NuScale Power™

April 14, 2017

TO: Senate Business and Transportation Committee

FR: Chris Colbert, Chief Strategy Officer, NuScale Power, LLC

RE: Supplementary information in Support of SB 990 Testimony

We are supplementing our testimony of April 12, 2017, in support of SB 990, with the following additional information. We have summarized this additional information in the attached power point presentation.

Background: NuScale is an Oregon Company. NuScale Power, LLC (NuScale) small modular reactor (SMR) technology was created and is being developed in Oregon. Our company's major base of operations is Corvallis, Oregon and NuScale is headquartered in Portland. NuScale's SMR test facility is located on the campus of Oregon State University. NuScale has served as an economic engine benefitting Oregon and other Oregon-based businesses. In 2016, NuScale paid more than $27 million in Oregon salaries and provided $2 million in Oregon tax deposits. We have worked with Oregon-based suppliers including Oregon Iron Works, Harris Thermal, Greenberry, and many more. To date, NuScale has invested more than $560 million in the development and licensing of its SMR design. Siting and building a NuScale SMR in Oregon would create thousands of high paying jobs and offer new economic opportunities for Oregon suppliers.

Resiliency: The NuScale Plant is designed to withstand an array of natural and human-caused events. The requirements and expectations in this regard are set out in various U.S. Nuclear Regulatory Commission regulations, policy statements, and guidance documents. As these documents are lengthy, we provide below a synopsis of the requirements for a number of such events, and design considerations addressing those events.

- Natural hazards: NRC regulations at 10 CFR Part 50, Appendix A, and implementing documents require that the plant is capable of safely withstanding credible natural hazards. The plant is protected against natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches, based on the most severe of the natural phenomena that have been historically reported for a particular site, with margin appropriate to the available data The NuScale design is based on generic site parameters developed to encompass a wide range of sites, and the plant owner is required to ensure the design is suitable for the actual site. The NuScale design provides the capability to withstand these natural events without depending on electrical power or external sources of cooling water.

- Terrorism: NRC regulations at 10 CFR Part 73 and implementing documents require a variety of measures to protect nuclear reactors and stored fuel against sabotage, theft, diversion, and other malicious acts. NRC implements physical protection requirements consistent with the significance of the facilities or material to be protected, and licensees are responsible for providing the protection. Physical protection includes both design features incorporated in the NuScale design (e.g., protected areas and intrusion detection), and operational programs to be provided by the plant operator (e.g., an armed response force).

- Aircraft impact: NRC regulations at 10 CFR 50.150 and implementing documents require applicants for new nuclear power reactors to perform a design-specific assessment of the effects on the facility of the impact of a large commercial aircraft. The NuScale design incorporates design features and functional capabilities to assure the reactor core remains cooled, the containment remains intact, spent fuel cooling is maintained, and spent fuel pool integrity is maintained in the event of the worst-case assumed aircraft strike, exceeding NRC's minimum criteria.

NuScale Power, LLC
6500 SW Redwood Lane, Suite 210 Portland, Oregon 97224 Office 503-715-2222 Fax 503-746-6041
www.nuscalepower.com

- Cyber security: NRC regulations at 10 CFR 73.54 and implementing documents require measures to protect digital computers, communication systems, and networks associated with safety-related, important-to-safety, security, and emergency preparedness functions from cyber-attacks. NRC requires the facility to protect against cyber-attacks that would compromise the integrity, deny access, or impact the operation of those systems, networks, and equipment.

Flexibility: The NuScale Power Module can rapidly adjust power output by adjusting reactor power or bypassing steam from the steam turbine generator to the condenser. This is a valuable capability given the intermittency of renewable generation and its increasing penetration into the electric supply system. Currently, this renewable energy intermittency is balanced using fast-start, natural gas turbines. NuScale performed an analysis of the NuScale ramping capability using historical data from the Horse Butte wind farm outside of Idaho Falls and demonstrated that a single NuScale Power Module could vary power using steam bypass only, and more efficiently with a combination of steam bypass and reactor power changes. We have included this study which was peer-reviewed and published at the 2015 International Congress on Advances in Nuclear Power Plants (ICAPP).

Reliability: The NuScale Plant may have one to twelve NuScale Power Modules. As each NuScale Power Module can produce 50 MWe, the output of a NuScale Plant can be 50 MWe to 600 MWe. For a 600 MWe NuScale Plant, we have performed an analysis that the NuScale Plant can supply 100 MWe to a mission critical load with a 99.99% reliability over 60 years. We have included this analysis which was submitted for peer review and published as part of ICAPP 2016.

Economic Development: The economic benefits of a NuScale Plant commence with construction and extend through the 60 year life of the NuScale Plant. The peak construction labor force is ~1200, and the construction period is approximately three years. The permanent operations staff is ~365, approximately one quarter of which will have bachelor's degrees and the remainder with high school and associates degrees. The average salary for a nuclear plant worker is ~$90,000 per year, which is significantly higher than other base load generating plants, e.g., natural gas combined cycle, clean coal, biomass or geothermal. We have included a white paper summarizing the job potential of various baseload generating technologies.

Carbon-free: Nuclear power currently provides 20% of U.S. electricity and nearly 60% of its carbon-free energy. All other renewables, excluding hydro, provide 8%. This underscores that nuclear energy is an important carbon-free technology that can be deployed on the scale necessary to deeply decarbonize the U.S. and global electricity sector. NuScale's technology adds the flexibility needed for nuclear energy to work on a more decentralized grid with renewables, decreasing the need for fossil fuel back-up.

Affordable: With a long-run levelized cost of electricity (LCOE) of $86/MWh, the NuScale Plant compares favorably to the next lowest cost option, natural gas combined cycle with carbon capture and sequestration (CCS), $85/MWh. At a ~$3bn overnight capital cost for a twelve NPM, 600 MWe NuScale Plant, the plant is within the financial capability of utilities that would consider similar sized coal or natural gas plants. We have included in the NuScale Power Summary Presentation a chart that compares the LCOE of a NuScale Plant, first plant and nth plant, to other technologies based on analyses and methodologies by the U.S. Energy Information Administration.

Attachments:

NuScale Power Summary Presentation
ICAPP 2015 published paper: "Can Nuclear Energy and Renewables be Friends?"
ICAPP 2016 published paper: "Highly Reliable Nuclear Power for Mission-Critical Applications"
White Paper: Upgrading America's Energy System

NuScale Power, LLC
6500 SW Redwood Lane, Suite 210 Portland, Oregon 97224 Office 503-715-2222 Fax 503-746-6041
www.nuscalepower.com

NuScale Power: Oregon-based clean energy technology

April 14, 2017

Who is NuScale Power?

- Initial concept started with Department of Energy MASLWR program at Oregon State University.
- NuScale Power was formed in 2007 for the sole purpose of completing the design of and commercializing a small modular reactor – the NuScale Power Module (NPM).
- Fluor became lead investor in 2011.
- In 2013, NuScale won $217M in matching funds in a competitive DOE funding opportunity.
- >350 patents granted or pending in 20 countries.
- >300 full-time employees, with majority in Portland and Corvallis offices
- In 2016, NuScale paid more than $27M in Oregon salaries and $2M in Oregon taxes.
- Working with Oregon-based suppliers including: Oregon Iron Works, Harris Thermal, Greenberry, and many more.
- NPM design currently undergoing rigorous review by the U.S. Nuclear Regulatory Commission.

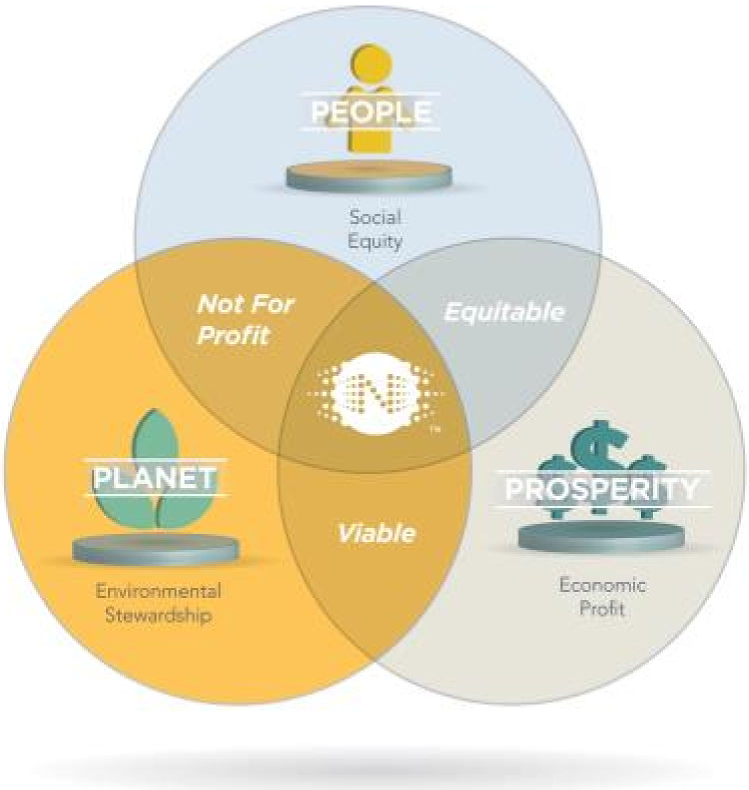
NuScale Engineering Offices Corvallis, OR

One-third scale NIST-1 Test Facility

NuScale Control Room Simulator

NuScale Nonproprietary

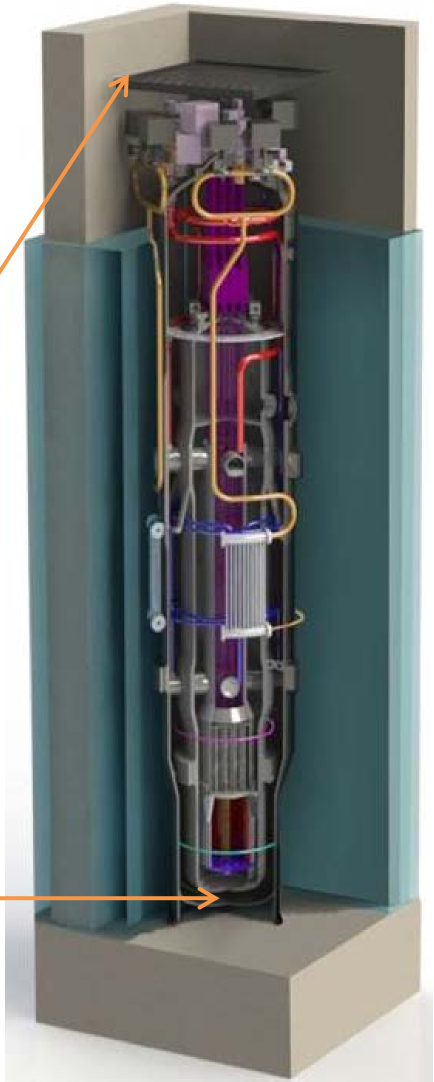
Commitment to People, Planet, Prosperity



NuScale Power provides scalable advanced nuclear technology for the production of **electricity, heat, and water** to improve the quality of life for people around the world.

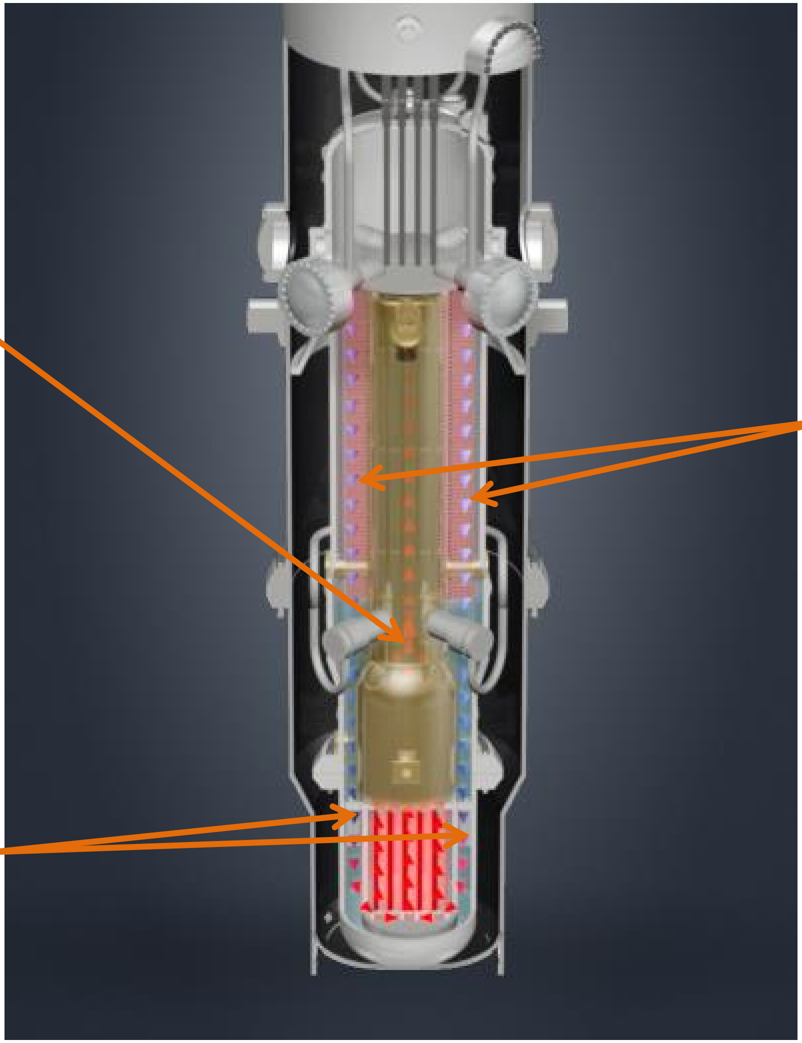
What is a NuScale Power Module?

- A NuScale Power Module (NPM) includes the **reactor vessel, steam generators, pressurizer,** and **containment** in an integral package.
- Each individual NPM is 50 MWe (gross), small enough to be factory built for easy transport and installation.
- The NPM has a simple design that eliminates reactor coolant pumps and large bore piping along with 13 other systems and components needed to protect the core in large conventional reactors.
- Each NPM has a dedicated turbine generator train for flexible, independent operation.
- NPMs can be incrementally added to match load growth - up to 12 NPMs for 600 MWe gross (~570 net) total output.



