DOE SMR Workshop - The Pathway to SMR Commercialization

Bethesda, Maryland

June 22 and 23, 2016
Report and Stakeholder Recommendations

DISCLAIMER

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Introduction

Background

The past decade has seen the global emergence of nuclear reactor technologies that are designed as smaller and more flexible plants than the large 1,000 megawatt versions that currently dominate the baseload power landscape. These Small Modular Reactors (SMRs) will employ passive safety features, have fewer parts and components, operate with smaller nuclear cores (and thus smaller source terms), and leverage their modular design to be constructed faster and at less capital cost to the customer. The plants are expected to be a better match for replacing aging and retiring coal plants in the range of 200-500 MWe, and can be deployed more readily in areas that currently are not feasible for the larger plants.

Since 2012, the U.S. Department of Energy (DOE) Office of Nuclear Energy (NE) has been supporting the development of domestic SMR designs through the SMR Licensing Technical Support (LTS) program. The SMR LTS program is designed to help accelerate the deployment of these clean and innovative technologies into the commercial power production arena. The program has provided financial assistance for SMR design development toward one or more license applications to the U.S. Nuclear Regulatory Commission (NRC) for Design Certification, and separate applications for an Early Site Permit (ESP) and a Construction and Operating License (COL). The support provided by the SMR LTS program has generated considerable momentum in the industry. As this initial licensing support program approaches completion, DOE determined that it should evaluate further initiatives to support efforts to bring U.S. SMR technologies to commercialization.

To gather input from the nuclear industry on potential options to support SMR commercialization, DOE sponsored a comprehensive workshop on June 22 and 23, 2016. The Department retained consultants Jack Lance and Bruce Landrey to plan and facilitate the workshop, prepare this report, and identify future program options. Mr. Lance is the former Director of Applied Engineering at Idaho National Laboratory. Mr. Landrey is a former executive with NuScale Power and the Tennessee Valley Authority. The workshop included participation from domestic SMR vendors, utilities, companies supporting the nuclear supply chain, national laboratories, universities, government agencies, and industry-related professional organizations. More than 120 representatives from these organizations registered to attend the workshop. The first day addressed the question of what manufacturing techniques, capabilities, or process improvements could provide the most significant benefit to improvement of SMR economics, and how to accomplish the transition from prototype fabrication capability to a robust SMR manufacturing enterprise. The second day addressed the question of what SMR capabilities should be developed further to improve the global marketability of SMRs. Participants were asked to consider SMR-focused concepts that support the development of many non-electric applications; the use of SMR-generated process heat in various industrial and community environments, capabilities to deliver secure power to critical missions, improvements in load-following capabilities to support grid stability, and the use of SMRs as a component of hybrid energy systems, are examples.

The results of the workshop are intended to help inform DOE of future research, development and demonstration needs that can support the development of a domestic SMR industry, with the ultimate goal of positioning U.S. SMRs to succeed globally. The commercialization of U.S. SMR technologies will further the Administration's "all of the above" clean energy strategy, contribute toward meeting national climate and clean energy goals, and facilitate U.S. industrial competitiveness.

Workshop Proceedings

The workshop was structured to provide industry input to the Department in a logically sequenced manner, addressing the micro-level (manufacturing and fabricating components and plants) needs on the first day and the macro-level (SMR system capability) needs on the next day. The workshop opened with a discussion of DOE's Gateway for Accelerated Innovation in Nuclear (GAIN) initiative. DOE established GAIN to provide potential industry partners with opportunities to access the technical, regulatory, and financial support necessary to move innovative nuclear energy technologies toward commercialization. The discussion provided potential DOE partners with insight into opportunities to access the unique capabilities of the DOE laboratory system to accomplish innovative research and development projects that can more effectively bring these concepts to market.

A presentation from the Nuclear Energy Institute (NEI) discussed the industry-led "SMR Start" initiative, and its strategy to support SMR commercialization. SMR Start's fourteen members include utilities and SMR technology developers. NEI further clarified the challenges facing SMR deployment and reiterated the need for advocacy, industry focus and continued Government support at the federal and state levels. Nuclear power and SMRs have a number of attributes that should be given value by the market and policy makers, according to NEI, but are not. These start with the fact that nuclear is carbon-free, and include grid and price stability, 24/7/365 operation, and fuel and portfolio diversity. A key point made by NEI was that successful deployment of the lead SMR plants is needed to spur continued domestic development, and to position the U.S. as a global leader in SMR technologies. NEI also pointed out that all international competitors in the SMR and nuclear markets have the financial and business development backing of their governments. As a result, NEI said it is imperative that the U.S. government and DOE make a major investment to support the commercialization of SMRs to ensure that the U.S. remains competitive in the global SMR market.   NEI further stated that U.S. government support for SMR commercialization will create a new industry segment, which will result in tax revenues, jobs and local economic benefits, an increase in U.S. exports and manufacturing jobs, and strengthen efforts to reduce carbon emissions.

DOE provided an overview of its current advanced manufacturing technology development projects, including industry-generic research on additive manufacturing, welding and joining, concrete material and rebar, surface modification and cladding, and data configuration management. The discussion provided participants with insight into the activities DOE is already supporting, and how those activities might mesh with efforts to commercialize SMRs.

