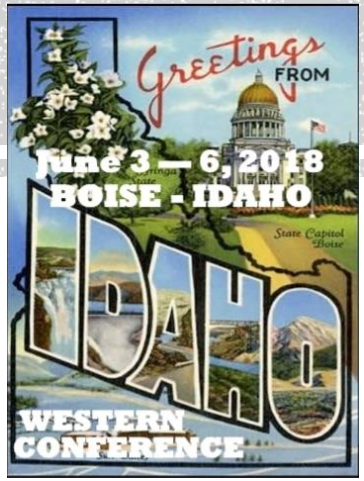
SMALLER, SAFER, MORE SECURE:

Nuclear reactors of the future



SMALLER, SAFER, MORE SECURE:

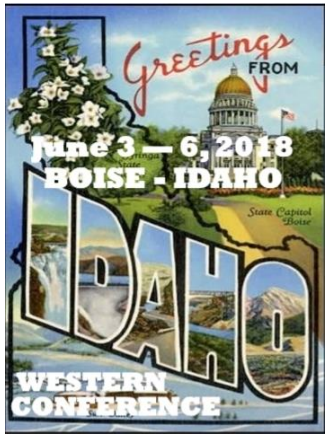
Nuclear Reactors of the Future

Moderator:
Stan Wise, Pendleton Group, former commissioner with Georgia Public Service Commission

Panelists:
Dr. Rita Baranwal – Director, GAIN Initiative at Idaho National Laboratory

Douglas Little – Deputy Assistant Secretary for Intergovernmental and External Affairs, US Department of Energy

Dr. Jose Reyes – Founder and Chief Technology Officer, NuScale Power



GAINing Access to National Treasures

Rita Baranwal, GAIN Director

June 4, 2018

GAIN
Gateway for Accelerated Innovation in Nuclear

The Idaho National Laboratory

International Intellectual Leadership

Building a Laboratory

National Reactor Testing Station

INEL
Idaho National Engineering Laboratory

Energy Mission – Reactor Science, Safety and Sustainability Solutions

INEEL
Idaho National Engineering and Environmental Laboratory

Environmental Management Mission

INL

INEEL & ANL-W combined to create the new Idaho National Laboratory

Nuclear Energy

National and Homeland Security

Energy and Environment

Argonne NATIONAL LABORATORY

Advancing Nuclear Energy

Securing & Modernizing Critical Infrastructure

Enabling Clean Energy Systems

1949 **1974** **1997** **2005** **2018**

Our Vision and Mission Positions INL to be Relevant to Tomorrow's Energy Future

INL Vision

INL will change the world's energy future and secure our critical infrastructure.

INL Mission

Discover, demonstrate and secure innovative nuclear energy solutions, clean energy options and critical infrastructure.

The Idaho National Laboratory Site

Geography

- 890 square miles
- 177 miles of paved roads
- 21 miles of railroad lines
- 111 miles of electrical transmission and distribution lines
- Mass transit system

Infrastructure / Mission

- 579 buildings
- 3 fire stations
- 4 reactors
- Nuclear and radiological facilities
- 2 spent fuel pools
- 300 metric tons of used fuel
- Classified space
- Explosive range
- Landfills
- Significant security profile

…the National Nuclear Energy Laboratory

INL is positioned to address the world's most challenging problems

Nuclear S&T

- Nuclear fuels and materials
- Nuclear systems design and analysis
- Fuel cycle science and technology
- Nuclear safety and regulatory research

Advanced Test Reactor

- Steady state neutron irradiation of materials and fuels
  - Naval Nuclear Propulsion Program
  - Industry
  - National laboratories and universities

Materials & Fuels Complex

- TREAT – Transient testing
- Analytical laboratories
- Post-irradiation examination
- Advanced characterization
- Fuel fabrication
- Space nuclear power and isotope technologies

Energy & Environment S&T

- Advanced transportation
- Environmental sustainability
- Clean energy
- Advanced manufacturing
- Biomass

National & Homeland Security S&T

- Critical infrastructure protection and resiliency
- Nuclear nonproliferation
- Physical defense systems

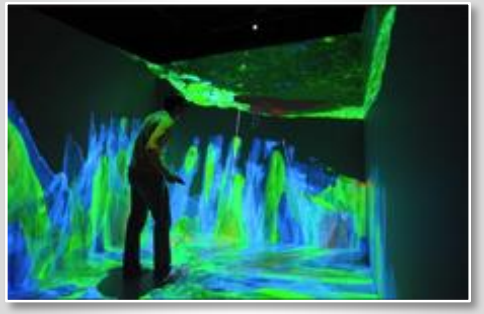
INL is focused on four critical initiatives to meet energy, competitiveness, and national security goals

Enhance core capabilities, talent, S&T infrastructure, programs, and partnerships

Nuclear energy competitiveness and leadership

Integrated nuclear fuel cycle solutions

Advanced hybrid energy systems



Cyber and physical security centered around Cybercore Integration Center

What is the Gateway for Accelerated Innovation in Nuclear?

What are the issues

- Time to market is too long
- Facilities needed for RD&D are expensive
- Capabilities at government sites have not been easily accessible
- Technology readiness levels vary
- Some innovators require assistance with regulatory processes

What do we need to do

- Provide nuclear innovators and investors with single point of access into DOE complex
- Provide focused research opportunities and dedicated industry engagement
- Expand upon DOE's work with Nuclear Regulatory Commission (NRC)

What is the DOE initiative

- Private-public partnership, dedicated to **accelerating** innovative nuclear energy technologies **time to market**

DOE recognizes the magnitude of the need, the associated sense of urgency and the benefits of a strong and agile private-public partnership in achieving the national goals.