Coolant Flow Driven By Physics

Convection **– energy from the nuclear reaction heats the primary reactor coolant causing it to rise by convection and natural buoyancy through the riser, much like a chimney effect**

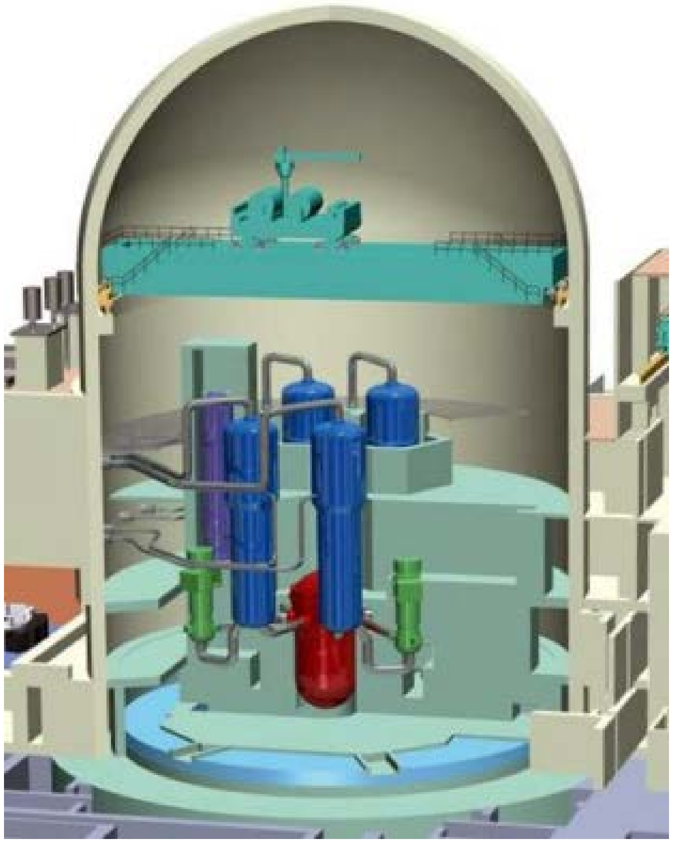


Conduction **– heat is transferred through the walls of the tubes in the steam generator, heating the water (secondary coolant) inside them to turn it to steam. Primary water cools.**

Gravity **– colder (denser) primary coolant "falls" to bottom of reactor pressure vessel, cycle continues**

NPM Size Comparison

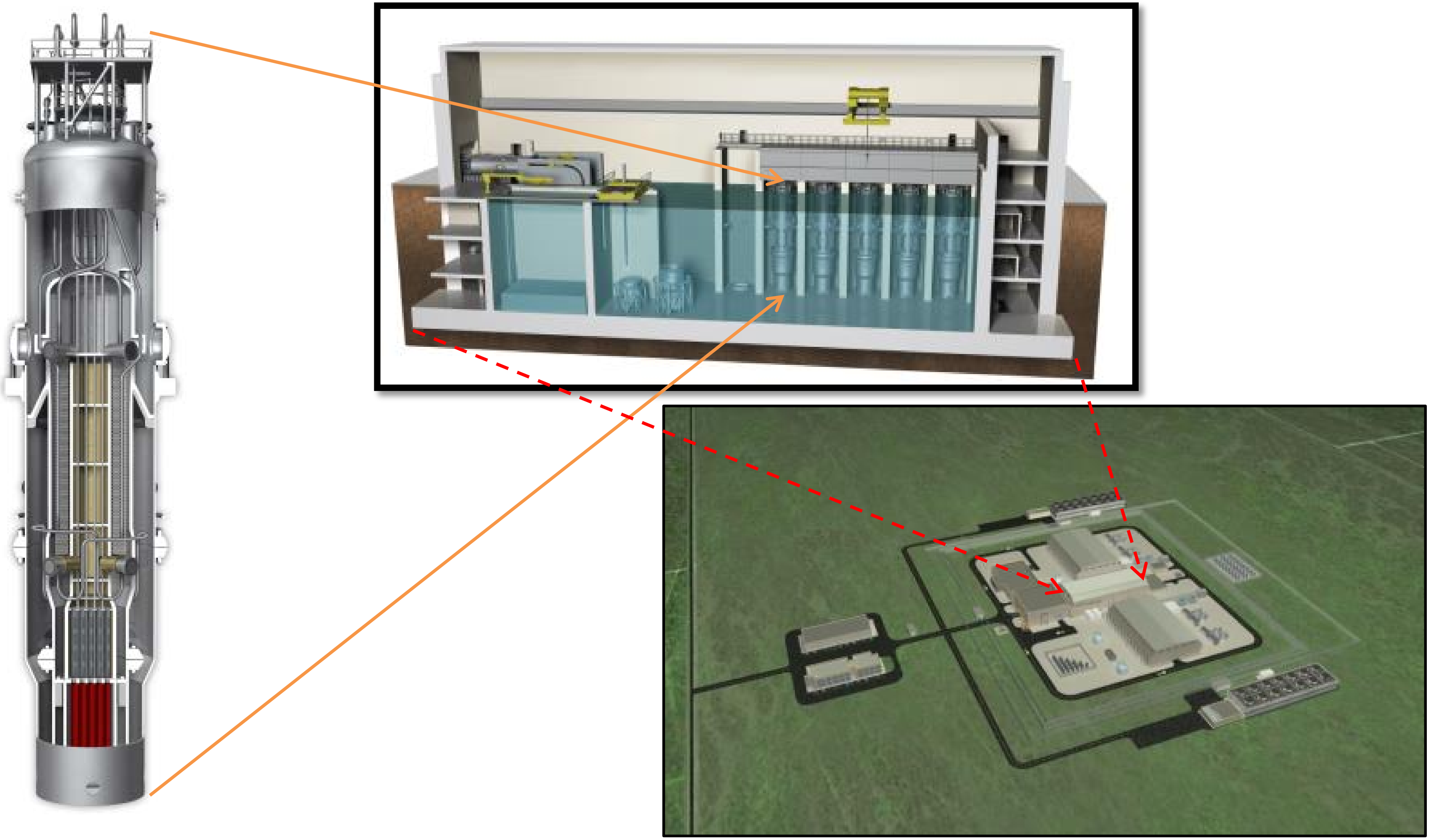
Typical 1000 MW Pressurized-Water Reactor Containment & Reactor System



*Source: NRC

NuScale Power Module
50 MWe Combined Containment Vessel and Integral Reactor System

NuScale Power Plant - Overview



Advantages of Small Modular Approach

Diverse Applications

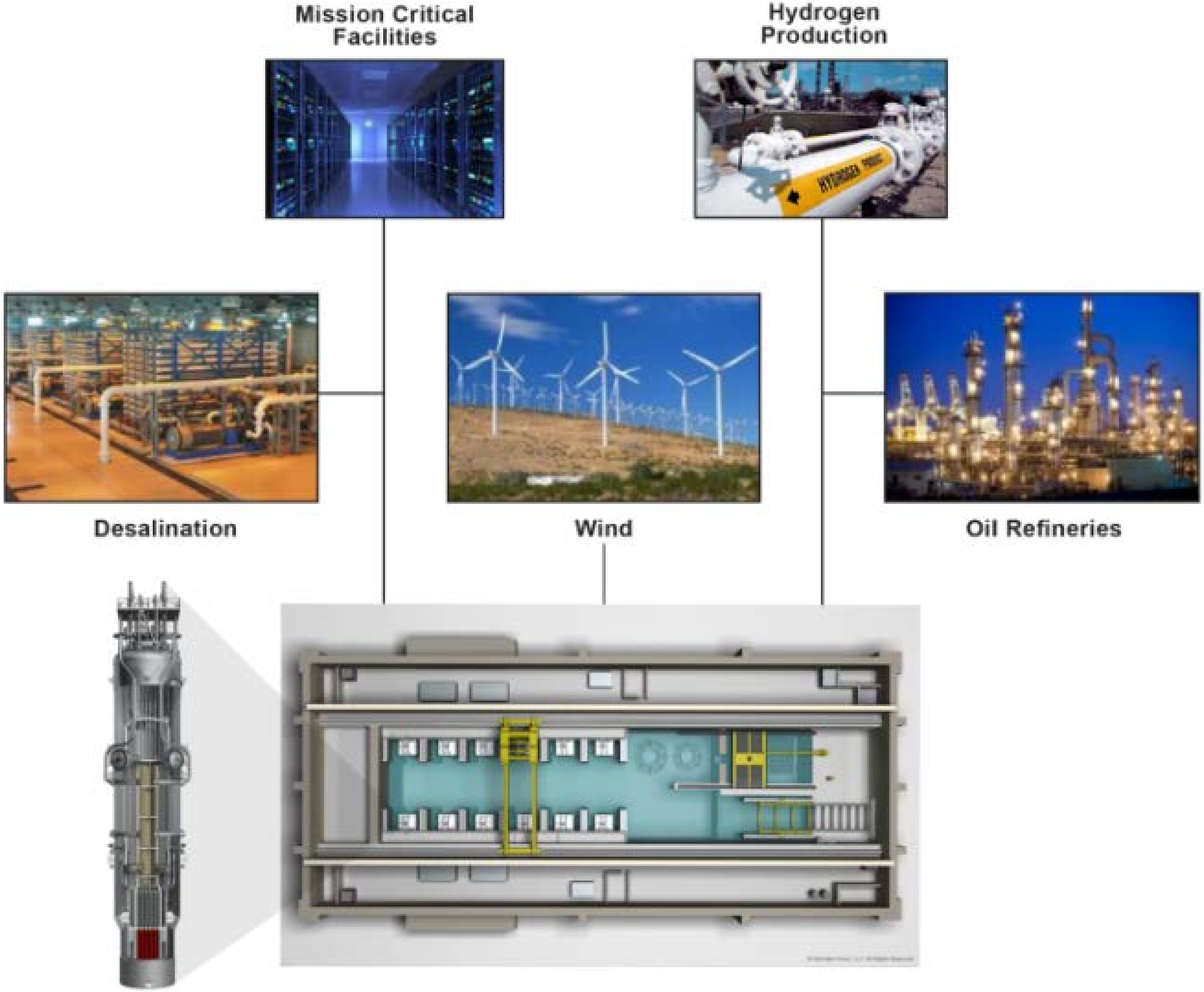
NuScale Power provides scalable advanced nuclear technology for the production of **electricity, heat, and water** to improve the quality of life for people around the world.

Modular and scalable approach, along with flexible operation, allows for diverse applications.

NuScale has completed 5 studies with partners on:

- **Clean Water** - Desalination
- **Clean Transportation Fuel** – Hydrogen Production
- **Clean Air** - Reduction of Carbon Emissions at Oil Refineries
- **Clean Energy** - Facilitating Growth of Renewables – Load Following
- **Reliable Power** – Protecting Critical Infrastructure

NuScale Diverse Energy Platform

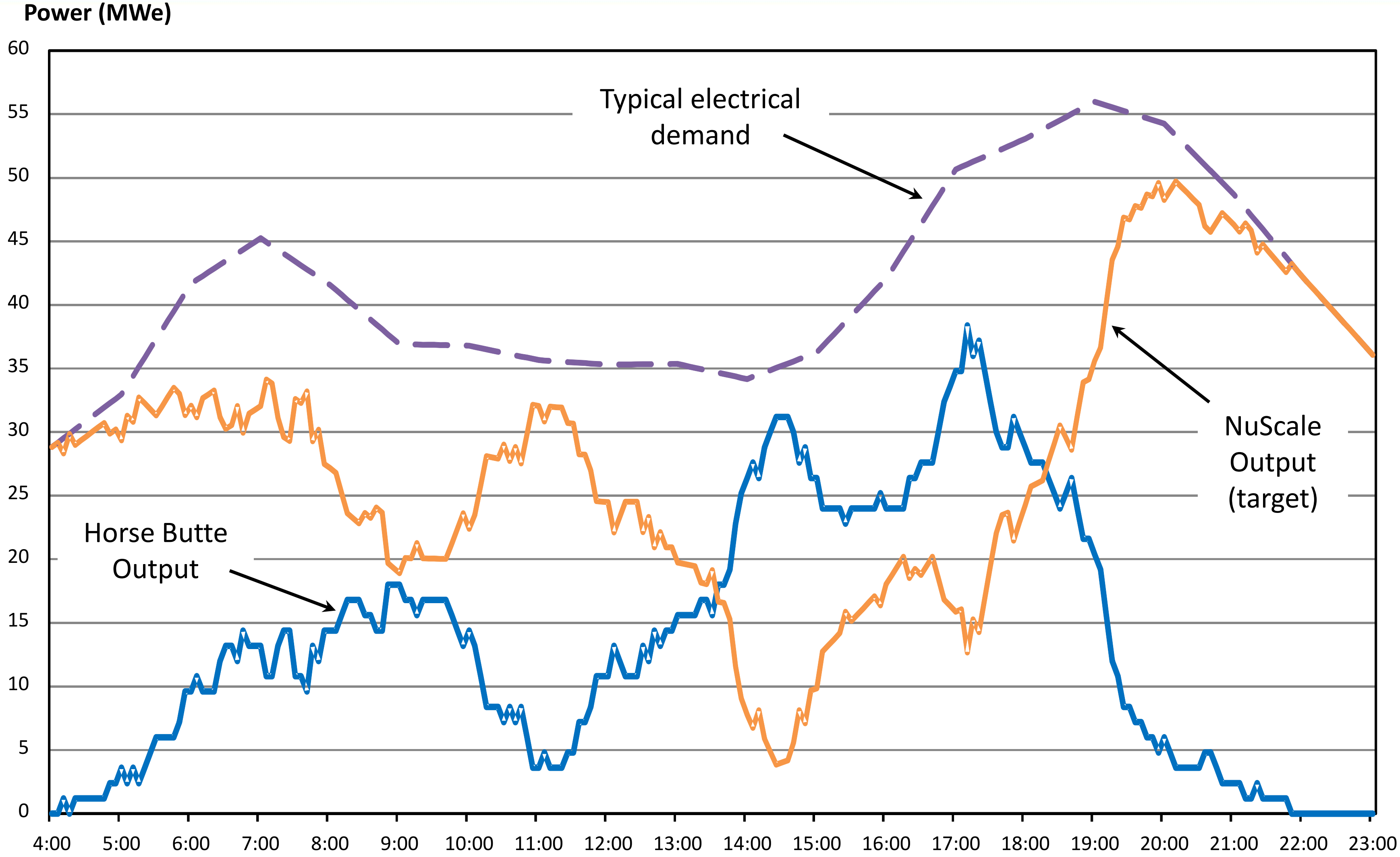


Integration with Wind Farm

(With UAMPS and Energy Northwest)

- NuScale includes unique capabilities for following electric load requirements as they vary with customer demand and rapid output variations from renewables: NuFollow™
- There are three means to change power output from a NuScale facility:
  - **Dispatchable modules** – taking one or more reactors offline for extended periods of low grid demand or sustained wind output
  - **Power Maneuverability** – adjusting reactor power for one or more modules. Meets EPRI URD Rev 13
    - 24 hour load cycle 100%→20%→100%
    - Ramp Rate 40% per hour
    - Step Change 20% in 10 minutes
  - **Turbine Bypass** – bypassing turbine steam to the condenser (short time frames
- Explored integration with Horse Butte wind farm in Idaho

Load-Following with Horse Butte Wind Farm



NuScale Nonproprietary

Reliable Power for Mission Critical Facilities

UTILITY MACROGRID

- Connection to a micro-grid, island mode capability, and the ability for 100% turbine bypass allows a NuScale plant to assure 100MWe net power at 99.99% reliability over a 60 year lifetime
- Using highly robust power modules and a multi-module plant design can provide clean, abundant and highly reliable power to those utility customers who require it
- Working with utilities and customers to get "Five 9s"

470 MWe (net)
> 95% Capacity

NuScale 12-Module Plant

DEDICATED MICROGRID
100 MWe (net)
> 99.99% Availability

MISSION CRITICAL FACILITY

Resiliency

Natural Disasters

- NRC regulations require that the plant is capable of safely withstanding natural hazards, such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches.
- The NuScale design provides the capability to withstand these natural events without depending on electrical power or external sources of cooling water.

Terrorism

- NRC regulations require a variety of measures to protect nuclear reactors and stored fuel against sabotage, theft, diversion, and other malicious acts.
- Physical protection includes both design features incorporated in the NuScale design and operational programs to be provided by the plant operator (e.g., an armed response force).

Aircraft Impact

- The NuScale design incorporates design features and functional capabilities to assure the reactor core remains cooled, the containment remains intact, spent fuel cooling is maintained, and spent fuel pool integrity is maintained in the event of the worst-case assumed aircraft strike, exceeding that of the minimum NRC requirements.

Cyber Security

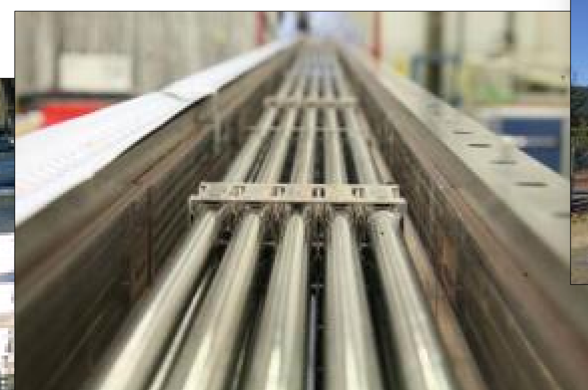
- NRC regulations require measures to protect digital computers, communication systems, and safety-related networks from cyber-attacks.
- NRC requires the facility to protect against cyber attacks that would compromise the integrity, deny access, or impact the operation of those systems, networks, and equipment.

