployment is targeted for the U.S.; however, should a vibrant export market materialize – a distinct possibility – the throughput would need to scale accordingly. There may be a role for public policies in this phase, but they would be less about the development of SMR technology than promoting the domestic use of clean power. The appropriate policy tools in this stage would be those that seek to fundamentally reshape how energy is used in the economy over the long-term such as a carbon tax, a cap and trade system, or clean energy standards. In addition, in order to promote the development of domestic manufacturing sector, the government could consider the use of manufacturing tax credits or other such incentives to bolster this segment of the economy.

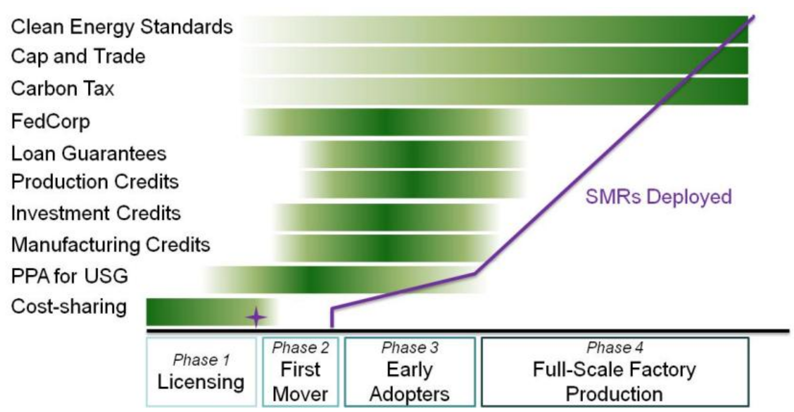

Figure 2 – Development Phases and Policy Tools

Uncertainty and the Role of Government

The stages of deployment and the potential policy tools attributed to those stages are depicted together in Figure 2. While not all of these policies/tools would be needed at the same time, a subset of them could be combined to create an appropriate strategy to advance SMRs in support of national objectives. Any strategy that is conceived is based upon an expectation of how the technology will evolve. The key aspects of the framework described above are that SMRs are not expected to be immediately competitive in the commercial market but will become so through learning effects realized through factory fabrication as well as the repeated engineering and construction of standardized designs. This expectation must be subject to reevaluation and analysis as the development program progresses.

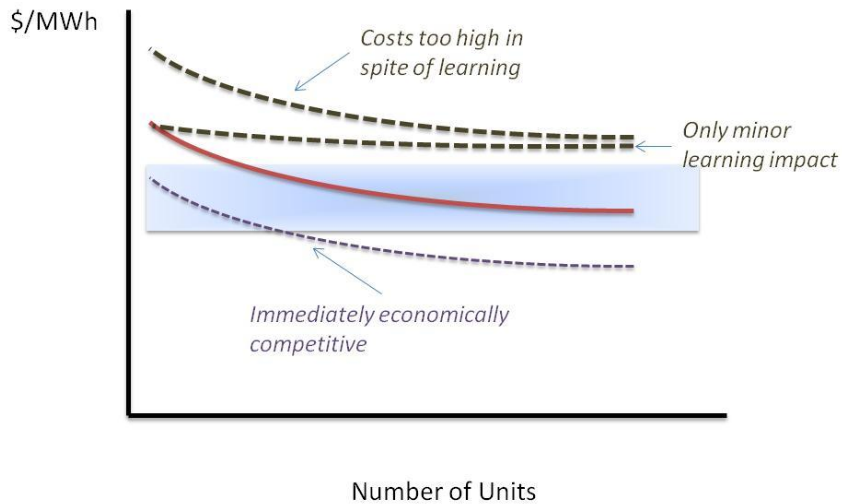

Figure 3 - Alterative Possible SMR Economic Evolutions

If the premises on which the strategy is based do not hold, the need and appropriateness of the policies within the strategy need to be reconsidered. Figure 3 highlights three possible outcomes that would lead to reexamination. If it were to turn out that even the initial SMRs were economically attractive then the need for policies intended to promote commercial adoption of SMRs would likely not be needed. On the other hand, if the economics of SMRs look less favorable either because the initial costs greatly exceed the market rates or learning effects do not materialize, then the strategy would need to reconsider whether public investment will ever yield deployment on a scale that will make a sufficient impact on the Nation's goals.

This reassessment process is necessary but difficult because all of the components are likely to be in flux over time. Predicting fossil fuel prices is notoriously difficult and combining that with forecasts of whether policies such as a carbon tax might be introduced make it even more challenging. Cost estimates for new technologies often shift as details are spelled out and commercial terms are reached. The program will seek to reduce these uncertainties to the extent it can by soliciting updated cost estimates from vendors on a regular basis and conducting related economic studies to better assess the possible improvements from factory manufacturing and learning effects. Recognizing these uncertainties is part of a strategic process. Formulating strategies in the face of these uncertainties will be an ongoing challenge as the Nation seeks to realize the benefits that the widespread deployment of SMRs would provide.

Advanced Reactor Technologies

This framework has focused on reactors that could be operational within the next decade but there are promising advanced reactor technologies being developed that may be ready for commercialization after that window. DOE continues to support R&D on advanced reactor concepts such as fast-neutron systems that may provide capabilities that support improved fuel cycles and high-temperature systems that could expand the market for nuclear power. These concepts rely on different coolants and fuels with which there is less commercial operating experience.

As advanced SMR concepts approach commercialization, the policy framework laid out for the near-term SMRs could be adapted to bring them to the marketplace. Doing so, however, will require a fresh analysis of the business models being proposed to assess which incentives might be appropriate at which point. The model at the heart of the near-term SMR deployment is the learning cost dynamics and the phases identified above reflect this approach. Should the business case for advanced reactors be built around other characteristics, such as fuel cycle services or process heat markets, then what will be needed to reach commercialization may be different.

Summary

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 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.