Staff members from both the House and Senate provided their viewpoints on the state of the nuclear industry, and described current Congressional support for SMRs. The speakers were invited to stay for the workshop to see and hear the industry's thoughts on the current challenges facing SMR deployment, and to better understand DOE's plans to incorporate industry ideas into its program planning process. The speakers confirmed that there is bicameral and bipartisan support for SMR development. They said that several pieces of legislation have been introduced that are intended to reform the nuclear regulatory process, enhance U.S. capabilities to develop new reactor technologies through high-performance computation, and enhance the economic viability of nuclear as a clean, efficient power source. These actions, including the Nuclear Energy Innovation and Modernization Act, the Nuclear Energy Innovation Capabilities Act, and the Energy Policy Modernization Act, are the most significant pieces of legislation in support of nuclear power since the Energy Policy Act of 2005. While all of these bills remain pending, there is general optimism that some or all of them will go to Conference and eventually pass. The staff members stated that they value the diversity afforded by nuclear power, and recognize the need for continued Government support for new, improved and advanced nuclear technologies to assure national energy security. They noted that there are significant opportunities in the global market and there is a desire in Congress to ensure the technology is American born and bred. The SMR Start initiative also was lauded for demonstrating industry support of SMRs to Congress, and providing a strong indicator that there is a market for SMR technology.

On the second day of the workshop, the consultants invited a representative from Bloomberg New Energy Finance to provide a global perspective on the viability of nuclear power in today's marketplace. The discussion made it clear that the availability of low-cost natural gas in the U.S. is making it difficult for nuclear power to maintain its economic competitiveness. The speaker said that continued and adequate support from the U.S. Government is required to assist new nuclear development. Further, the speaker said it is clear that the market is at the start of a large contraction in domestic and international coal usage. It remains to be seen whether nuclear power, and SMRs in particular, will be used to replace these coal plants due to the low costs of natural gas. The discussion provided the workshop participants with the challenge to recognize that nuclear cost competitiveness is an uphill battle, and that careful thought on the next steps for public and private support for nuclear is needed. This, of course, was the reason for the workshop.

Through the insights of all of the speakers, it became clear that now is the time to address the issues and challenges facing the industry. Many ideas and concepts were discussed by the workshop participants. Some were at the basic technology level which would have focused, but limited impact. Others were on a more ambitious national program-level, with the intent to change industry paradigms. One such idea involved a nuclear program along the lines of the space program in the 1960's as a way to jumpstart the development of a fleet of standardized SMRs that would replace old coal plants and become the primary source of baseload power for the country. Participants said that a full commitment to the commercialization of U.S. SMR technology from the U.S. government would help the U.S. nuclear industry recapture global leadership in commercial nuclear power, and be of geopolitical strategic importance to the nation. Success in "filling the order book" and bringing about continuous deployment of SMRs would ensure the industry achieves Nth of a kind benefits in manufacturing, construction and operations. While a "Nuclear Moonshot" program is unlikely in the near-term without a compelling crisis driving it, the possibility of one day achieving mass SMR deployment is a worthy goal.

Speakers and panelists from nuclear vendors, suppliers, engineering, procurement and construction contractors, utilities/potential customers, and researchers discussed their views on where they believe DOE investment can provide the greatest momentum for the industry. Workshop panels discussed how a larger customer base can help develop a manufacturing basis, create domestic jobs, and improve the long-term commercial success of SMRs. Several discussions focused on how developing alternative missions for SMRs, such as providing clean, secure power to Department of Defense facilities, would improve their viability and integration with renewable energy on the U.S. electrical grid. The following report is intended to capture these thoughts and provide the Department with viable options that can become a part of an overarching SMR commercialization program.

Day 1 – Manufacturing

Ideas supporting "Manufacturing Innovation" were solicited from workshop attendees by using panels of industry experts. These subject matter experts represented the SMR vendor community, component manufacturers, engineering, procurement and construction (EPC) companies, and Industry supported organizations. Panelists provided their organization's perspective on the readiness of the manufacturing infrastructure to produce the components needed for SMRs, and what Government support might be needed to assure the industry can meet the potential future demands of SMR manufacturing and deployment. The panelists then responded to questions from one another and the audience at large. The panel sessions were followed by an open forum to collect additional comments, clarifications and general observations. The ideas, concepts, insights and recommendations fall into the eight categories discussed below.

1. Design Issues

Design issues discussed during the workshop relate to both general issues and specific design innovations that can support the SMR building technologies. In the general issues category, for example, the point was made that "optimize does not necessarily mean modularize." In essence, modularization should not be assumed to be synonymous with optimization. Several panelists agreed that the design and first-of-a-kind-engineering (FOAKE) will have a significant impact on how future plants are constructed. To that end, there was consensus among the participants that Government funding for the construction of an SMR, with the intent to operate it, is one of the most effective strategies to identify and resolve design and construction issues.