The Future of Energy Getting Closer

NuScale RPV Head Ingot Being Forged

NuScale Control Room Simulator

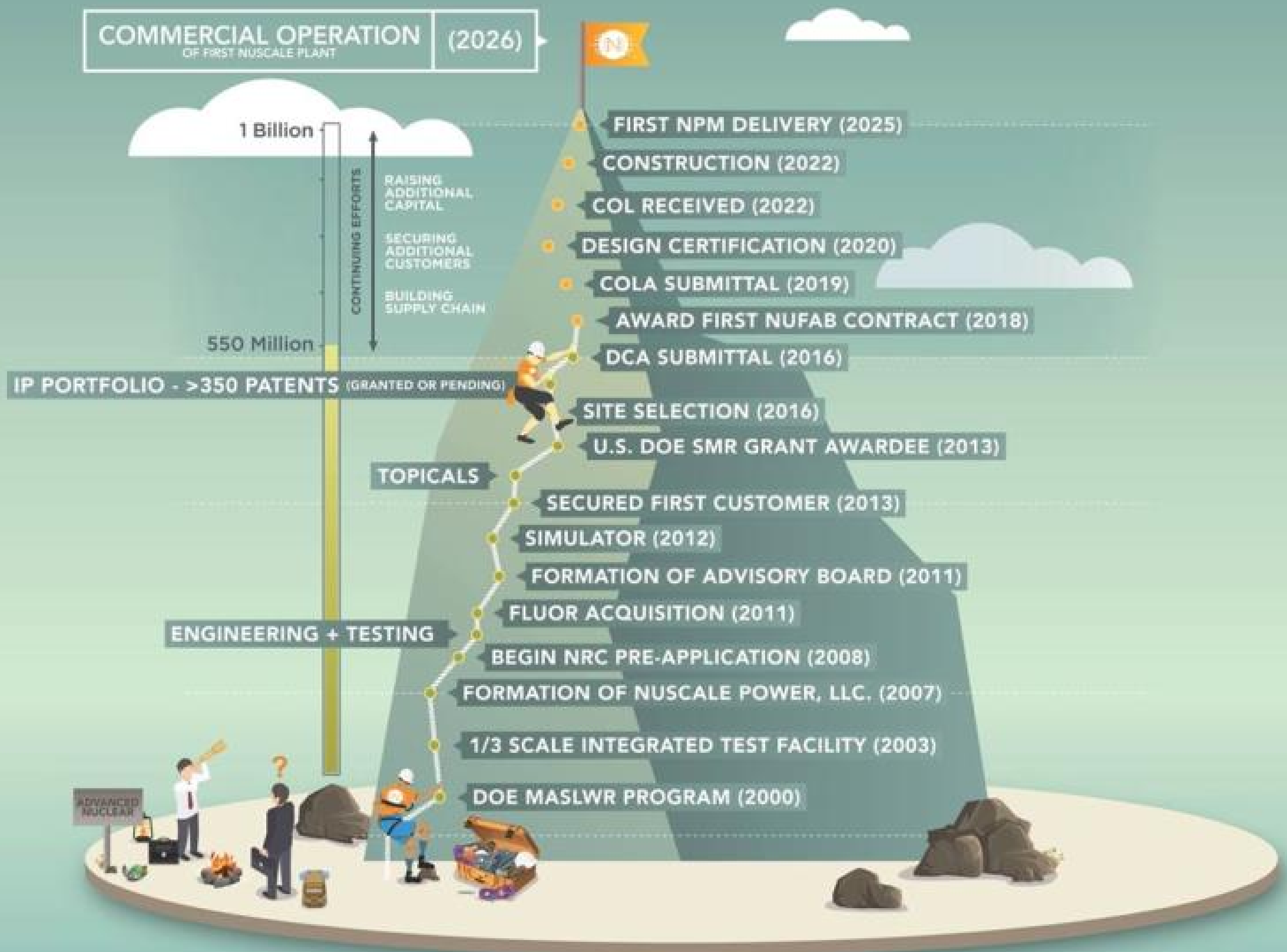
NuScale Full-scale Upper Module Mockup



NuFuel HTP2 Testing

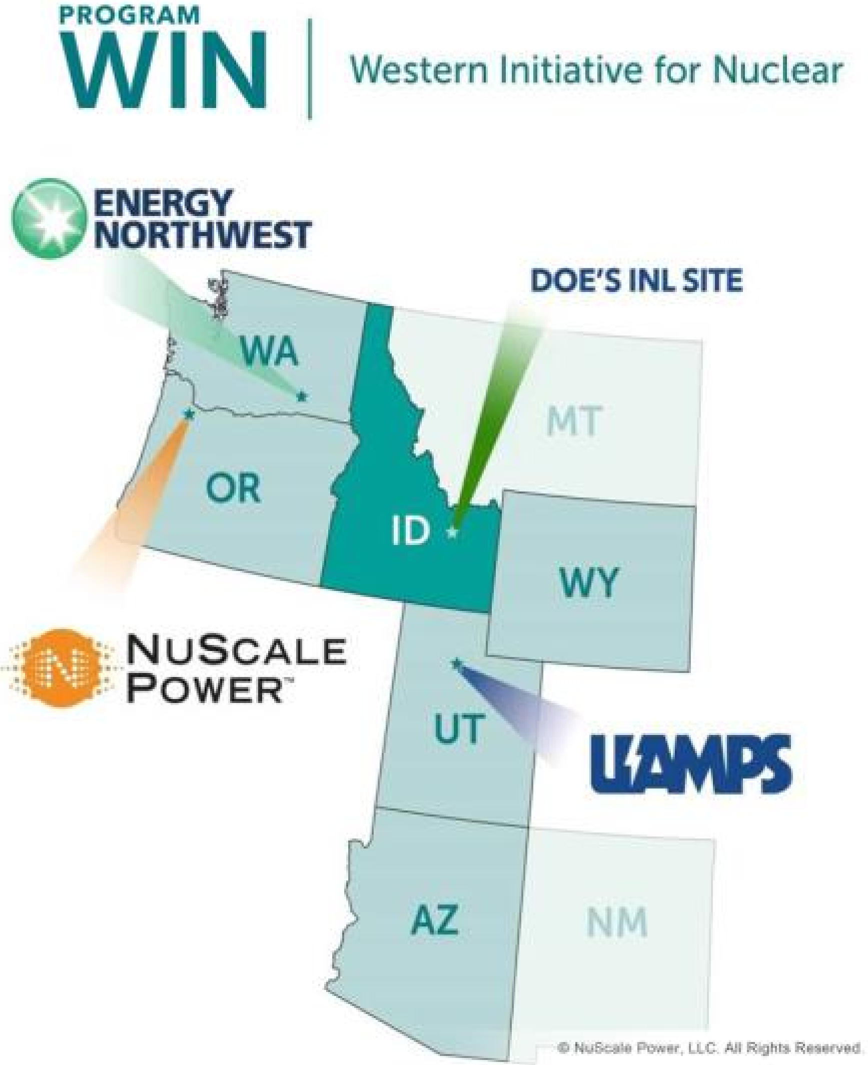
NuScale Integral System Test Facility (Oregon State University)

Blazing the Trail to Commercialization



First Deployment: UAMPS CFPP

- Utah Associated Municipal Power Systems (UAMPS) Carbon Free Power Project (CFPP) will be first deployment
- Preferred location within the Idaho National Laboratory (INL) site
- A 12-module plant (600 Mwe gross)
- DOE awarded $16 million in cost sharing to perform site selection, secure site and water, and prepare combined operating and license application to NRC
- 2026 commercial operation



NUSCALE POWER

Construction Jobs

Construction Jobs per 600 MW Plant	**1,209**
Carpenter, heavy equipment operator, laborer, welders	388
Electricians	182
Ironworkers, welders	91
Pipefitters, plumbers	90
Painters, insulators, laborers	89
Electrical Technicians	76
Mason, sheet metal workers, plasterer	51
Home Office: Engineers, Project Management, Supply Chain, QA, Security, HR	242

Plant Operation Jobs

Plant Staffing for Typical Baseload Power Plants

	Coal	Natural Gas Combined Cycle	NuScale Power Plant
Plant Employees (per 600 MWe)	146	24	365
Average Annual Wage for Staff	$71,800	$75,130	$89,940

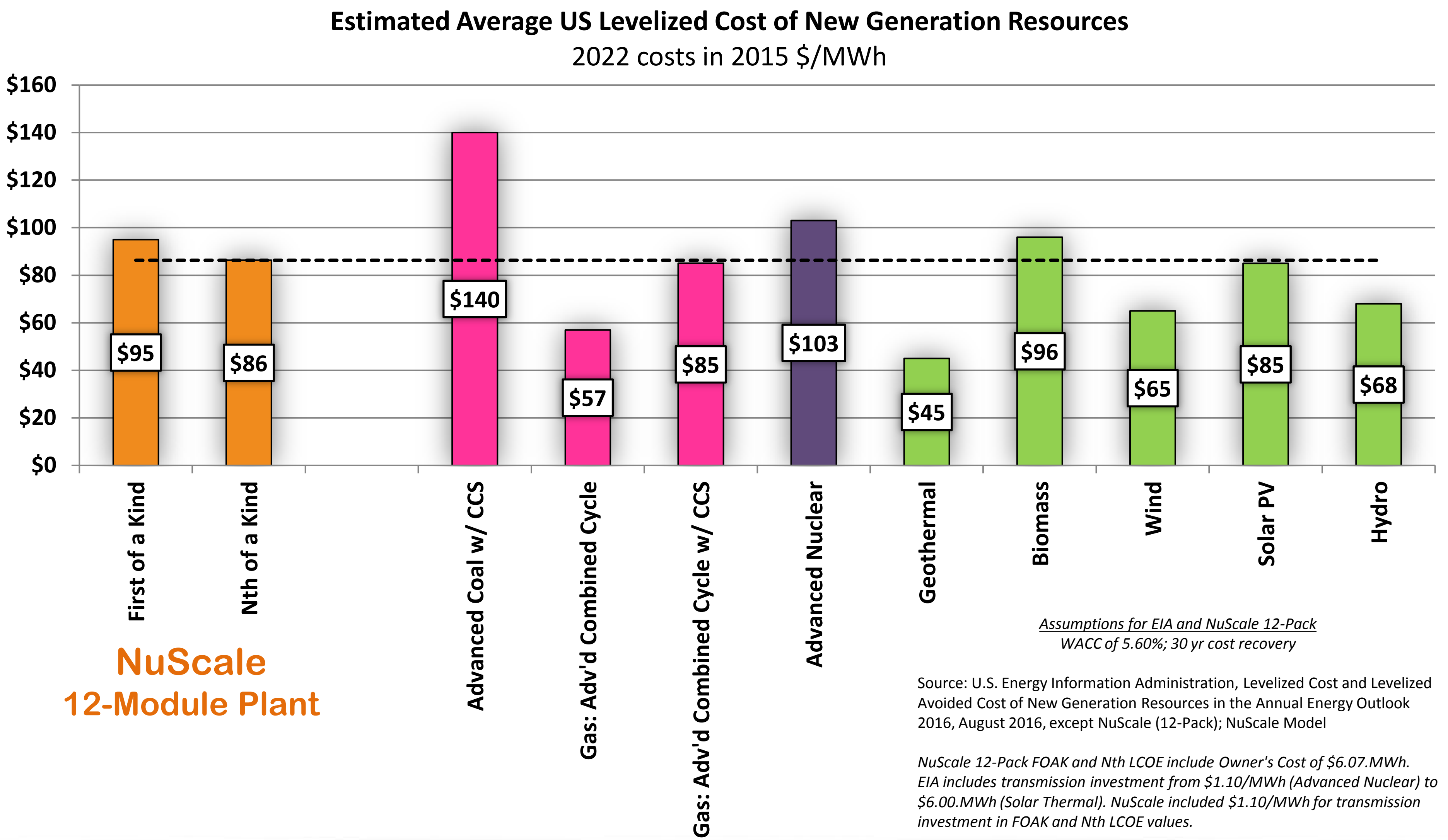
Jobs by educational requirement at 600 MW NuScale Power Plant

- Associates Degree, Vocation, or Military 170
- High School Diploma 110
- BS Engineering 85

➢ *Opportunity to train current coal plant workers to work at NuScale plant*

Sources: Utah Associated Municipal Power Systems (UAMPS); NuScale Power; Occupational Employment and Wages, May 2015, Bureau of Labor Statistics

Levelized Cost of Electricity

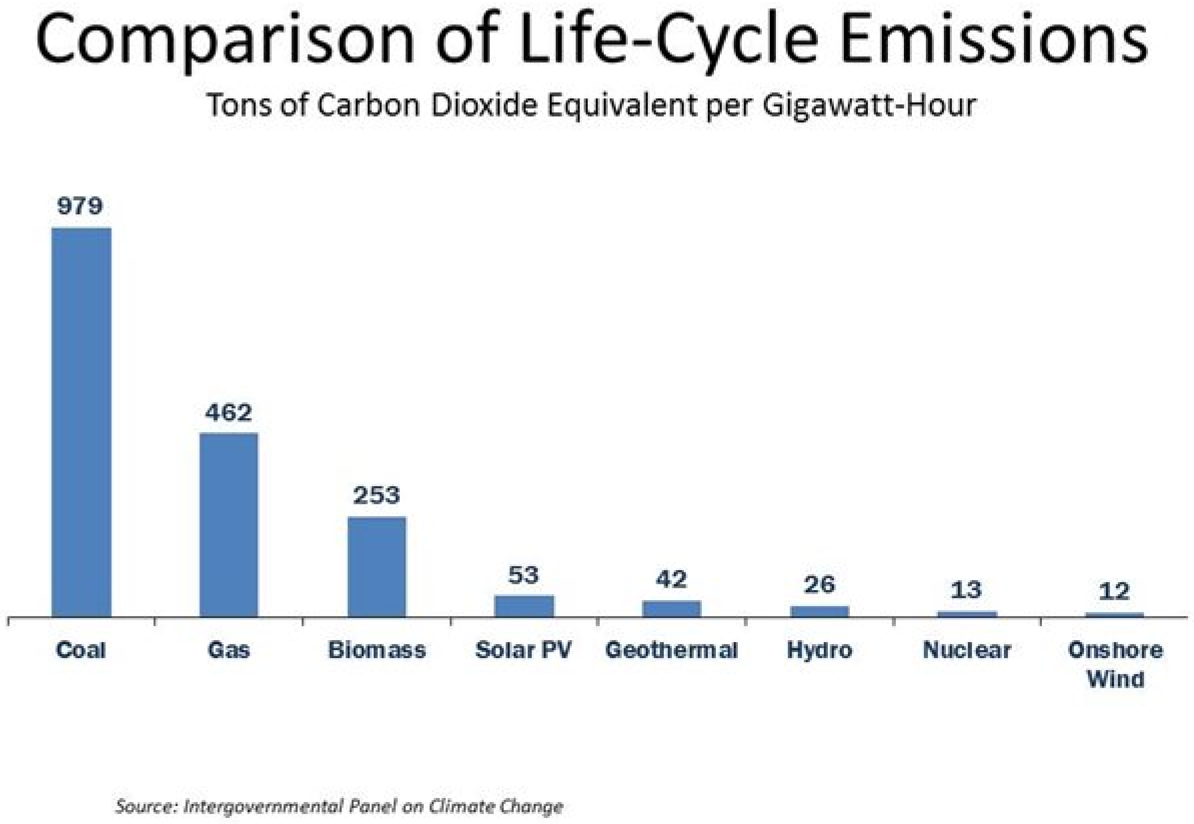


Assumptions for EIA and NuScale 12-Pack
WACC of 5.60%; 30 yr cost recovery

Source: U.S. Energy Information Administration, Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016, August 2016, except NuScale (12-Pack); NuScale Model

NuScale 12-Pack FOAK and Nth LCOE include Owner's Cost of $6.07.MWh. EIA includes transmission investment from $1.10/MWh (Advanced Nuclear) to $6.00.MWh (Solar Thermal). NuScale included $1.10/MWh for transmission investment in FOAK and Nth LCOE values.