Participants also pointed to the fact that the SMR designs are smaller plants with smaller source terms. As a result, efforts should be supported to ensure the new SMRs have smaller EPZ's, appropriately sized to the plants' characteristics, and fewer personnel assigned to physical security. Participants also raised the question about whether the design of SMRs should include "black start" capability. If so, steps must be taken to secure NRC regulatory approval for these key issues. Another general issue was the potential benefit of incorporating integrated information management systems into the design and construction process. This approach could ensure cradle-to-grave design control.

Some of the specific design innovations identified during the discussions included the potential to add to the EPRI Utility Requirements Document the ability to use rolled and welded plate for the fabrication of large, Class 1 vessels. The question was also raised as to whether the advent of new technologies has resulted in a need to change ASME Sec. XI codes for In-Service Inspections. The potential benefits were also discussed of developing new designs for the use of high strength rebar, and the development of new rebar connections and headed bars. This will require working with engineering, and codes and standards groups to facilitate approvals.

2. Technology Improvements

Specific innovations in manufacturing, fabrication and construction technologies were suggested from many of the participants. These technologies are outlined below.

- Advances in welding and joining technologies can be useful both in the manufacturers shop and on the construction site. The most sought after and elusive goal is to have a self-correcting, self-inspecting welding process that completes a weld with no defects and provides an inspection report that meets construction and in-service codes.
- Welding technologies need to be developed that use advances in hybrid laser welder development and electron beam welding to improve the quality and through-put of heavy section welding both in the shop and in the field.
- Improvements in the cladding and surface modification of safety related components was suggested as an improvement to current methods. Specific mention was the use of diode laser cladding, a method which would be faster and allow protection of the base metal with less deposited material.
- Improvements in welding go hand-in-hand with improvements in non-destructive testing and quality-related inspections. These processes must be more automated in the performance of the inspections and the reduction of data to a final decision. This is required both in the shop and in the plant, during and after construction.
- The forging industry suggested a need for changes in the methods for determining fracture toughness and for measuring hydrogen in completed forgings. The desire is to eliminate the drop weight testing in lieu of a more accurate test, and to find a fast and reliable method for hydrogen analysis. A

suggestion also was made that development of accurate laser measuring of the forging while in process, would save time and cost.

- Several areas for advanced manufacturing of nuclear components were mentioned in the discussions. 3D printing was discussed as an option that is being used in other industries. Conditions for its development include reliable process control, a thorough knowledge of the materials to be printed, and approval by codes and standards committees.
- 3D printing was also discussed in support of a modern component casting industry. Sand molds for casting parts have been made by the use of 3D printing. This area should be expanded for nuclear component use.
- 3D printed structures are also a possible process for the fabrication of civil structures that are not safety class. It was noted that companies in China have built multi-storied buildings out of concrete using a 3D printing method.
- Continued development of Hot Isostatic Press/ Powdered Metal (HIP/PM) components is a key development area. This process can replace the casting and forging of components with a tailored material specification or a duplicate of a code-approved material. Components as large as vessel nozzles and large valve bodies have been made. Major vessel parts are a possibility. Advancing the process and its manufacturing size capability is a goal in this area. This process is at a point where a major demonstration is required to begin the industry consensus standard/code and regulatory approval process.

3. Factory Technologies

Designing and building a next generation factory for the production of nuclear components and parts presents extensive opportunities for innovation, according to participants. The starting point for a next generation factory is the virtual design of components using 3D modeling, and then carrying that to design input into the autonomous machines that will make the components. The factory itself should be designed using modern industrial engineering concepts that allow advanced modeling and simulation of the entire factory floor, and the flow of components on the floor. Robotic handling of material and parts is a necessity. Machines should take advantage of the latest technologies such as ultrasonic assisted machining and cryogenic enhanced machining.

4. Forging

Forging providers suggested that the capability to make components for SMRs is not the issue, but that the capacity to meet market needs might be. They stated they have the capability to provide the nuclear quality forgings required for SMR components. Support in setting up trial demonstrations of forging production, and for developing specific trial melts of material would help to prove and demonstrate this capability. Participants said the forging industry could also use support for the following:

- Developing tooling for repetitive parts
- Ingot molds for low carbon stainless steel parts
- Laser measurement equipment for large hollow forging production
- Testing equipment and processes to eliminate drop weight testing and improve testing for fracture toughness.

5. People

Well trained and qualified people are key needs throughout the manufacturing and construction environments. Participants said efforts must be made to train, qualify and maintain a skilled and healthy workforce. Technical schools, apprenticeship programs and manufacturers' workforce development programs can all provide a measure of success. There also is a need for manufacturing engineers who are skilled in virtual factory modeling in order to support more automation and higher capacity for factories.

6. Supply Chain Concerns

Participants said they expect that SMR's will rely heavily on the existing, but diminished, supply chain for the current LWR fleet. As noted earlier, participants believe that capability is not an issue, but that capacity might be. SMR's are less complicated with fewer components, but they may still tax the supply chain if there are several new builds. Regulatory and Codes and Standards issues must be addressed to implement new materials, processes and designs. A program must be developed to increase the number of suppliers with nuclear-certified programs (such as N-Stamp qualification). This should include efforts to increase and enhance the human capital to support the supply chain. Procurement officers will decide whether to purchase components with N-stamp qualifications, or to use commercial grade dedication processes. In either case, an effort is needed to streamline the procurement process.

Specific items discussed by SMR Workshop participants included:

- Suppliers of raw materials may want to add a finishing capability to their products. An example would be a forging or casting supplier performing finish machining on the raw parts.
- Use modeling and simulation now to simulate the supply chain, and identify bottlenecks.
- Take the initiative now to evaluate the Codes and Standards for SMR manufacturing and develop new ones as needed.
- Stimulate workforce development to ensure the talent is available to design, manufacture, build and operate SMRs.
- Look at innovation in transportation, particularly for the transport of heavy and physically large components.
- Develop a simple process for the code qualification of alternate materials and processes.

7. Center for Advanced Nuclear Manufacturing

Throughout the course of the meeting, participants raised the concept of the development of a "Center for Advanced Nuclear Manufacturing" in the U.S. Participants suggested that DOE look to the Advanced Manufacturing Research Center (AMRC) at the University of Sheffield in the UK as a model. Participants also discussed whether such a Center in U.S. needs a specific physical location for the research facility, or if a virtual center might be established that brokers other facilities and capabilities. One option is to establish a "virtual" Center in its first phase, moving to a physical center at a later date. Questions remain to be answered about which organizations and agencies would support the Center, and who would operate it. Participants also proposed that a Center for Advanced Nuclear Manufacturing might support a prototype build of partial or full scale components for an SMR, and whether the Center might also be used to train employees for manufacturing facilities.

8. Advanced Manufacturing Roadmap

Participants suggested that compiling the ideas and concepts developed at the SMR commercialization workshop, along with other initiatives DOE is considering, into an Advanced Manufacturing Roadmap would facilitate both prioritization and implementation. The roadmap would put order to the evolution of the research in manufacturing and construction processes. It would also integrate other necessary assets, like the Modeling and Simulation Center at ORNL, the Advanced Test Reactor at INL, and the various private and public efforts already underway to improve U.S. manufacturing and productivity. An Advanced Manufacturing Roadmap could also facilitate alignment and collaboration with the efforts of other government agencies, such as DoD.

Day 2 – Capitalizing on the Unique Capabilities of SMRs

What Customers (Utilities) Want In SMRs

The second day of the conference focused on generating ideas on how to capitalize on the unique characteristics of SMRs. To start the day, four utilities participated in a discussion on “What the Customers Want in SMRs.” The discussion included representatives from Duke Energy, Southern Nuclear Operating Company, the Utah Association of Municipal Utility Systems (UAMPS), and Ontario Power Generation (OPG). UAMPS has proposed to build a NuScale SMR to serve its customers. OPG operates several nuclear reactors and is evaluating the use of SMRs to serve customers in Ontario, Canada. Additional panels discussed the unique characteristics of the light water SMR designs, the use of SMRs to provide clean, secure energy to critical assets including DoD and DOE installations, the opportunities to use both thermal and electric energy from SMRs to support non-electric applications such as desalination or the production of commodities, and the potential to replace retiring coal plants with SMRs.

During the discussions, the panelists identified seven key areas that they believe are important to the successful commercialization of SMRs and for a decision by their companies to build and operate an SMR.

1. <u>Improving SMR economics</u> – All facets of SMR economics must be competitive with the cost of alternatives.
2. <u>Siting flexibility</u> – SMRs have the potential to leverage some of their unique characteristics to offer utilities greater flexibility in siting a new nuclear power plant.
3. <u>Regulatory predictability</u> – utilities must have confidence that they can move through the NRC regulatory process in a manner that allows for the timely construction and operation of an SMR.

4. Responding to the new grid – Like it or not, the electrical transmission grid will continue to change, and utilities need power plants that meet these changing requirements.
5. Secure, reliable energy – At the same time that the grid is changing, customers – especially those that rely on sophisticated electronics – increasingly need assurance that their electric power supply is secure and reliable.
6. Taking full advantage of thermal and electric energy – SMRs that can go beyond the production of electricity to more fully utilize their total energy production can result in improved economics and the ability to meet the needs of a changing world through the support of processes such as desalination.
7. Coal plant replacement – Replacing coal-fired power plants with SMRs could prove to be a valuable option for utilities that are retiring coal-fired power plants to address concerns about climate change.

1. Improving SMR Economics

Participants consistently made the point that “It’s all about cost competitiveness.” They noted that the size of SMRs better matches growth rates, and the total capital cost puts less pressure on an owner’s balance sheet. They further encouraged DOE to look at the full economic and financial picture of SMRs as a generating resource, and help the industry pursue every opportunity to lower costs. The opportunities extend well beyond finding ways to reduce the capital cost of building new SMRs, and include siting, licensing, permitting, operations and maintenance, and financial incentives such as tax credits, loan guarantees, and accelerated depreciation. Among the suggestions put forth by the participants for DOE were:

- Support industry efforts to use modern technologies and the unique characteristics of SMRs to reduce the number of people the NRC requires to staff the plant. Fewer security personnel is a frequently cited example. One participant pointed out that a 300 MWe combined cycle natural gas plant requires only eight FTEs.
- Level the playing field for new nuclear and SMRs by providing owners with the same financial incentives they receive from developing solar and other renewable resources.
- Provide the SMR with long term power purchase agreements (up to 30 years) with Federal customers. Long term PPAs with Federal customers are viewed favorably by investors and can lower the cost of capital to the SMR owner.
- Explore the feasibility of the Federal government sharing in the cost to build the first plant(s).