Nuclear Energy is Low-Carbon Energy



Acknowledgement & Disclaimer

This material is based upon work supported by the Department of Energy under Award Number DE-NE0000633.

NuScale Power™

6650 SW Redwood Lane, Suite 210
Portland, OR 97224
971.371.1592

1100 NE Circle Blvd., Suite 200
Corvallis, OR 97330
541.360.0500

11333 Woodglen Ave., Suite 205
Rockville, MD 20852
301.770.0472

6060 Piedmont Row Drive South, Suite 600
Charlotte, NC 28287
980.349.4804

1933 Jadwin Ave., Suite 130
Richland, WA 99354

1st Floor Portland House
Bressenden Place
London SW1E 5BH
United Kingdom
+44 (0) 2079 321700

http://www.nuscalepower.com
Twitter: @NuScale_Power

NUSCALE POWER™

Can Nuclear Power and Renewables be Friends?

D. T. Ingersoll,[a] C. Colbert,[a] Z. Houghton,[a] R. Snuggerud,[a] J. W. Gaston[b] and M. Empey[c]
[a]NuScale Power, LLC
1100 NE Circle Blvd, Suite 200, Corvallis, OR 97330
[b]Energy Northwest
P. O. Box 968, Richland WA 99352-0968
[c]Utah Associated Municipal Power Systems
155 North 400 west, Suite 480, Salt Lake City, UT 84103
Tel: 541-360-0585, Email: dingersoll@nuscalepower.com

Abstract – *The increasing penetration of renewables, especially wind generation, have dramatically changed the economics and realities of grid management in ways that now encourage some level of load-following capabilities for historically baseload plants, including nuclear. The NuScale small modular reactor design currently under development in the United States is well suited for integration with renewables because of several design features related to the nuclear steam supply system, the power conversion system, and the overall plant architecture. The multi-module nature of a NuScale plant allows the plant output to be varied in three ways spanning a wide range of different time frames: (1) taking one or more modules offline for extended periods of sustained wind output, (2) adjusting reactor power for one or more modules for intermediate periods to compensate for hourly changes in wind generation, or (3) bypassing the steam turbine for rapid responses to wind generation variations. Results are presented from a recent analysis of nuclear-wind integration that utilized historical wind generation data from the Horse Butte wind farm in Idaho. Also discussed is the experience of Energy Northwest in their implementation of limited load-shaping at the Columbia Generating Station.*

I. INTRODUCTION

Competition for constrained federal funding and ideological biases have tended to pit various energy technologies against each other, especially between renewable sources, typically wind and solar, and traditional sources, including hydro, coal, natural gas, and nuclear. Of the traditional sources, only hydro and nuclear offer abundant power with virtually no emission of greenhouse gases (GHG). However, new sites for large hydroelectric plants are very limited and have their own environmental issues. As such, nuclear appears to be the only resource that has the potential to not only add to the "clean" energy provided by wind and solar technologies, but actually enable larger contributions of these renewable sources without jeopardizing grid stability or risking unmet electricity demand. However, doing so may require nuclear plant designs to incorporate features that enhance their load-following capabilities.

Conventional wisdom suggests that nuclear power plants should be operated continuously at full capacity and that natural gas plants are best suited to provide "peaking" capability to meet excess demand. This historical strategy has been driven mostly by economic considerations since nuclear plants have relatively high capital cost and low fuel cost compared to natural gas plants. Because of the low fuel cost in a nuclear plant, running the plant at 50% power has minimal impact on operations costs but reduces revenue by one-half. The increasing penetration of renewable sources, especially wind, has altered this economic argument since wind turbines are also capital-intensive (per unit of power produced) and their fuel cost is zero. Also, wind generation tax credits encourage their full-out operation. Finally, some regional policies require grid dispatchers to preferentially use renewable energy first, which exacerbates the economic challenges of operating base-load plants and are driving plant owners to change their concepts of economic dispatch.

Many nuclear plants currently operating were designed to load-follow and were originally outfitted with automatic grid control (AGC) features. However, the U.S. Nuclear Regulatory Commission established a policy that precluded the use of automatic dispatching for true load following, although they allow manual load-shaping if conducted by a licensed reactor operator. Globally, France's pressurized water reactors routinely load-follow due to the high percentage of nuclear-generated electricity on their grid (nominally 75%). Canadian reactor units are also required to load-follow due to the percentage of nuclear power there and German reactors load-follow primarily because of a relatively high contribution of intermittent wind generation on their grid.[1]

Load-following with nuclear plants, especially larger plants, requires complicated power maneuvering procedures and plant components that can tolerate thermal cycling. The 1,170 MWe Columbia Generating Station (CGS) in Richland, Washington, is the only commercial nuclear plant in the United States that performs routine power maneuvering in response to anticipated load variations—a process that they refer to as load shaping. The load-shaping capability is required during the spring season to avoid excessive spill-over at the hydroelectric plants in the Bonneville Power Authority (BPA) network. An increasing wind generating capacity in the BPA network may also introduce new load-shaping requirements at the CGS. Case in point: a record-breaking 4,289 MWe of wind generation was produced on the BPA transmission network on October 16, 2012, which was the first time in history that wind generation surpassed the output of the region's hydroelectric generation.[2]

The CGS performs short-term load shaping according to guidelines agreed to by the BPA and approved by the US NRC. Generally, operators adjust reactor recirculation flow to maneuver the plant to 85% of full power and adjust control rods to drop power to 65% power. The maneuvers are performed in response to down-power requests from BPA, which must be received at least 12 hours prior for reduction to 85% power, 48 hours for reduction to 65% power and 72 hours for full shutdown. Power maneuvers between 100% and 85% using reactor recirculation flow adjustments are relatively straight forward but can require many small adjustments due to the buildup and decay of xenon in the fuel, which is a strong neutron absorber. As an example, a single step-change cycle to 85% power, return to 100% power and subsequent reduction back to 85% power can require as many as 17 different reactivity manipulations using recirculation flow and control rod movement.

II. SMALL MODULAR REACTORS

There has been a growing interest in the United States and internationally for the development and deployment of smaller sized commercial nuclear power plants to meet the expanding need for clean, abundant power in a broader range of energy markets. These small modular reactors (SMRs) are characterized by having power ratings generally below 300 MWe and are substantially factory manufactured and installed into the plant rather than stick-built on the site. Multi-module deployments use multiple identical SMRs in a single plant to provide a scalable, flexible approach to deploying nuclear power. Because of their scalable and flexible plant features, these designs are expected to be more readily adaptable to integration with inherently variable generating sources such as wind.

A highly innovative SMR design has been under development in the United States since 2000 and is being commercialized by NuScale Power with the strong financial backing of Fluor Corporation and the US Department of Energy. The robust and scalable nature of the NuScale plant design, which is based on well-established light-water reactor (LWR) technology, creates a unique solution to provide affordable, clean and abundant energy to the grid in the near-term with the opportunity to complement the increasing generation from renewable sources, especially wind turbines. The coupling of emissions-free renewables and nuclear power can reduce the overall greenhouse gas (GHG) emissions in the United States to help achieve our desired air quality standards and meet evolving GHG emission policies in response to climate change concerns.

The NuScale plant features are especially well suited for the energy demographics in the northwestern United States and considerable interest has emerged in deploying NuScale plants in this region. The Utah Associated Municipal Power Systems (UAMPS) recently announced the establishment of a Carbon Free Power Project to pursue the construction of a NuScale plant within their operating region, potentially on or near the Idaho National Laboratory Site outside Idaho Falls, ID. Also near Idaho Falls is the Horse Butte Wind Farm (HBWF), which contributes nearly 60 MWe to UAMPS Members. Therefore, an initial analysis was conducted to understand the potential integration of a NuScale plant with the HBWF and to demonstrate the compatibility and synergy of these clean energy sources. This paper provides a brief description of the design and characteristics of the NuScale SMR and the HBWF, followed by results and conclusions from the integration of these two generating sources, including implications on load-following operations of the NuScale plant.

III. NUSCALE DESIGN OVERVIEW

The NuScale SMR plant is an innovative design that builds on sixty years of world-wide experience with the commercial application of pressurized water reactor (PWR) technology. The design incorporates several features that reduce complexity, improve safety, enhance operability, and reduce costs. From the outset, the top level design goals for the NuScale plant have been to achieve a high level of safety and asset protection while providing an affordable approach to nuclear power that gives the plant owner the maximum flexibility in plant application while allowing for standardized and simplified construction, operation and maintenance to improve safety and lower lifecycle costs.

The fundamental building block of the NuScale plant is the NuScale power module. The power module consists of a small 160 MWt reactor core housed with other primary system components in an integral reactor pressure vessel and surrounded by a steel containment pressure vessel, which is immersed in a large pool of water. Several power modules (as many as 12) are co-located in the same pool to comprise a single plant. A dedicated turbine/generator system is coupled to each module to provide a gross electrical power of 50 MWe.

A diagram of the NuScale power module is shown in Fig. 1. The reactor vessel is approximately 17.7 m (58 ft) tall and 2.7 m (9 ft) in diameter. The integral vessel contains the nuclear core consisting of 37 fuel assemblies and 16 control rod clusters. Above the core is a central hot riser tube, a helical coil steam generator surrounding the hot riser tube, and an internal pressurizer.

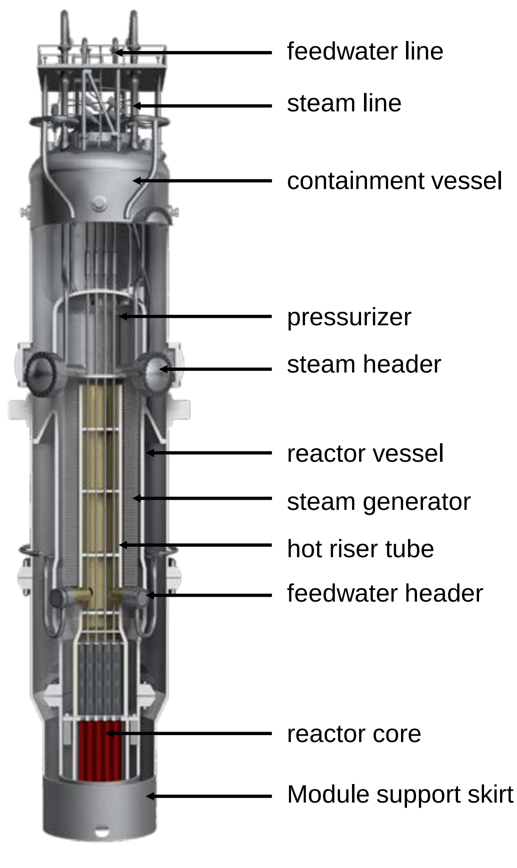


Fig. 1. Schematic of a NuScale power module.

Primary reactor coolant is circulated upward through the reactor core and the heated water is transported upward through the hot riser tube. The coolant flow is turned downward at the pressurizer plate and flows over the shell side of the steam generator, where it is cooled by conduction of heat to the secondary coolant and continues to flow downward until its direction is again reversed at the lower reactor vessel head and turned upward back into the core. The coolant circulation is maintained entirely by natural buoyancy forces of the lower density heated water exiting the reactor core and the higher density cooled water exiting the steam generator annulus. On the secondary side, feedwater is pumped into the steam generator tubes where it boils to generate superheated steam, which is circulated to a dedicated turbine-generator system. Low pressure steam exiting the turbine is condensed and recirculated to the feedwater system.

The entire nuclear steam supply system is enclosed in a steel containment vessel that is approximately 23.2 m (76 ft) tall and 4.6 m (15 ft) in diameter. The small volume, high design pressure containment vessel is a unique feature of the NuScale design and contributes significantly to the large safety margins and overall resilience of the plant. Multiple modules are placed in a single large pool contained within an aircraft-resistant reactor building. A cut-away view of a twelve-module reactor plant is shown in Fig. 2.

As can be seen in Fig. 2, the NuScale power modules are located below grade in a large common pool of water. The reactor pool provides passive containment cooling and decay heat removal. Specifically, the pool provides an assured heat sink with a capacity to absorb the entire decay heat produced by up to 12 fully mature cores for greater than 30 days. After 30 days, air cooling of the 12 NuScale power modules is sufficient to avoid fuel damage. The pool also helps to reduce and delay fission product releases in the unlikely event of fuel failure and provides radiation shielding outside containment to reduce operational exposure. Finally, the below grade pool provides enhanced physical security by adding additional challenges to fuel access.

There are several key features of the NuScale plant that collectively distinguish it from the many other SMRs being developed today.

- *Compact size.* The nuclear steam supply system, including containment, can be entirely prefabricated off site and shipped by rail, truck or barge to the site. This reduces construction time due to parallel fabrication considerations and reduces overall schedule uncertainty due to the reduced amount of on-site construction activities.
- *Natural circulation cooling.* Natural circulation operation and integral design eliminates pumps, pipes, and valves in the primary system and hence the maintenance and potential failures associated with those components, while also reducing house load.
- *Triple Crown of Safety.* The NuScale plant, with its innovative design is able to safely shut down and self-

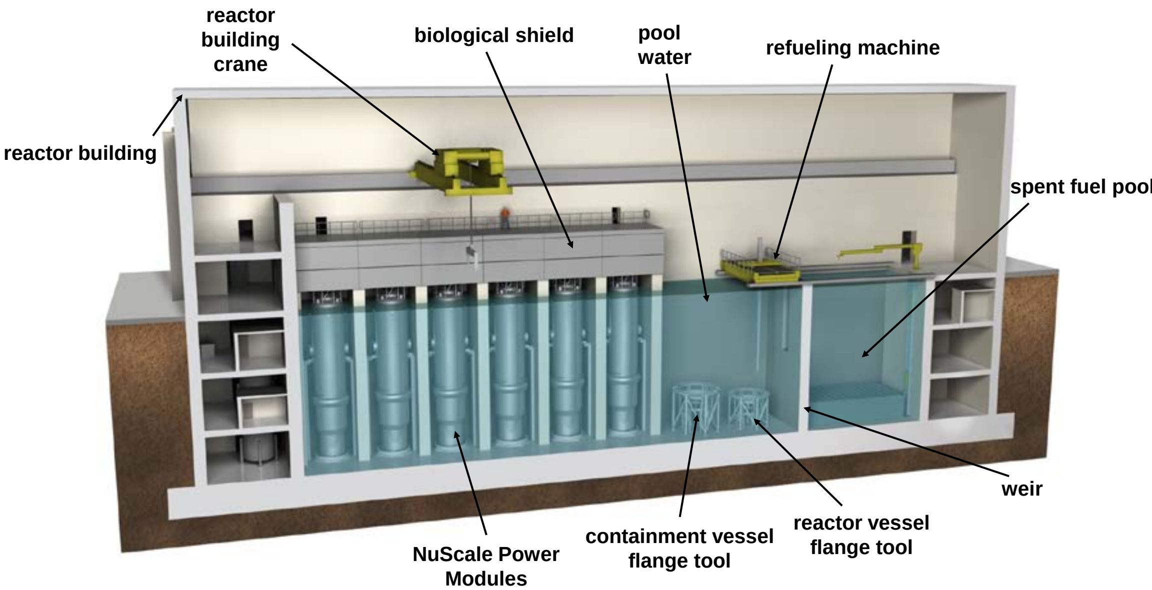


Fig. 2. Cut-away view of reactor building for 12-module NuScale plant.

- cool with no operator action, no AC or DC power, and no additional water for an unlimited period of time.
- *Dedicated power trains.* Because each power module, including the power conversion system, is independent of other modules, each module can be shut down while other modules continue to operate. This feature allows for flexible dispatching of the plant output to match grid demand or balance intermittent generation from wind turbines.

The synergy created by these unique features, especially plant simplicity and the plant-level flexibilities afforded by the multi-module configuration, all combine to position the NuScale plant for early and successful integration with renewable generating sources.