2. Siting Flexibility

Many of the unique characteristics of SMRs are expected to offer greater flexibility in selecting sites than with large light water reactors. The incorporation of passive cooling systems and the smaller amount of nuclear fuel should facilitate NRC approval of smaller Emergency Planning Zones for SMRs. Some support reducing the EPZ to the site boundary. Reducing the size of the EPZ will allow the siting of SMRs closer to population centers while lowering the cost of emergency planning. DOE was encouraged to support industry’s efforts.

The availability of water and what it is used for is increasingly becoming a serious issue around the world. DOE was encouraged to support efforts that can help minimize the water required for an SMR through improvements to dry cooling and other technologies.

3. Regulatory Predictability

The challenges presented by the NRC regulatory process, and the inability to move through it in a timely and predictable manner, have an adverse effect on every part of the commercial nuclear industry. The challenges bring uncertainty to both costs and timelines, and dramatically increase the perceived risk for any party considering investing in a new nuclear technology or power plant. One participant noted that it takes eight to nine years from the time of application to the receipt of a combined Construction and Operating License, compared to two years to permit a natural gas power plant. Participants encouraged DOE to take steps to help resolve NRC related issues as well as support initiatives like the effort to reduce the size of EPZ's for SMRs.

4. Responding to the New Grid

The grid will continue to change. Participants said utilities have no choice but to accept and adapt to the continuing changes. The ability to adjust the output of an SMR, or load follow, to match the variable output of intermittent wind and solar resources is one of the most frequently discussed capabilities that utilities expect in SMRs. SMR technology developers said they are incorporating load following capability into their designs, largely through steam bypass. Participants said more needs to be done to thoroughly understand the effect of load following on plant operations, the safety case, fuel performance and longevity, and economics. In essence, how does load following challenge the plant, and what steps can be taken to mitigate those challenges? Participants suggested that load following capabilities could best be analyzed through the development of a DOE-sponsored commercial-scale SMR demonstration project.

5. Secure, Reliable Energy

In this age of electronic interconnectivity, every facet of our nation increasingly relies on a reliable supply of electric energy. For many of our nation's most critical assets that supply must also be highly secure. With the increase in intermittent power resources and the removal of baseload coal and nuclear plants, there is concern that the grid is becoming less reliable. Cyber-security for the grid and the power plants connected to it also is of increasing concern. Exactly what is meant by "secure, reliable energy" remains to be defined, according to the discussion. So too is the ability to identify and quantify the value of the benefits. Participants pointed to some of the unique characteristics of SMRs that can contribute to energy security and reliability. These include the reduction in single-shaft risk because the electrical generators in the SMR designs have dramatically smaller outputs, and some of the designs include two or more generators per power plant. Another potential characteristic is the ability of an SMR to operate in island mode to serve a grid that itself is islanded from the larger whole, and black start, the ability to return the SMR to operation without the need for offsite power. Participants noted that the affect of island mode and black start on SMR design, operations and licensing needs to be better understood. Participants also discussed the status of microgrids and the potential to power them with SMRs to provide secure power to critical assets like defense installations and national laboratories. Participants said there is merit in supporting the design of a location-specific SMR-powered microgrid that could serve a critical DOE or DoD installation to address any technical, regulatory, or operational issues. Once designed, DOE might proceed with building the microgrid to prove the concept and achieve the benefits.

6. Taking full advantage of Thermal and Electric Energy

Finding ways to extract the maximum value from the thermal energy produced by an SMR can improve economics and deliver more benefits to society. Panelists and participants discussed a number of potential opportunities for using both the thermal and electric energy produced by an SMR:

- District Heating – Nuclear power plants already are used for a combination of electricity production and district heating in nine countries. The U.S. is the third largest market for district heating in the world, although nuclear power plants are not being used for that purpose here. There is an opportunity to establish a better understanding of the potential for using SMRs for district heating in the U.S. and internationally.
- Desalination – Access to clean, potable water is an issue and of growing concern in parts of the U.S. and around the world. Nuclear power plants already are the source of energy for desalination projects in 15 locations outside the U.S. Saudi Arabia recently signed an agreement to explore the use of an SMR being designed in South Korea for desalination. More information is needed on how an SMR can best support the various desalination processes, as well as on the potential markets.
- Hydrogen Production – The U.S. currently uses more than 12 million tons of hydrogen each year for fertilizer production, refining, and in the food industry. A 300 MWe SMR can support the production of hydrogen as the feedstock for 1,150 tons per day, or more than 400,000 tons per year, of fertilizer.
- Industrial process heat – SMRs frequently are discussed as a potential source of thermal energy for process heat applications. One of the potential impediments, however, is that the pressure and the 300° C temperature of steam produced by a light water SMR is below the requirements for process heat. Whether there is an economic and efficient way to boost the temperature and pressure has not been thoroughly evaluated. In addition, co-location of an SMR with a petrochemical plant or refinery raises questions about safety and the regulatory response that need further evaluation.
- Hybrid Energy Systems – Idaho National Laboratory is conducting research into the potential of using SMRs as the source of thermal and electric energy for Hybrid Energy Systems (HES). An HES integrates the operation of multiple energy resources – wind, solar, storage – to achieve synergies and maximize the value of the energy they produce. INL is evaluating the possibility of leasing two of the NuScale Power Modules at the proposed UAMPS project to evaluate HES in real-world applications. The Joint Use Module Program (JUMP) would evaluate the financial, regulatory, and operational feasibility of HES.

- Isotope production – Nuclear isotopes are critical components for many medical and defense applications. The smaller size of SMR reactors might lend itself to design approaches that facilitate the production of isotopes.

7. Coal Plant Replacement

U.S. utilities increasingly are deciding upon early retirement for coal-fired power plants in order to address concerns about climate change and to avoid the cost of retrofitting the plants with expensive equipment to meet new clean air standards. The rate with which U.S. utilities are deciding to retire coal fired power plants is accelerating. The Energy Information Agency projects that more than 90 gigawatts of coal-fired capacity will be retired by 2040. One possibility under discussion is to replace the energy from a coal-fired plant that is scheduled to close with an SMR. The coal plant will have infrastructure – access to transmission, cooling water, administrative and other buildings – that can be used by an SMR. It also has skilled personnel that can be trained to operate and maintain the SMR. In addition, replacing one baseload resource, a coal plant, with another, an SMR, helps ensure continued stability of the electric grid. While the possibility of replacing coal plants with SMRs is discussed at a high level, it has not been evaluated in-depth. Participants discussed the need to fully understand what it takes to transition a coal plant to an SMR - what stays, what goes; permitting and licensing requirements; the economics; the benefits. Public acceptance also is important as there are many cases that communities, over the decades, have grown up around and now encroach upon coal-fired power plants. To more fully understand the issues, and as a potential first step in replacing a coal plant with an SMR, participants suggested that DOE might support a utility in securing an Early Site Permit at a candidate coal-fired power plant. Participants also discussed taking a macro look at the potential of the coal plant to SMR strategy, including quantifying the potential based on the size of the EPZ boundary.

Program Options

The consultants identified several themes that emerged during the two days of the workshop and present options DOE can consider for future programs. The themes ranged from support for focused technology development to the desire for the Government to support commercial-scale demonstration projects that could incorporate many of the focused technologies, capabilities or processes. Several of the themes were present on both days of the workshop. The following section consolidates the information, ideas and concepts provided by the participants. It identifies activities or concepts that DOE might consider to be potentially "actionable" and could elect to pursue based on compatibility with program scope, the timing of the proposed activity, and the realities of the Federal budget process. Potential policy-related and legislative actions also surfaced during the discussions and are included for consideration. While these policy/legislative actions are not funded directly in NE outyear programs, establishing a better understanding of the potential for these actions to improve the commercial outlook for SMRs may provide a basis for promotion of specific legislative and policy language for the Administration to consider. The discussion also provides a basic, relative cost/schedule indicator, which will factor into the likelihood of the concept receiving programmatic consideration. The concepts below are not listed in order of preference.

I. **Finalize SMR Designs for Commercial Construction & Operation** – Many participants said that DOE's current efforts to support SMR commercialization by cost-sharing certification and licensing activities are proving effective and moving the industry in the right direction. The next hurdle to overcome following the submittal of NRC licensing applications is support of the NRC's review of the applications and the need to finalize designs for commercial construction and operation. Participants encouraged DOE to pursue a program option to provide cost-shared support for completing licensing and conducting detailed design, and first-of-a-kind engineering, balance of plant design, and other customer-driven requirements for the extant SMR designs. (Cost – Medium. Schedule – Near-term.)

II. **Improve SMR Economic Competitiveness** – Participants encouraged DOE to establish program options and to pursue initiatives that will help to build the customer base for SMRs and improve the economic competitiveness of the technology. It was suggested that DOE extend the current SMR LTS program, or start a new program to incentivize and support additional COL and ESP licensing requests from domestic utilities with potential interest in SMR deployment. The participants also pointed out that the incentives to customers offered under the Energy Policy Act of 2005 will only be partially utilized, as the milestones to qualify for them have now passed. They encouraged DOE to support efforts to fully utilize the incentives by promoting the amendment related to extending the milestones in the Act. They also said that DOE should support efforts to establish financial incentives that are equal for all clean energy resources, including SMRs. DOE support for efforts to achieve long-term power purchase agreements between Federal facilities and SMRs that are uniform in duration (preferably 25 years or more) could incentivize customers and provide risk-mitigation assurance to investors. Participants also pointed out that there are a number of areas where the unique characteristics of SMR designs lend themselves to improving the technology's economic competitiveness through changes to regulatory requirements. Participants encouraged DOE to support industry efforts to capitalize on these characteristics. Establishing a smaller emergency planning zone (EPZ), for example, would lower operating costs and offer more siting flexibility for SMRs. Participants also said DOE could incorporate into a program efforts to create cradle-to-grave information management systems that can improve efficiencies at every step of the design, construction, operation and decommissioning continuum. (Cost – Medium. Schedule – Near-term.)