IV. UAMPS CARBON FREE POWER PROJECT

In October 2014, the Utah Associated Municipal Power Systems (UAMPS) announced the introduction of their Carbon Free Power Project (CFPP). UAMPS is a consortium of 44 utilities with service areas in eight states, including Utah, Arizona, New Mexico, Idaho, California, Nevada, Oregon and Wyoming. The consortium established their CFPP to encourage the deployment of clean baseload electrical power options in response to the expected closure of coal fired generating plants in the coming decades. As a result of their SmartEnergy analysis, UAMPS concluded that SMRs represent an important option for their future consideration and are working with NuScale Power for the deployment of the first NuScale plant within the UAMPS service area. Although site evaluations are underway, a promising location for the plant is in the vicinity of Idaho Falls, Idaho—possibly on the 890 mi^2 Idaho National Laboratory (INL) federal reservation. Energy Northwest (ENW) is expected to be the operator of the UAMPS CFPP plant in Idaho. They bring not only their experience in operating the CGS, but also their experience in load-shaping maneuvers on a large nuclear plant.

Also in the vicinity of Idaho Falls is the Horse Butte wind farm (HBWF). The 17,600 acre wind farm was commissioned in 2012 and is comprised of 32 Vestas V100 turbines, each with a capacity of 1,800 kWe, yielding a maximum generating capacity of 57.6 MWe. The turbines, operated by UAMPS, have a hub height of 80 m and a diameter of 100 m. The location of the HBWF and the INL Site relative to Idaho Falls is shown in Fig. 3.

Fig. 3. Location of Horse Butte wind farm and Idaho National Laboratory Site in Idaho.

V. INTEGRATING NUSCALE PLANT WITH HBWF

The NuScale plant incorporates unique features that enhance its ability to load follow, either due to changes in electricity demand or variable generation by renewable sources on the grid. This is accomplished through a combination of the small unit capacity of a NuScale module (50 MWe gross) and a multi-module approach to the plant design. This design strategy provides a uniquely scalable plant and gives the plant owner considerable flexibility in both the build-out of the plant and also its operation, including for load-following. The key power management options of the NuScale plant for load-following operations, designated NuFollow™, include the following:

- Taking one or more modules offline for extended periods of low grid demand or sustained wind output,
- Maneuvering reactor power for one or more modules during intermediate periods to compensate for hourly changes in demand or wind generation, or
- Bypassing the module's steam turbine directly to the condenser for rapid responses to load or wind generation variations.

Each of these methods has a different response time and implications with respect to plant performance and operation. In general, their impacts are reduced relative to large plants due to the smaller reactor systems, smaller turbine/generator systems, and system simplifications that are enabled by the smaller reactor size.

Equipment in the NuScale plant is being designed for load-following operation to further reduce impacts from power cycling. One example is that the module design and operating parameters allow reactor power changes using only control rod movement down to 40% reactor power, i.e. it does not require adjustments to the boron concentration in the primary coolant. This improves the maneuverability of the reactor while not creating additional liquid wastes associated with boron addition and dilution. The condenser is designed to accommodate full steam bypass, thus allowing rapid changes to system output while minimizing the impact to the reactor, which can continue to run at full power. Finally, the multi-module nature of the NuScale plant and the staggered refueling of individual modules result in a plant configuration in which at least one module is near beginning of life (BOL). It is generally easier to perform power maneuvers on BOL cores because of the higher reactivity in the core enables™ better xenon override. Therefore the operator has the flexibility to use near-BOL modules to perform power maneuvering functions for intermediate-term load-following while the modules with higher burnup can be used for coarse-level power adjustments.

The Electric Power Research Institute (EPRI) maintains the User Requirements Document (URD), which is a major compendium of guidelines and specifications for standardized plant designs, including specifications for desired load-following characteristics. EPRI recently updated the URD to Rev.13 specifically to envelope SMRs. The new version contains more aggressive load-following specifications to reflect the more flexible features anticipated for SMRs. The NuScale plant is able to meet all of the new Rev.13 requirements, as listed in Table 1.

To understand how well a NuScale plant can mitigate variability from a wind farm, an analysis was conducted using actual wind generation data from the Horse Butte wind farm. The HBWF presents an especially challenging case study because its total generating capacity is comparatively small (less than 60 MWe), which can result in short-term changes in generation that are significant fractions of the farm's total output. Figure 4 shows the frequency of occurrence of 5-minute changes in output from the HBWF, expressed as percent per minute and normalized to the maximum wind generation during a 7-day period. This frequency distribution is compared to similar 7-day results for wind generation across the entire BPA system, which was roughly one hundred times larger than the HBWR output. As seen in the figure, most of the ramp rates for the larger BPA system were on the order of 1% per minute. In contrast, the HBWF experienced a significant number of ramp rates up to 5% per minute. Hence in this case, the smaller HBWF requires a higher level of agility from the NuScale load-following response.

It should be noted, however, that the substantially larger total output from the BPA system results in a different challenge—one of bulk replacement power. Over the same 7-day period shown in Fig. 4, the absolute BPA wind output varied from zero to over 4.2 GWe, and the largest 5-minute change was 136 MWe. Output changes of this magnitude require a combined response of several generating assets on the grid, including nuclear, hydroelectric and fossil.

Figure 5 provides a hypothetical scenario to demonstrate the integration of a NuScale plant with the Horse Butte wind farm. Included in the graph are: (1) the US-averaged daily electricity demand profile (arbitrary normalization) showing typical morning and evening demand peaks, (2) the actual generation from the HBWF taken for a single day in November, 2014, and (3) the output from a single NuScale module that would be needed to meet the grid demand beyond what the HBWF can provide.

Table 1. Load-following characteristics included in EPRI User Requirements Document specifications.

URD Requirement	Rev.12 Description	Rev.13 (SMR) Description
3.4.1.1	24 hour load cycle: 100% → 50% → 100%	24 hour load cycle: 100% → 20% → 100%
3.4.1.1	Ramp rate of 25% per hour	Ramp rate of 40% per hour
3.4.2.1	Capable of automatic frequency response	Capable of automatic frequency response
3.4.3	Step change of 20% in 10 minutes	Step change of 20% in 10 minutes
3.4.4.1	Frequency variation tolerance	Frequency variation tolerance

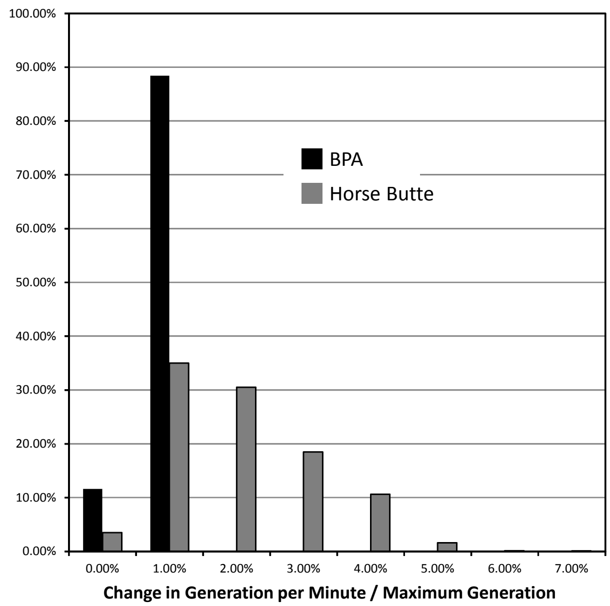


Fig. 4. Impact of wind farm size on relative generation changes.

Figure 6 provides two examples of how the NuScale module might yield the desired output. In one case, shown in the upper portion of the figure, the variation in the NuScale output is entirely a result of turbine bypass, i.e. the reactor continues to operate at full power. The amount of wasted power, which results from dumping main steam directly to the condenser, is also plotted and exactly tracks the power produced by the wind farm. Another approach that achieves the same demand-matching is to maneuver the module's reactor power for coarse-level load shaping and to use the turbine bypass equipment to provide the balance of load-following. This option is shown in the lower portion of the figure. This scenario has the benefit of reducing both the amount of wasted energy and cycling of the power conversion equipment. However, the dispatcher must have an accurate forecast of wind power and the operator must be allowed to make changes in reactor power with minimal notice. Forecast and dispatch adjustments would need to be made hourly to support these types of operations. Also, maneuvering the reactor power introduces a number of operational considerations.

From an economic perspective, it is preferable to not throttle back the nuclear plant or dump steam, but rather sell the excess electricity from the combined output of the HBWF and the gross output from the NuScale module to neighboring utilities. However, this may not be an option in some applications and locations. One method for selling such excess power is currently in the early stages of deployment, the Electricity Imbalance Market (EIM). This new market was established to help balancing authorities cope with increased penetration of non-dispatchable renewable energy. Participation in this market requires the unit to have Automatic Generation Control (AGC), among other features. Adaptation of AGC to nuclear power is not new technology; however it will require new approaches and considerations to accommodate regulatory policies.

An alternative to selling excess capacity is to use the power, either as electricity or steam, to support non-grid applications such as water desalination or chemical production. Using this "hybrid energy system" approach, the combined wind and nuclear output can be optimized to meet grid demand and yield additional valued products without requiring the nuclear plant to vary its output. Interest has been growing in recent years for the economic benefits of hybrid energy systems, especially for integration of nuclear power and renewables.[3,4]

This simple case study demonstrates that the NuScale plant can be integrated with intermittent renewable sources, even for the challenging dynamics of a smaller scale wind farm. The plant's NuFollow™ features allow for enhanced load-following capabilities and several operational flexibilities for responding to demand and generation variations.

Even with the NuFollow™ features, load following with a nuclear plant has several operational and economic impacts. Reactor operations are the least impacted when changes in electrical output are accomplished by closing or opening the bypass valve to redirect main steam flow from the turbine to the condenser. This can be done much more

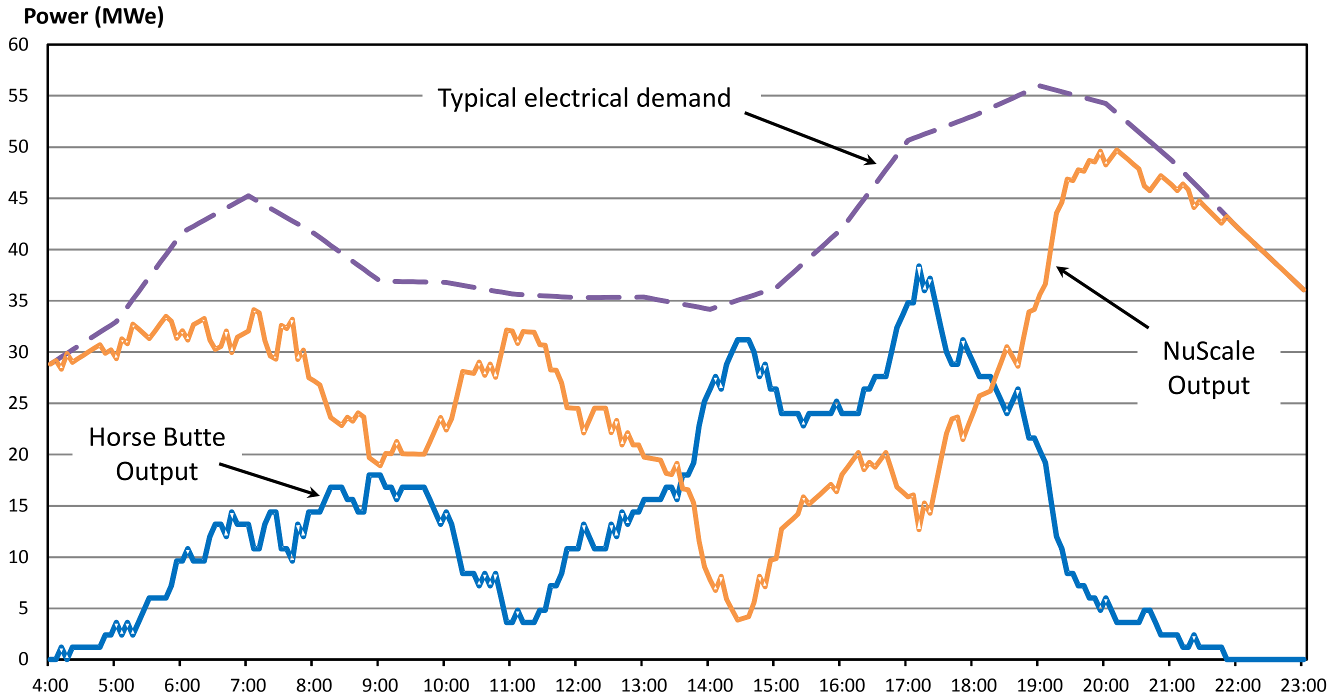


Fig. 5. Example of NuScale module load-following to compensate for generation from the Horse Butte wind farm and daily demand variation.

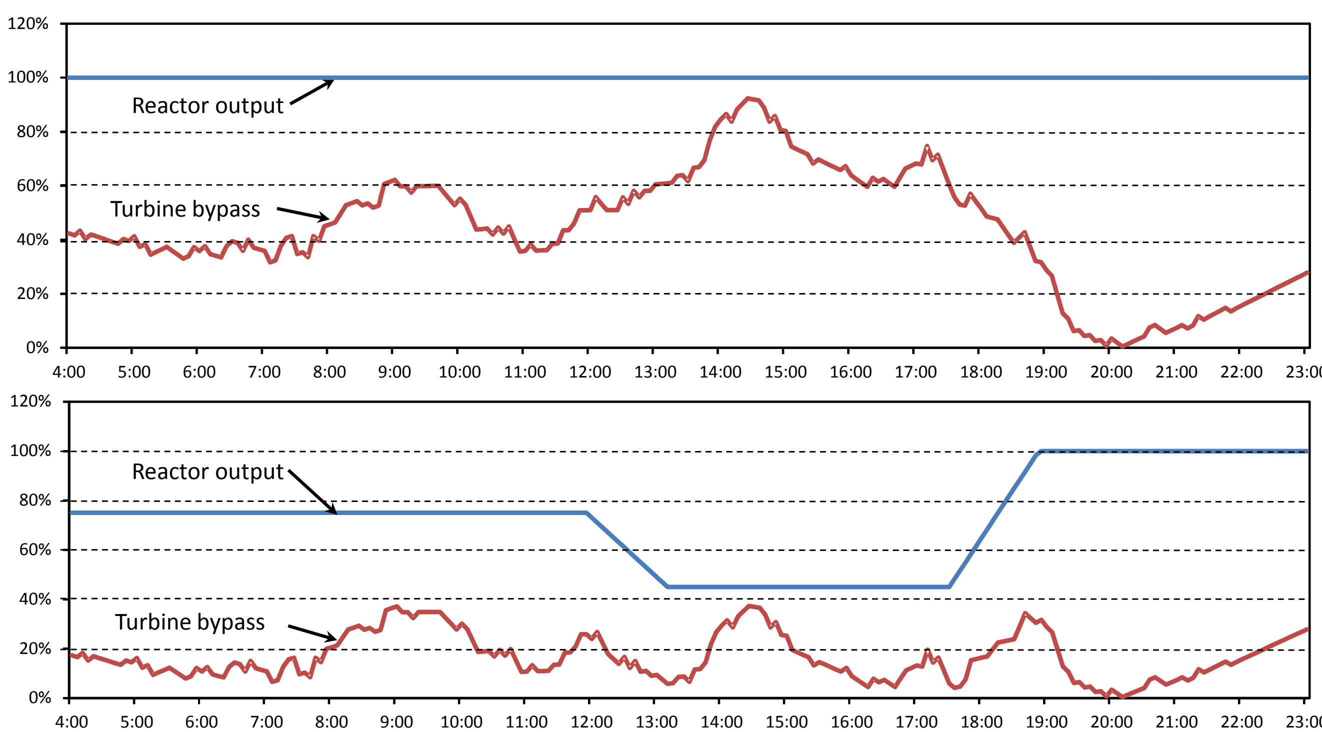


Fig. 6. Two load-following options to achieve the NuScale module output shown in Fig. 5: use only turbine bypass (upper graph), or use combination of reactor power maneuvering and turbine bypass (lower graph).

quickly than adjusting reactor power and allows for increased maneuverability of the plant's output. The drawback of this operation is that an excessive amount of energy is wasted in the form of turbine bypass flow and extended periods of high bypass flow to the condenser will tend to increase wear on the equipment, thus resulting in increased maintenance and equipment replacement.