III. **Support the Development of a Prototype SMR NSSS** – The development of a DOE program that would result in a commercial-scale prototype of the nuclear steam supply system, or major sub-systems or components, could address and answer many of the questions about the readiness of the supply chain, according to participants. Development of operable and testable prototype equipment would test the viability and practicality of new manufacturing practices, alternate materials and testing methods. It would facilitate improvements to the NSSS designs that enhance manufacturing processes, quality, and timeliness. A prototype NSSS could potentially be used in a commercial scale demonstration project, or in a training center for SMR operators. (Cost – Low. Schedule – Near-term.)

IV. **Support the Deployment of the First Commercial SMR** – A more ambitious DOE program that would deliver multiple benefits, according to participants, would be support by DOE for the construction and operation of the first commercial, full-scale SMR. The SMR could be deployed to serve multiple Federal facilities with clean energy. Further, it could potentially be integrated into a microgrid to provide one or more facilities with secure energy for critical assets. The SMR also could be used to further prove out concepts such as hybrid energy systems, process heat applications, desalination and isotope manufacturing. The SMR also could support efforts to identify ways to reduce water requirements through improvements to dry cooling techniques and the development of alternative processes. Idaho National Laboratory is evaluating the potential to use some of the output from an SMR for research and development into non-electric applications in its proposed Joint Use Module Program (JUMP). (Cost – Very high. Schedule – Mid to Long-term.)

V. **Support the Development of Advanced Manufacturing Methodologies** – Many of the participants discussed new manufacturing and fabrication technologies that hold the potential to improve the quality of components while reducing cost and schedule. They encouraged DOE to provide programmatic support for these efforts. These new technologies could be broadly applicable in nuclear and other industries, and could be particularly valuable for SMRs where high throughput is needed. The technologies include HIP/PM processes, 3-D additive manufacturing, and new cladding and inspection techniques, and improvements to current forging techniques. Advanced manufacturing development can take place at current manufacturing facilities, DOE laboratories, or other locations. Participants suggested that federal support leading to the development of advance manufacturing techniques could focus on manufacturing or fabricating components for a prototype SMR NSSS. (Cost – Low. Schedule – Near-term.)

VI. **Establish a Center of Excellence for Advanced Nuclear Manufacturing** – Participants frequently discussed manufacturing-related research and development efforts that are taking place at multiple industry and national laboratory locations. They also discussed the number of Centers of Innovations for the nuclear and other industries. Participants said the diffusion of these efforts makes it difficult to identify research that might be of value, leverage and integrate efforts across industries and locations, and manage costs. Participants proposed a DOE program option that would create a public/private partnership to establish a Center of Excellence for Advance Nuclear Manufacturing, which could bundle development efforts into a single program or under a single roof. The first step could be a “virtual” center to coordinate efforts in multiple locations offering a single access point. For example, participants said they would like to see DOE establish a database that identifies R&D capabilities and initiatives at the national laboratories, the Nuclear Science User Facilities, and other Federally-funded programs. DOE’s GAIN program might provide a platform for development of the database. The database could provide the first step for the virtual Center of Excellence. Efforts later could be consolidated into a physical location, which would offer greater synergies within and across programs and better manage costs. The work likely is applicable to other sectors of the nuclear industry as well as the broader power industry providing opportunities for synergies and multi-program funding. Collaborations with other industries and agencies, such as aerospace and DoD, would help derive additional value from the effort. (Cost – Low to Medium. Schedule – Near-term.)

VII. **Prove Out the Supply Chain** – Participants discussed whether the nuclear supply chain, in its current state, has the capability and capacity to support the deployment of SMRs. One option proposed by participants is a DOE program that simulates the manufacturing supply chain, from manufacturing technologies, to the human talent pool, in order to identify both strengths and gaps in the capability to deliver everything required to build an SMR. The simulation might also identify opportunities to improve processes and thereby enhance assurances around timeliness, quality and cost. As part of this program, it was proposed that DOE leverage its powerful computing capabilities to simulate the advanced manufacturing supply chain required to deliver the parts, components and commodities required to build an SMR. The simulation also would be applicable to advanced reactor designs. (Cost – Low. Schedule – Near-term.)

VIII. **Align Codes & Standards, and Requirements, with SMR Requirements** – Participants expressed concern that current codes and standards might not align with the materials, processes and techniques that are planned for SMR component manufacturing and construction. For example, ASME does not have codes for the use of HIP to make nuclear grade parts. Participants said DOE can provide programmatic support for the development or revision of ASME and other codes and standards necessary for timely SMR deployment, or establish a test case for qualifying components made with processes that are not addressed under current codes. Similarly, participants pointed to certain manufacturing techniques, such as the use of rolled and welded plate in reactor pressure vessels, which are not covered in the EPRI Utility Requirements Document. Participants suggested a collaborative process engaging utilities, manufacturers, EPCs, SMR designers along with DOE support to review the EPRI URD in light of the current state of plans for SMR deployment. (Cost – Low. Schedule – Medium-term.)