Adjusting reactor power for partial or full load-following requires a reliable wind forecast such that reactor power can be scheduled for daily or even hourly dispatches while remaining at a power level reasonably above that required to generate the expected electrical output. Turbine output is then trimmed via the turbine bypass valves for fine-tuned matching of output to demand. This option minimizes the amount of wasted energy which in turn minimizes the excess loading of the bypass equipment, including the condenser. Additional challenges associated with reactor power maneuvering include:

- *Fuel design*: Must be optimized for resilience due to frequent thermal cycling of the fuel.
- *Capacity factor*: Routine thermal and operational cycling will likely cause components to degrade faster and may result in increased maintenance and lower module availability.
- *Reactivity control*: Although the reactor module is designed for power maneuvering using only control rods, extended periods of low power operation may require some boron adjustment.
- *Staffing*: The impact of routine power maneuvering could impact operator workload and maintenance, and hence overall staffing requirements.
- *Waste heat rejection*: A sustained operation using turbine bypass will increase the waste heat load of the plant and place additional requirements on the cooling tower capacity.
- *Refueling schedule*: Sustained operation of the module at low power may impact the schedule for refueling. This is less of an issue for a NuScale plant because of the staggered refueling strategy enabled by the multi-module design of the plant and the fact that refueling activities will be conducted by permanent, in-house staff.

Ultimately, it will be economics, policy mandates and regulatory requirements that will drive the decision regarding the extent of load-following by the nuclear plant in an integrated nuclear-renewable environment.

VI. SUMMARY

The NuScale plant incorporates several design features that enhance its responsiveness to load-following operations. The module design allows changes to reactor power down to 40% using only control rod movement (no boron adjustments) to increase power maneuverability. The condenser is designed to accommodate full steam bypass, thus allowing rapid changes to system output while minimizing the impact to the reactor system, which can be maintained at full power. For larger output adjustments, entire modules can be shut down for extended periods of low demand or high renewable generation.

A hypothetical scenario was analysed in which a single small NuScale module was used to balance the output of a relatively small wind farm to balance an isolated load. In this case study, the only generation options were wind and nuclear with sufficient nuclear power to supply all expected demand but allowing preferential use of the non-dispatchable wind power. The analysis showed that the NuScale module could adequately compensate for wind output variations using a combination of power maneuvring and turbine bypass, or turbine bypass alone. The same result applies to more realistic scenarios of larger markets with an increasingly high penetration of wind and reduced coal and gas generation as fuel prices and carbon penalties increase. In these scenarios, the addition of an efficient load-following nuclear power plant will help minimize the need for fossil-based peaking power while allowing greater penetration of renewable sources.

ACKNOWLEDGEMENT AND DISCLAIMER

This material is based upon work supported by the Department of Energy under Award Number DE-NE0000633. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

REFERENCES

1. *Technical and Economic Aspects of Load Following with Nuclear Power Plants*, Nuclear Energy Agency, June 2011.
2. "Wind power surpasses hydro for the first time in Northwest region," OregonLive, available at URL: http://www.oregonlive.com/environment/index.ssf/2012/10/wind_power_surpasses_hydro_for.html.
3. S. Bragg-Sitton, R. Boardman, J. Collins, M. Ruth, and W. Zinaman, *Integrated Nuclear-Renewable Systems*

Workshop Proceedings, Idaho National Laboratory, INL/EXT-14-32857, August 2014.

4. G. Locatelli, S. Boarin, F. Pellegrino, and M. E. Ricotti, “Load-Following with Small Modular Reactors (SMR): A real options analysis,” *Energy* (2014) http://dx.doi.org/10.1016/j.energy.2014.11.040

HIGHLY RELIABLE NUCLEAR POWER FOR MISSION-CRITICAL APPLICATIONS

J. Doyle, B. Haley, C. Fachiol, B. Galyean, D. T. Ingersoll
NuScale Power, LLC
1100 NE Circle Blvd, Suite 200, Corvallis, OR 97330
Tel: 541-360-0681, Email: jdoyle@nuscalepower.com

Abstract *– Some energy consumers require power on a 24/7/365 basis with a high level of certainty, including defense installations, isolated communities and some industrial processes. For these customers, interruptions in electricity or heat can mean substantial financial loss or even the loss of lives. In the absence of grid-scale energy storage, a high level of power reliability can only be accomplished through the robustness and redundancy of power generators. The NuScale small modular reactor design is well suited to provide highly reliable power because of several features related to both the nuclear steam supply system and the overall plant design. In analogy to RAID (redundant array of independent disks) systems used to provide highly reliable data storage, a NuScale plant can assure sustained power generation by virtue of its redundant array of integral reactors (RAIR).This paper describes the NuScale RAIR plant features and summarizes the results of a rigorous analysis of RAIR reliability as a function of power, or conversely, the RAIR plant output power as a function of power reliability. The analysis utilized MATLAB and included probability distributions for the frequency and duration of module outages due to planned and unplanned events. The study also evaluated the impact of implementing turbine bypass rather than cold shutdown and using one or more modules to supply house loads in the case of loss of offsite power. Reliability results are presented for a 12-module RAIR plant with and without turbine bypass during a loss of offsite power enabled, and different possible connections to the offsite power distribution grid and dedicated service loads. Results indicate that a very high level of reliability can be achieved at relatively high power output levels, especially when turbine bypass is enabled in the 12-module plant, coupled with a direct connection to a dedicated service load.*

I. INTRODUCTION

While many energy customers can tolerate minor fluctuations or interruptions in power, others require power on a 24/7/365 basis with a high level of certainty. These types of customers include defense installations, isolated communities, some industrial processes, major computer systems and other mission-critical applications. For these customers, interruptions in electricity or heat can mean substantial financial loss or even the loss of life. In the absence of grid-scale energy storage, a high level of power reliability can only be accomplished through the robustness and redundancy of power generators.

The NuScale small modular reactor design currently under development in the United States is well suited to provide highly reliable power because of several features related to both the nuclear steam supply system and the overall plant design. First, the NuScale power module utilizes an integral pressured water reactor (iPWR) configuration that yields a simplified and highly robust design of the individual modules (Ref. 1). Second, the multi-module nature of a NuScale plant, which can contain up to 12 separate modules and power conversion systems operating independently, allows the plant to provide some level of power on a continuous basis even when individual modules are taken offline for refueling or maintenance. Modules can also be returned to service one at a time to match the demand of the offsite grid in 50 MWe increments to help black start the grid when power is ready to be restored. Finally, the plant can be designed so one or more modules can provide house load in the case of a loss of offsite power.

In analogy to redundant array of independent disks (RAID) systems used to provide highly reliable data storage, the NuScale plant can assure sustained power generation by virtue of its redundant array of integral reactors (RAIR). In the case of RAID data storage, identical data is written simultaneously in multiple locations, thus trading storage capacity for reliability. By placing this data on multiple disks, there is inherent security in the system that the information can be retrieved when desired. Individual disks can even be "hot swapped," meaning the disk can be replaced while the storage system is operating without loss of data. The design of the NuScale plant is similar to a RAID. A NuScale plant is an array of 12 reactors, each operating in a similar and independent fashion to achieve an identical mission: power generation. Due to this redundancy in design, modules can be hot swapped, i.e. they can be removed from operation for refueling or maintenance while the other modules continue to produce power. Therefore, power output from a NuScale power plant can be assured at varying confidence levels, albeit at a reduced total power level, throughout the lifetime of the plant.

II. NUSCALE DESIGN OVERVIEW

The NuScale SMR plant is an innovative design that builds on sixty years of world-wide experience with the commercial application of pressurized water reactor (PWR) technology. The design incorporates several features that reduce complexity, improve safety, enhance operability, and reduce costs. From the outset, the top level design goals for the NuScale plant have been to achieve a high level of safety and asset protection while providing an affordable approach to nuclear power that gives the plant owner the maximum flexibility in plant application while allowing for standardized and simplified construction, operation and maintenance to improve safety and lower lifecycle costs.

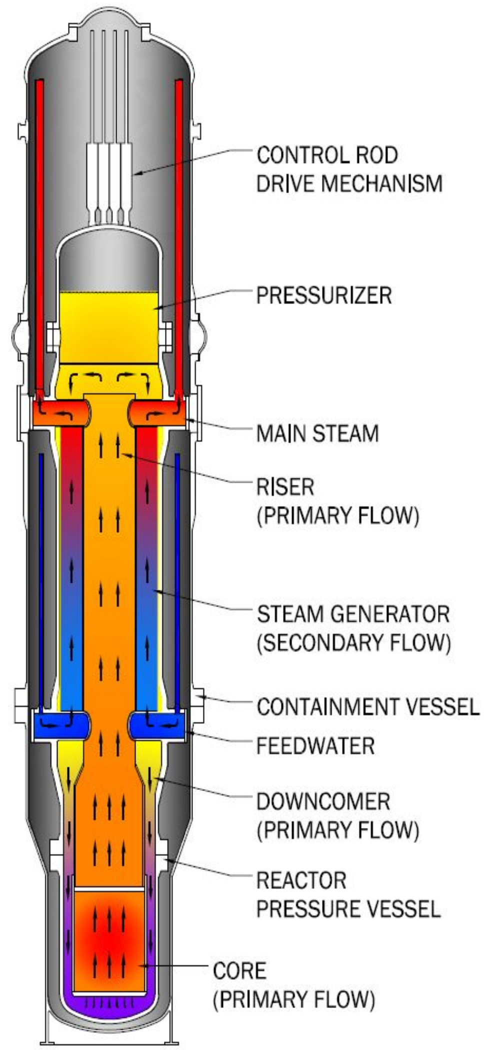
The fundamental building block of the NuScale plant is the NuScale power module. The power module consists of a small 160 MWt reactor core housed with other primary system components in an integral reactor pressure vessel and surrounded by a steel containment pressure vessel, which is immersed in a large pool of water. Several power modules (as many as 12) are co-located in the same pool to comprise a single plant. Dedicated turbine/generator systems provide a gross electrical power of 50 MWe for each module.

A diagram of the NuScale power module is shown in Fig. 1. The reactor vessel is approximately 17.7 m (58 ft) tall and 3.0 m (10 ft) in diameter. The integral vessel contains the nuclear core consisting of 37 fuel assemblies and 16 control rod clusters. Above the core is a central hot riser tube, a pair of helical coil steam generators surrounding the hot riser tube, and an internal pressurizer.

Also shown in the Fig. 1 are the primary and secondary coolant flow paths. Primary reactor coolant is circulated upward through the reactor core and the heated water is transported upward through the hot riser tube. The coolant flow is turned downward at the pressurizer plate and flows over the shell side of the steam generator, where it is cooled by conduction of heat to the secondary coolant via the steam generators and continues to flow downward until its direction is again reversed at the lower reactor vessel head and turned upward back into the core.

The coolant circulation is maintained entirely by natural buoyancy forces of the lower density heated water exiting the reactor core and the higher density cooled water exiting the steam generator annulus. On the secondary side, feedwater is pumped into the steam generator tubes where it boils to generate superheated steam, which is circulated to a dedicated turbine-generator system. Low pressure steam exiting the turbine is condensed and recirculated to the feedwater system. The entire nuclear steam supply system is enclosed in a steel containment vessel that is approximately 23.2 m (76 ft) tall and 4.6 m (15 ft) in diameter. The small volume, high design pressure containment vessel is a unique feature of the NuScale design and contributes significantly to the large safety margins and overall resilience of the plant. Multiple modules are placed in a single large pool contained within an aircraft-resistant reactor building. A cut-away, top-down view of a 12-module reactor plant is shown in Fig. 2. Not shown in the figure are the 12 turbine/generator systems that are located in two turbine buildings immediately adjacent to the reactor building.

Fig. 1. Schematic of a NuScale power module.



The NuScale power modules are located below grade in a large common pool of water. The reactor pool provides passive containment cooling and decay heat removal. Specifically, the pool provides an assured heat sink with a capacity to absorb the entire decay heat produced by up to 12 fully mature cores for greater than 30 days. After 30 days, air cooling of the 12 NuScale power modules is sufficient to avoid fuel damage. The pool also helps to reduce and delay fission product releases in the unlikely event of fuel failure and provides radiation shielding outside containment to reduce operational exposure. Finally, the below grade pool provides enhanced physical security by adding additional challenges to fuel access.

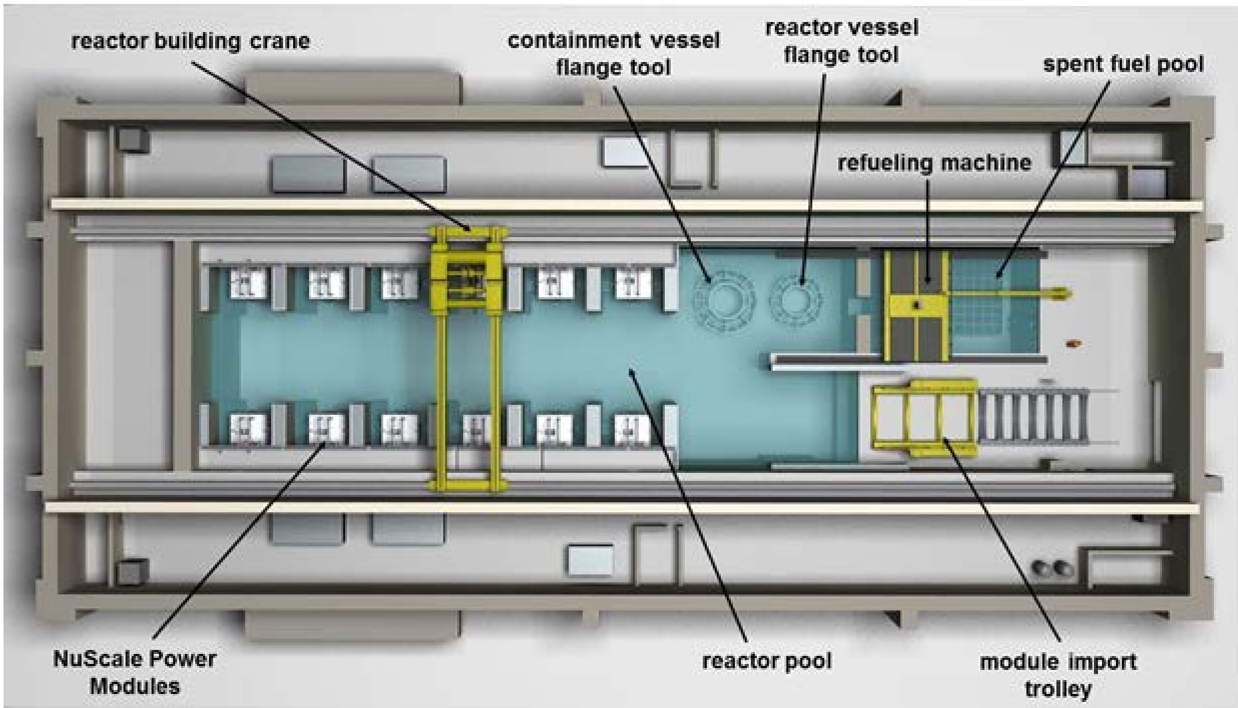


Fig. 2. Top view of reactor building for 12-module NuScale plant.

There are several key features of the NuScale plant that collectively distinguish it from the many other SMRs being developed today and contribute to its simplicity and flexibility.

- *Compact size.* The nuclear steam supply system, including containment, can be entirely prefabricated off site and shipped by rail, truck or barge to the site. This reduces construction time due to parallel fabrication considerations and reduces overall schedule uncertainty due to the reduced amount of on-site construction activities.
- *Natural circulation cooling.* Natural circulation operation and integral design eliminates pumps, pipes, and valves in the primary system and hence the maintenance and potential failures associated with those components, while also reducing house load.
- *Triple Crown of Safety.* The NuScale plant, with its innovative design is able to safely shut down and self-cool with no operator action, no AC or DC power, and no additional water for an unlimited period of time.
- *Dedicated power trains.* Because each power module, including the power conversion system, is independent of other modules, each module can be shut down while other modules continue to operate. This feature allows for continuous plant output and greatly enhances the overall reliability of output power.

III. ANALYSIS APPROACH AND ASSUMPTIONS

To assure a certain level of power output from a NuScale RAIR, an analysis of plant availability considering a number of plant "upsets" is performed. Results from this analysis are used to predict a highly reliable level of power which can be consistently output from a NuScale power plant. The methodology utilized in this analysis is discussed further below

To determine the power output level which can be assured by a NuScale plant, the Matrix Laboratory (MATLAB) programming language was used to simulate fifty thousand 60 year NuScale plant lifetimes. The plant was simulated on a daily basis (i.e. a time step of one day) with a variety of plant upsets included in the analysis. These upsets include the following:

- *Refueling outages.* Each module is refueled every 24 months at which time the module is taken offline for a nominal 10 days to accomplish refueling and inspection activities. It is expected that in a 12-module plant, there will be a refueling outage for one module every 2 months.
- *Short term outages.* Short term outages are initiated by an unplanned reactor trip but do not require the module to be opened to be serviced. During short term outages the module remains in the reactor bay and multiple modules can be repaired

simultaneously. Secondary system upsets are included in this type of outage.

- *Long term outages.* Long term outages are caused by failure of components internal to the module and the module must be opened in order to conduct repairs. There is one disassembly tool in a NuScale plant, so only a single module can be refueled or repaired at one time.
- *Two module outages.* Short term outages can occur for two modules simultaneously due to a loss of an AC bus for example. In these cases, the two modules can be taken offline and returned to service simultaneously.
- *Six module outages.* While many systems are independent among modules, some systems such as the circulating water system that provides cooling to the feedwater system condensers are common to six modules. In these cases, six modules are taken offline and repaired simultaneously, followed by a staggered restart.
- *12 module outages.* Twelve module outages can occur due to a failure of equipment that is common to all 12 modules other than loss of offsite power, which is handled separately. In these cases, twelve modules are taken offline and repaired simultaneously, followed by a staggered restart.
- *Loss of offsite power.* A loss of offsite power affects the whole plant simultaneously. The modules are suspended from their current state and placed into a LOOP state. Only refueling can be triggered during a LOOP. Once power is restored, the modules are brought online in a staggered fashion, one module at a time. Following LOOP recovery, the modules are returned to their previous states. If refueling is triggered during a LOOP and the module was in a down state prior to LOOP initiation, the module is returned to the down state and placed in refueling following recovery from the down state. Otherwise, the module is placed directly into the refueling state.

The study was performed in three major steps. The first analysis consisted of determining the performance of a single module. The second analysis involved determining the availability of all 12 modules as a function of power and assuming that all modules were completely independent. The final analysis considered the impacts of shared systems that can cause 2, 6 or 12 modules to sustain an outage simultaneously. In all cases, it was assumed that the output of a module was either 100% (50 MWe) or zero.

A module has five states: operating (up), refueling, down and closed (closed), down and open (open), or down due to a loss-of-offsite-power (LOOP). In the closed state, the module is not operating, but can be repaired without being opened. In the open state, the module is not operating and must be opened to be repaired. At a NuScale plant, a module is refueled once every two years, and the module is out of service for approximately 10 days. For a 12-module plant, refueling will occur every two months. Following refueling, the module is returned to full power. The remaining transition rates from up to closed, open, or LOOP were determined from a probabilistic risk assessment analysis, using modified initiating event frequencies from Initiating Event Rates at U.S. Nuclear Power Plants 1998-2013 (Ref. 2) to represent the systems in the NuScale design. The initiating event frequencies used are shown in Table I. The error factor shown in Table I is a measure of uncertainty in a lognormal distribution, and is taken as the ratio of the 95th percentile value of the distribution to the median value of the distribution (Ref. 3).

Table I. Initiating Event Frequencies

Initiator Description	Frequency (mcyr^{-1})	Error Factor
CVCS LOCA Inside Containment - Charging Line	2.60E-04	5.57
CVCS LOCA Outside Containment - Charging Line	3.00E-04	6.86
CVCS LOCA Outside Containment - Letdown Line	2.56E-04	13.18
Spurious Opening of an ECCS Valve	1.00E-05	3.11
Loss of DC Power	8.86E-05	33.44
Loss of Offsite Power	3.2E-02	3.46
Steam Generator Tube Failure	1.30E-03	3.40
LOCA Inside Containment	1.62E-03	1.78
Secondary Side Line Break	1.10E-02	3.62
Loss of Power Conversion System (PCS)	1.81E-01	1.10
Transient with PCS Available	1.16	1.04

To determine the frequency that the module transitions from up to closed, three initiating event frequencies were summed together: loss of DC power, loss of power conversion system, and transient with power conversion system available. These initiating events were judged to not require the module to be opened for repair. For example, the DC batteries and busses are located external to the module as well as the secondary systems such as the feedwater and condensate system. The frequency of transitioning from up to closed is then estimated using a lognormal distribution with a mean of 1.34 transitions per module critical year, or 3.672E-03 transitions per module critical day, with an error factor of 1.04.

The remaining initiating events in Table I contribute to the frequency with which a module transitions from up to open. Recovery from these events was judged to be difficult and causing damage to critical equipment internal to the module. The resulting frequency of transitioning from up to open is estimated using a lognormal distribution with a mean of 1.47E-02 transitions per module critical year, or 4.037E-05 transitions per module critical day, and an error factor of 2.47. Lastly, the LOOP initiating event frequency is the same as listed in Table I, which is 3.20E-02 transitions per plant critical year, or 8.761E-05 per plant critical day, with an error factor of 4.51.

If the module is in the refueling, closed, open, or LOOP states, it must remain in that state for a certain number of days depending on the state, before transitioning from that state. For the refueling, closed, or open states, the module returns to full power after module recovery. In the LOOP state, the module is returned to its previous state which is not necessarily the up state. For example, if a module is in the open state with 10 days of recovery time remaining when a LOOP is initiated, then that module is returned to the open state with 10 days of recovery remaining following a return of power to the grid. To determine the number of days required to recover from the closed or open state, reactor operating data for the United States from 2005 through 2014 were used (Ref.4). Values ranging from 1 to 25 days were used for the duration of a closed state event and 26 to 363 for an open state event. This data, which is derived from the existing fleet of large reactors, is expected to be conservative for a NuScale plant due to the fewer number of systems in a NuScale module. The actual value used for a specific module history was selected randomly using a probability distribution determined as the frequency of a downtime lasting some number of days divided by the total number of downtime occurrences for that module state (open or closed). For example, if there were 10 total short term downtimes reported between 2005-2014 and 5 of those had a duration of 1 day, then the probability of a 1 day downtime is estimated at 50%.

The recovery time for a LOOP was estimated using the NRC’s Analysis of Loss-of-Offsite-Power Events 1998-2013 (Ref. 5). Data for weather related LOOP recovery time was used because this was the most limiting case. The length of recovery time was determined using equation 4 of Ref. 5. The minimum recovery time was determined to be 24 hours (1 day) based on the recovery times for plant-centered, switchyard-centered, and grid-related LOOPs.

In this study, a 12-module NuScale power plant was simulated for the expected full plant lifetime of 60 years using MATLAB 2015b. In each Monte Carlo simulation, module objects are created within a plant object and each day of the year is simulated for 21,915 days (60 years including leap days). Transitions from full power are actuated with probabilistic triggers in daily timesteps and then a module is forced into that state for some number of days before repair or refueling is complete. This simulation assumes that the plant was operating at steady state, full power conditions prior to the initiation of the simulation. In reality, the modules will come online in a staggered fashion, with each module being brought online as it is installed in the plant. Since this analysis is considering a 12 module plant, the plant is not considered to have 12 modules until the 12th module is installed and brought online.

Two different NuScale plant and electricity grid configurations are considered, and two different plant responses to a LOOP are considered. Plant connections to the power grid are modeled as (1) the plant is connected to the large electrical distribution grid (macrogrid) or (2) the plant is connected to the macrogrid and the plant also has a direct connection to a dedicated service load (microgrid). In configuration 2, the assured power generated by the NuScale plant is delivered to the microgrid and the excess power is sold to utilities for use on the macrogrid. When a LOOP occurs in configuration 2, the modules supplying power to the microgrid remain in operation, while the remaining modules are critical but bypass the turbine generators and dump steam directly to the condensers until the macrogrid returns to service. The plant responses to a LOOP are modeled as (1) all 12 modules are placed in cold shutdown and brought back online with a staggered restart following the macrogrid return to service, and (2) one module supplies power to the NuScale plant house loads while the remaining modules remain critical and are placed in turbine generator bypass for the duration of the LOOP.

Three scenarios were analyzed:

- *Case 1*. The NuScale plant is connected to the macrogrid, does not contain a connection to a microgrid, and the modules are all placed in cold shutdown during a LOOP.
- *Case 2*. The NuScale plant is connected to the macrogrid, does not contain a connection to a microgrid, and one module supplies plant house loads while the remaining modules are critical and placed in turbine bypass during a LOOP.
- *Case 3*. The NuScale plant is connected to both the macrogrid and a microgrid, and during a LOOP modules supplying electricity to the microgrid continue to do so while the remaining modules are critical and placed in turbine bypass.

Multiple module outages due to outages of shared secondary systems are captured in the 2, 6, and 12 module outage states, which remove from operation the indicated number of modules simultaneously. Each of these initiators is assumed to occur with a frequency of 1E-2 per year based on engineering judgement. The modules then restart in a staggered fashion with a 2 day offset between modules, similar to LOOP recovery.

In this analysis, it is assumed that more than one module can be repaired in the closed state simultaneously. Since there is only one crane, disassembly tool, and refueling area, it is assumed that only one module can be opened at any one time, and the remaining modules that must be opened for repair must wait until there is an open spot to be refueled/repaired. For Case 1, the LOOP is assumed to remove the first module from service for 1 to 3 days with an extra 2 days for each additional module. For Case 2, the LOOP is assumed to remove all 12 modules from service for 1 to 3 days after which time all 12 modules are immediately returned to service. In Cases 1 and 2, the modules are not considered to be available to supply power during a LOOP. To determine the power level that can be assured with 99.99% availability to a dedicated service load, the modules in Case 3 are still considered available during a LOOP, as they are available to supply power to the dedicated service load on the microgrid if needed, even though they are most likely in turbine bypass. Uncertainty in initiating event frequencies and in recovery time is considered in this analysis.

IV. RESULTS

The plant was simulated for 50,000 lifetimes for each of the 3 cases. Two types of results were calculated: the capacity factor of the plant and the availability of electrical output at each plant power level. The capacity factor was determined as the ratio of the total electric power output by the plant to the maximum possible electric power that could be output by the plant over 60 years. The maximum likelihood estimate (MLE) of a NuScale plant capacity factor for Case 1 was determined to be 96.57% with a standard deviation of 0.30%. The corresponding 5 and 95 percentiles were 96.01% and 96.97%, respectively. The MLE of a NuScale plant capacity factor for Case 2 was determined to be 96.67% with a standard deviation of 0.27%. The corresponding 5 and 95 percentiles were 96.17% and 97.02%, respectively. The MLE of a NuScale plant capacity factor for Case 3 was determined to be 96.68% with a standard deviation of 0.27%. The corresponding 5 and 95 percentiles are 96.18% and 97.03%, respectively. The capacity factor is larger by approximately 0.1% when the modules are placed in turbine bypass rather than .placed in cold shutdown in response to a LOOP. The small difference in capacity factor is due to the small number of LOOPs that occur over the 60 years of plant operation. Although the predicted capacity factor in Case 2 and Case 3 are higher than in Case 1, the MLE for each case is within one standard deviation of the others and the MLEs should therefore be considered equivalent.

The results for a 12-module plant are given in Table II, which lists the MLE for the number of modules operating simultaneously for each of the 3 cases. The result of 67.22% availability of 12 modules for Case 1 does not correspond to a capacity factor of 67.22%, as seen above. This is because while the plant is operating at 100% output 67.22% of the time, the plant is also operating at 92% output 26.98% of the time and 86% output 4.64% of the time and so on.

As shown in Table II, the plant spends the majority of the time with all 12 modules operating, with the amount of time spent with fewer modules operational declining drastically as the number of modules in operation decreases. The plant rarely falls below 8 modules in operation. The time spent with 7 or fewer modules in operation is due almost solely to LOOP events. When the consequence of a LOOP is reduced, as in Case 2 and Case 3, the time spent with 7 or fewer modules in operation is due to failures of shared systems. Occasions with 5 modules simultaneously removed from operation due to refueling, closed, or open outages occurs on the order of a few days over the entire 60 year lifespan of the plant.

Table II. Percentage of time the plant operates with indicated number of modules producing power

Number of Modules	Case 1 MLE	Case 2 MLE	Case 3 MLE
12	67.22	67.35	67.36
11	26.98	27.01	27.01
10	4.64	4.63	4.63
9	0.69	0.68	0.68
8	0.19	0.17	0.17
7	0.09	0.07	0.07
6	0.05	0.03	0.03
5	0.03	0.01	0.01
4	0.02	0.01	0.01
3	0.02	0.01	0.01
2	0.02	0.01	0.01
1	0.02	0.01	0.01
0	0.03	0.02	0.01

The MLEs for the probabilities that at least the indicated power level is available are presented in Table III for Case 1, where the modules are placed in cold shutdown in response to a LOOP and the plant is connected to the macrogrid. The probability that at least 450 MWe is generated is 99% with at least 9 modules operating. The probability of achieving power at the 99.9% level drops to 200 MWe. By placing the modules in cold shutdown in response to a LOOP, a probability of 99.97% is the highest level achievable, with LOOP events being the limiting factor accounting for nearly 0.2% of the overall plant operational time. Permitting the modules to enter turbine bypass in Case 2 rather than cold shutdown leads to minor changes the power reliability, as expected. The fraction of the time that the plant operates with a specific number of modules generating power is not significantly different from Case 1. However, by lowering the consequence of LOOP events, the likelihood of power generation from the plant increases, as shown in Table IV. For Case 2, 99.0% reliability is achieved at 500 MWe, 99.9% reliability is achieved at 350 MWe, and 99.99% reliability is not achieved; however, 99.98% is the highest level achievable at 100 MWe. When a microgrid connection to a dedicated service load is available, where power may still be supplied when the macrogrid is unavailable, a power output reliability of 99.99% can be achieved as shown in Table V. For Case 3, 99.0% reliability is achieved at 500 MWe, 99.9% reliability is achieved at 350 MWe, and 99.99% is achievable at 100 MWe. A comparison of the three cases is shown in Fig. 3.