IX. **Advanced Manufacturing Roadmap** – Participants proposed compiling the ideas and concepts developed at the SMR commercialization workshop, and in Program Options V through VIII above, along with other initiatives DOE is considering, into an Advanced Manufacturing Roadmap, which would facilitate both prioritization and implementation. The DOE-sponsored roadmap would put order to the evolution of the research in manufacturing and construction processes. It would also integrate other necessary assets, like the Modeling and Simulation Center at ORNL, the Advanced Test Reactor at INL, and the various private and public efforts already underway to improve U.S. manufacturing and productivity. An Advanced Manufacturing Roadmap could also facilitate alignment and collaboration with the efforts of other government agencies, such as DoD. (Cost – Low. Schedule – Near-term.)

X. **Design and Construct an SMR-Powered Microgrid** – The use of microgrids with their own power resources is proving an effective way to protect critical national assets at DOE and DoD facilities. Participants said that DOE and the national laboratories are in a position to take a leadership role in developing the design for an SMR-powered microgrid to serve a mission critical asset. For example, DOE could evaluate the development of an SMR-powered microgrid in markets that have critical DoD assets, and highly vulnerable fuel supplies, such as Alaska and Guam. This effort would be relatively low cost and would provide important information for the finalization of SMR designs. It also could be the pre-cursor to a pilot SMR project. (Cost – Low to medium. Schedule – Medium-term.)

XI. **Coal Plant to SMR Clean Energy Transition** – Participants noted that the U.S. energy supply has already started a massive transition away from the use of coal. Many of the coal plants scheduled for retirement are in a size range similar to the SMRs under development. In addition the coal plants have infrastructure that can support their replacement by SMRs. Participants encouraged DOE to establish a program that leads to a comprehensive effort to ensure that many of the retiring coal plants are replaced with clean energy from SMRs. As a starting point, of those coal plants already scheduled for retirement, this initiative can identify those that are the most suitable for replacement by an SMR. As part of this program, DOE can then support efforts to prepare and prosecute ESPs for one or more of those projects that the utilities can bank. It can also support utilities with the development and implementations of plans to preserve critical infrastructure and other assets – access to water, transmission, buildings. Further, participants said DOE can support development of detailed transition plans that include project development and financing, state and local permitting, and workforce transition. One of these locations might prove to be ideal for the development of a commercial demonstration project referenced above. (Cost – Medium. Schedule – Near to mid-term.)

XII. **SMR Nuclear Moonshot** – Participants discussed the need for a "Nuclear Moonshot," similar to the monolithic effort to place a man on the moon in the 1960s, to bring national attention and focus to deploying SMRs. Although an SMR program of that magnitude is unlikely, it was suggested that DOE can begin to aggregate initiatives such as the ones discussed above to bring SMRs to commercialization under a single program umbrella, including support for a demonstration SMR, which would mean Government costs would be very high. The "moonshot" concept would be expected to result in fleet-level deployment of SMRs to replace existing carbon-intensive generation with clean baseload power. Creating a single "SMR Launch" program umbrella would bring focus and common purpose to the initiatives. (Cost – Very high. Schedule – Long-term.)

Policy/Legislative Actions

Several policy and legislative-related actions that would further support the commercial development of SMRs were discussed by the participants during the workshop. These are policy-level initiatives that would require Congressional action. While these actions are not programs that the Office of Nuclear Energy would be authorized to undertake, they are important and worthy of discussion here.

1) ***Develop a national strategy for replacement of domestic coal-fired power plants with SMRs and renewables*** – It was suggested that DOE should take on the responsibility of establishing a strategy and policy that promotes the replacement of old, carbon-intensive coal plants with new, safe, clean SMR technologies. (See XI. above) This may involve the conduct of a pilot study to understand the specifics of what site infrastructure and capabilities could be leveraged, in addition to establishing preliminary cost estimates. This effort would need to be accepted at the Secretarial level, and worked in conjunction with the Offices of Fossil and Renewable Energy to establish a workable path forward.

2) ***Update existing incentives for SMRs*** – It was stated several times during the course of the workshop that nuclear power needed a level playing field with other carbon-free energy resources. (See II above). Without incentives equal to those received by wind and solar power, new SMR designs are unlikely to produce power at a competitive price. The four new nuclear plants under construction will use only a fraction of the $18 / MWh in production tax credits for new nuclear included in the Energy Policy Act of 2005. Milestone requirements in the Act have expired and the PTCs are no longer available to new nuclear of any type. Efforts to commercialize SMRs will benefit if the incentives in the EPAct 2005 are extended and possibly expanded to include some of the incentives available to other clean energy resources such as Investment Tax Credits and accelerated depreciation.

Conclusions

The workshop was successful in bringing together a broad representation of stakeholders in the SMR community. Participants actively discussed and debated where they see the greatest opportunities for DOE to support the commercialization of SMRs. The scope and budget requirements of some of the ideas makes them a challenge to pursue. Others, however, are within DOE's purview and within the scope of the Office of Nuclear Energy's historic budget requests. The participants recommended that DOE, and in particular the Office of Nuclear Energy, strongly consider the workshop recommendations in future program and budget planning to ensure the successful deployment of SMRs.