Table III. Probability that at least the indicated power is available for Case 1

Power	MLE	Std Dev	5%	95%
600	67.22	1.21	65.10	69.05
550	94.19	1.09	92.19	95.70
500	98.83	0.66	97.53	99.58
450	99.52	0.42	98.68	99.94
400	99.72	0.28	99.17	99.98
350	99.80	0.20	99.43	99.99
300	99.85	0.16	99.57	100.00
250	99.88	0.13	99.65	100.00
200	99.90	0.10	99.72	100.00
150	99.93	0.08	99.79	100.00
100	99.95	0.05	99.85	100.00
50	99.97	0.03	99.92	100.00
0	100.00	0.00	100.00	100.00

Table IV. Probability that at least the indicated number of modules are in operation for Case 2

Power	MLE	Std Dev	5%	95%
600	67.35	1.21	65.22	69.17
550	94.37	1.07	92.40	95.83
500	99.00	0.62	97.78	99.64
450	99.68	0.36	98.91	99.97
400	99.85	0.20	99.46	100.00
350	99.92	0.11	99.77	100.00
300	99.95	0.06	99.85	100.00
250	99.96	0.04	99.89	100.00
200	99.97	0.04	99.90	100.00
150	99.97	0.03	99.92	100.00
100	99.98	0.02	99.94	100.00
50	99.98	0.02	99.95	100.00
0	100.00	0.00	100.00	100.00

Table V. Probability that at least the indicated power is available for Case 3

Power	MLE	Std Dev	5%	95%
600	67.36	1.21	65.23	69.19
550	94.37	1.07	92.39	95.84
500	99.01	0.62	97.76	99.65
450	99.68	0.36	98.91	99.98
400	99.86	0.20	99.46	100.00
350	99.93	0.11	99.79	100.00
300	99.96	0.06	99.87	100.00
250	99.97	0.04	99.90	100.00
200	99.98	0.03	99.92	100.00
150	99.98	0.02	99.95	100.00
100	99.99	0.01	99.96	100.00
50	99.99	0.01	99.98	100.00
0	100.00	0.00	100.00	100.00

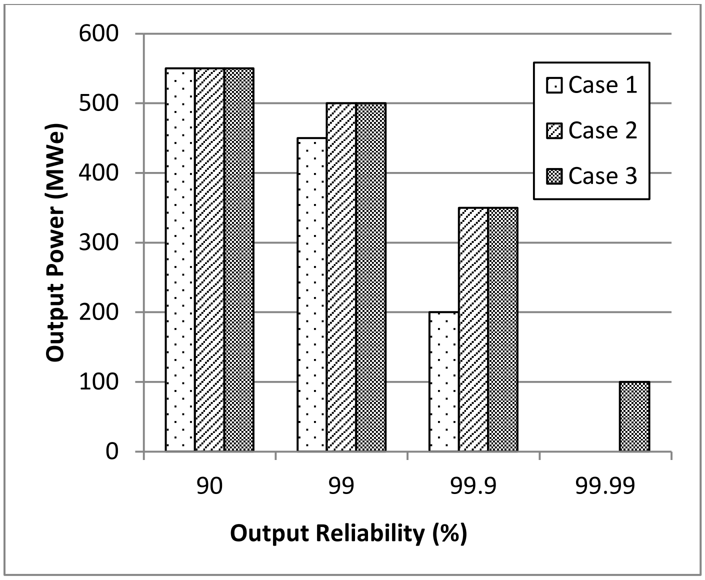


Fig. 3. Comparison of power reliability for all cases analyzed.

V. SUMMARY AND CONCLUSIONS

In this study, the reliability of a NuScale plant at different power levels was determined and the effect of multi-module outages and cold shutdown versus turbine bypass on plant availability were studied. Different plant responses to a LOOP had an insignificant effect on single plant capacity factor. However, the plant configuration to the macrogrid and micrograms coupled with the plant response to a LOOP has a visible effect on power output reliability. By placing the modules in cold shutdown in response to a LOOP, a gross plant output of 200 MWe is assured at a reliability of 99.9%. In contrast, by placing the modules in turbine bypass, a gross plant output of 350 MWe is assured at a reliability of 99.9%. The higher level of reliability of 99.99% can be assured at 100 MWe if the NuScale plant has a microgrid connection to a dedicated service load. Specific insights include:

- The capacity factor of a NuScale plant is approximately 96.6%, regardless of the plant connection to power distribution grids and internal plant response to a LOOP.
- At the 12-module plant level where modules are placed in cold shutdown in response to a LOOP, the highest level of power reliability achievable is 99.9% corresponding to a power level of 200 MWe. The potential occurrence of LOOP events precludes achieving a higher level of reliability.
- When modules are placed in turbine bypass in response to a LOOP, a total plant power level of 350 MWe with a likelihood of 99.9% can be achieved.
- When a NuScale plant is connected directly to a dedicated service load on a microgrid in addition to the macrogrid, a total plant power level of 100 MWe with a likelihood of 99.99% can be achieved.
- **In contrast to traditional plants, which cannot assure power at any level, power output can be assured at a NuScale plant at approximately 50% of total plant capacity at 99.9% reliability and 17% of total plant capacity at 99.99% reliability.**

The study substantiates the importance of module redundancy in achieving power generation at high levels of reliability as required by many mission-critical customers. The NuScale design using highly robust power modules and a multi-module plant design that can incorporate up to 12 modules is uniquely positioned to provide clean, abundant and highly reliable power to those customers.

ACKNOWLEDGEMENT AND DISCLAIMER

This material is based upon work supported by the Department of Energy under Award Number DE-NE0000633. Neither the U.S. Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the U.S. Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U.S. Government or any agency thereof.

REFERENCES

1. J. N. Reyes, Jr. “NuScale Plant Safety in Response to Extreme Events,” Nucl Tech, 128, 153-163 (May 2012).
2. Idaho National Laboratory, “Initiating Event Rates at U.S. Nuclear Power Plants, 1998-2013,” INL/EXT-14-31428 (February 2015).
3. *Distributions*, NRC Operating Experience Website, http://nrcoe.inl.gov/radscalc/Pages/AboutHTMLFiles/Distributions.htm
4. *Power Reactor Status Reports*, NRC Website, http://www.nrc.gov/reading-rm/doc-collections/event-status/reactor-status/, Updated December 30, 2014.
5. Idaho National Laboratory, “Analysis of Loss-of-Offsite-Power Events, 1998-2013,” INL/EXT-15-34443 (February 2015).

Upgrading America's Energy System

America's industrial success was built on affordable and abundant access to energy – driven by coal. However, our energy infrastructure is aging and nearly obsolete: hundreds of coal power plants will be 60 years old or older by 2040, as shown in Figure 1. Many coal plants are nearing the end of their expected lifespan and need to be replaced with the next generation of cost-competitive and abundant energy. It makes sense to do this at the existing plant sites where the people and infrastructure are in place to produce energy. While some coal plants may be replaced with new clean coal technology, environmental regulations, cheaper natural gas, and depletion of mine mouth coal are significant challenges. Plants are shutting down, jobs are being lost, and local communities are suffering.

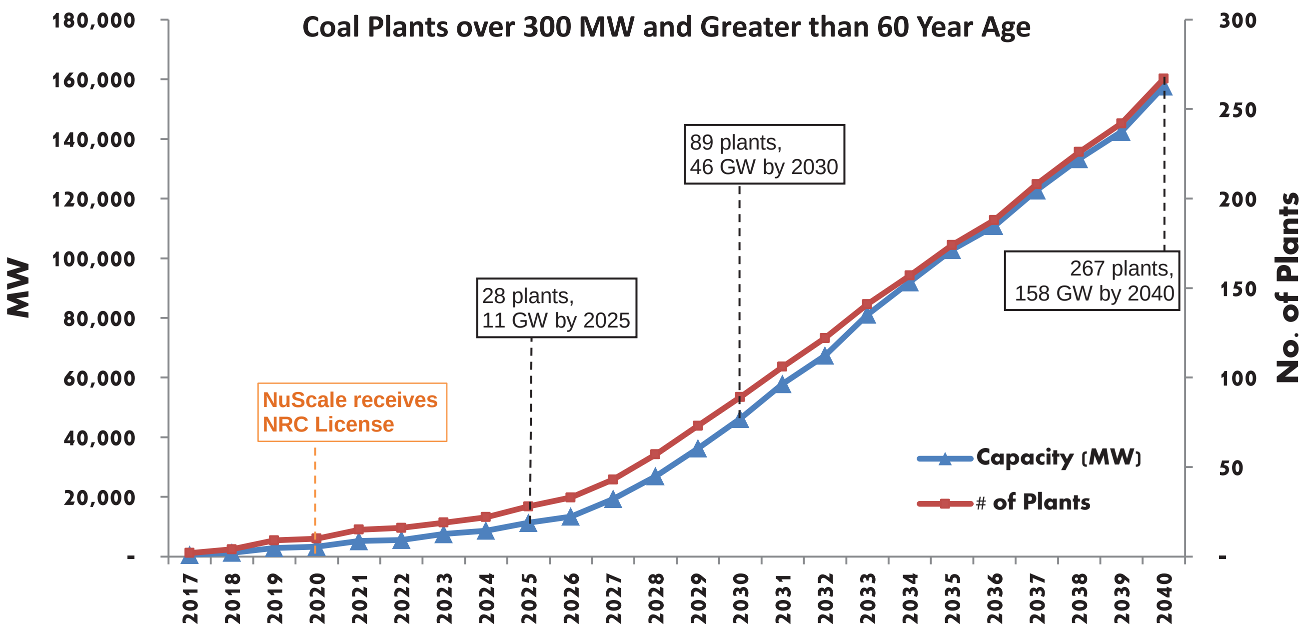


Figure 1: *The cumulative capacity and number of coal power plant projects that are expected to retire from 2018 to 2040 in the United States. Retirement and decommissioning of a project is assumed to occur after 60 years of operation and only coal plants above 300 MW in capacity are considered.*[1]

Revitalizing our electricity generation infrastructure presents an opportunity to upgrade America's energy system. It is time to turn to advanced energy sources that will provide economical, reliable, and abundant energy and cleaner air for the next 60 years. Repurposing retiring coal plant sites with small modular reactors (SMRs) can provide cost-competitive and secure electricity, foster economic development, and create more and higher-paying jobs.

The NuScale Power Plant is designed to house up to twelve, 50 MWe SMRs for a total gross capacity of 600 megawatts-electric (MWe). With a footprint of fewer than 74 acres, the NuScale Power Plant is an ideal size to replace aging coal power plants and utilize the existing energy infrastructure and human capital, without any changes in existing regulation. The reactors and attendant equipment (collectively known as the NuScale Power Module™) are fully factory manufactured and shipped to the facility site without the need for on-site construction or fabrication. This factory fabrication significantly reduces the project and construction schedules, costs, and risks. Their operation is also flexible to allow for meeting the intermittent capacity needs of today's electric grid. The U.S. Nuclear Regulatory Commission (NRC) is currently reviewing the application to certify NuScale's design. The license is planned to be issued in July 2020, which means that NuScale Power Plants can be in operation by the time many coal plants start reaching retirement age in the U.S.

Jobs

As a case study, let's examine the San Juan Generating Station, which is a four-unit coal power plant in New Mexico with a net capacity of 1683 MWe supplying electricity to about two million people in the Southwest. The facility employs 410 people along with an additional 360 people at the nearby coal mine that supplies the coal to the facility. Two of the four units are shutting down by the end of 2017 to comply with existing environmental regulations for air quality. Jobs will be lost and the local community will suffer a significant economic impact.[2]

This facility, like many other coal plants around the country, will likely be replaced with a combined cycle natural gas plant at that site or elsewhere on the Western grid. Natural gas is a good replacement right now because of the current low price, but the price of natural gas has historically seen considerable variability and our energy security is at risk by relying too heavily on one fuel for electricity generation. In addition, a natural gas fueled plant employs significantly fewer people on a per MW basis compared to the current coal fueled facility, even when the gas plant has a higher output than the coal plant. A NuScale Power Plant located on the site of the retired coal facility would actually increase the number of jobs and their wages, as shown in Table 1.

Table 1: *Comparison of employment and life cycle cost and environmental impact of various power plants*

	Coal Power Plant	Natural Gas Combined Cycle Power Plant	NuScale Power Plant
Plant Employees (per 600 MWe)[3]	146	24	360
Average Annual Wage for Plant Staff[4]	$71,800	$75,130	$89,940
Levelized Cost of Electricity ($/MWh)[5] [with CCS]	[$140]	$57 [$85]	$86
SO_x (mg/kWh)[6]	6700	300	11
NO_x (mg/kWh)[6]	3350	550	9
PM2.5 (mg/kWh)[6]	9210	100	~0
Greenhouse Gas Emissions (CO_2-equivalent (g/kWh) [with CCS][7]	1025 [167]	492 [167]	15

Economic Benefits

The Energy Information Administration projects that all new coal plants will need to be built with carbon capture and sequestration (CCS) technology to adhere to federal regulations, thus bringing the levelized cost of electricity (LCOE) to $140 per megawatt-hour (MWh) for new coal plants. By comparison, new advanced combined cycle natural gas plants will have an LCOE of $57, or up to $85 with CCS. A NuScale Power Plant is expected to have an LCOE of $86/MWh. While the levelized cost of a natural gas plant without CCS is lower compared to a new NuScale facility, gas prices have historically been volatile and could increase dramatically over the next 40 years. In addition, stricter regulations on emissions could further drive up the cost of natural gas plants.

In comparison, building and operating a nuclear power plant brings direct economic benefits to the community it serves. Better and higher-paying jobs allow citizens to invest more locally, creating a stimulus for the regional economy. On average, a nuclear power plant generates $470 million in sales of goods and services in the local community and pays about $16 million in state and local taxes, which can benefit schools and infrastructure.[8] In addition, a NuScale Power Plant creates more than a thousand jobs over a 3 to 4 year period during on-site construction of the plant.

The supply chain for NuScale's technology resides in the United States. Investment in NuScale's nuclear technology boosts the national economy by supporting potentially 12,000 jobs in the domestic nuclear supply chain. NuScale Power Modules™ fabricated in the U.S. can be exported to the many other countries interested in building nuclear power plants, with the potential to generate billions of dollars in exports per year to help reduce the trade deficit. Exporting nuclear technology would help restore U.S. leadership in nuclear energy and nuclear security.[9]

Environmental Impact

Environmental regulations are causing many coal plants to shut down. Replacing coal units with small modular reactors would result in cleaner air and therefore easier adherence to regulations on emissions for years to come. Table 1 shows the relative comparison of air pollutants – sulfur dioxide (SO_2), nitrogen oxides (NOX), and particulate matter (PM2.5) – emitted during the life cycle of coal, gas and nuclear power plants per kilowatt-hour (kWh). NuScale's power plants emit no harmful air pollutants during operation and very little over their life cycle.

Nuclear energy also has a significantly smaller environmental impact than coal and natural gas, from mining (or extraction) to waste. Over the entire life cycle, coal plants produce an average of 1025 grams of gas emissions (in terms of CO_2-equivalent) per kWh that is directly emitted into the environment and natural gas plants emit about 492 g/kWh. This amount is reduced to an average of 167 g/kWh with CCS for fossil-fueled plants but nuclear plants still emit much less, only about 15 g/kWh. In addition, the 600 MWe NuScale Power Plant has a total footprint of only 74 acres and an emergency planning zone contained within the site boundary.[10] This means that NuScale Power Plants can be built directly on existing coal plant sites.

It's time to upgrade America's energy system and invest in the deployment of new nuclear technology to replace aging coal plants. This transition would keep and increase jobs, provide economic benefits for plant communities and the country, and result in cleaner and clearer air. NuScale's technology is only a few years away from deployment, so we must act now to foster government and public support for this effort.

---

[1] GlobalData Analysis for NuScale Power

[2] PNM San Juan Generating Station Factsheet: https://www.pnm.com/documents/396023/440009/San+Juan+plan_fact+sheet.pdf/a37f9be1-f592-4437-b98b-54414ad3fff2

[3] Sources for sample plant staff: Utah Associated Municipal Power Systems (UAMPS); NuScale Power

[4] Occupational Employment and Wages, May 2015, Bureau of Labor Statistics

[5] Estimated Average US Levelized Cost of New Generation Resources (2022 costs in 2015 $/MWh). Source: U.S. Energy Information Administration; NuScale LCOE Model for nth of a kind.

[6] Masanet, E. et al., "Life-Cycle Assessment of Electric Power Systems," Annu. Rev. Environ. Resour. 2013. 38:107–36; Spath PL, Mann MK, "Life cycle assessment of a natural gas combined-cycle power generation system," National Renewable Energy Laboratory, 2000.

[7] International Atomic Energy Agency, Nuclear Power and Climate Change, 2016

[8] Nuclear Energy Institute, Economic Benefits: https://www.nei.org/Why-Nuclear-Energy/Economic-Growth-Job-Creation/Economic-Benefits

[9] For more information see Third Way, "Getting Back in the Game: A Strategy to Boost American Nuclear Exports" http://www.thirdway.org/report/getting-back-in-the-game-a-strategy-to-boost-american-nuclear-exports

[10] Source: NuScale Power; includes plant protected area, cooling towers and out-buildings