National focus areas

Priority Areas

- Continued operation of the existing fleet
- Replacement and future expansion of the US fleet
- Management and disposition of spent nuclear fuel

R&D Focus Areas

- LWR long-term operations – life extension & operating cost reduction
- Advanced LW-based reactors
- Fast spectrum test reactor
- Advanced fuels and materials
- Advanced reactors technologies
- Materials recovery & waste forms/Safeguards
- Spent fuel management and disposition
- Advanced modeling and simulation (M&S)
- Cross-cutting design support (e.g. NHES, AM)

Ups and Downs

Ups

440 | operating reactors in 30 countries

50+ | under construction in 13 countries

NuScale SMR/UAMPS
project cleared first U.S. regulatory hurdle

9 | U.S. plants saved from premature closure by state policies*

Downs

6 | U.S. reactors closed between 2013-2016*

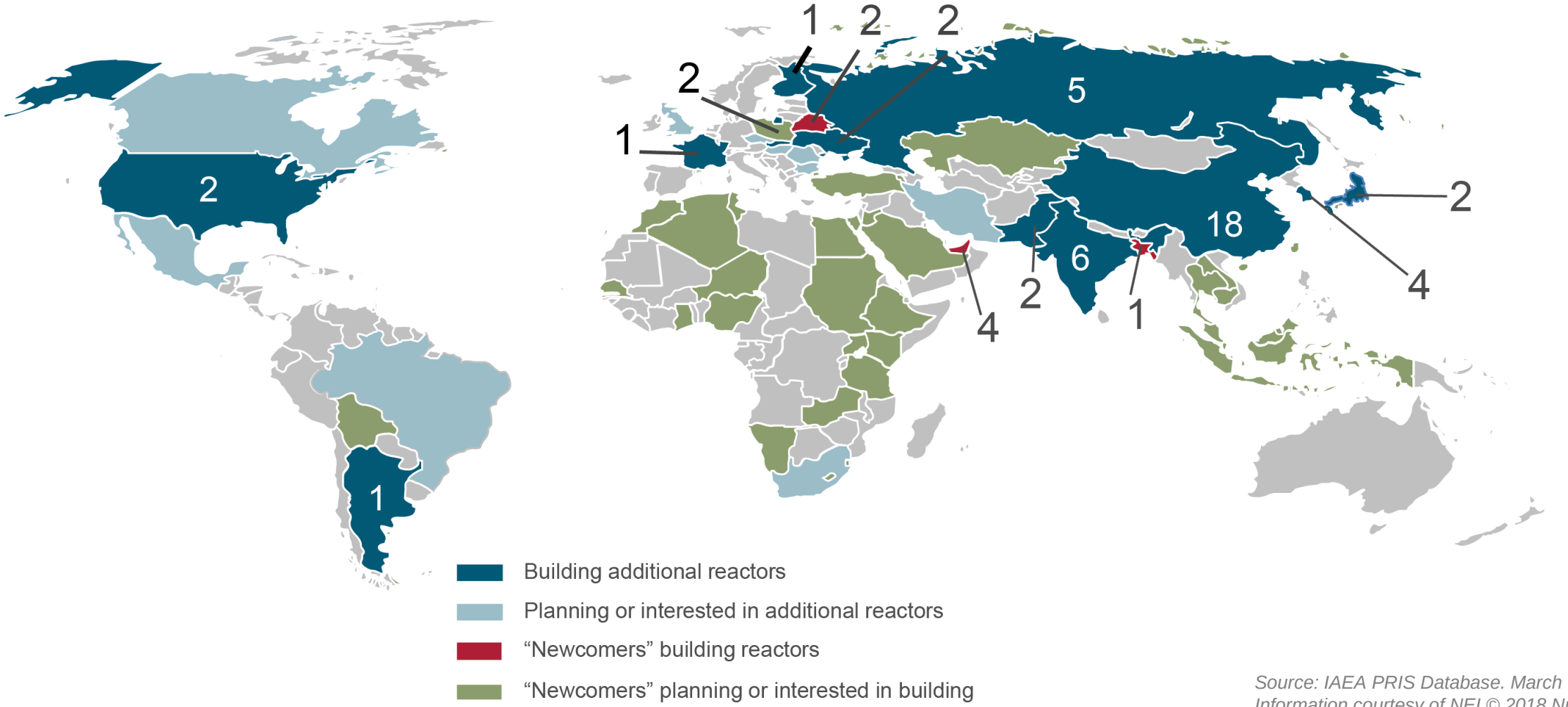
12 | more planned between 2018 and 2024-2025*

China and Russia are leading the way in new builds

*China has **18** reactors under construction with **31** more planned*

*Russia has **FIVE** under construction and **22** more planned*

Global Reactors Under Construction

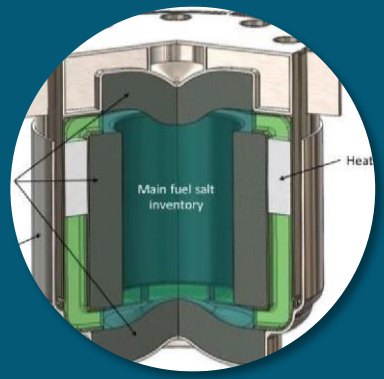


Source: IAEA PRIS Database. March 15, 2018. Information courtesy of NEI © 2018 Nuclear Energy Institute. All rights reserved

Advanced Reactors: Addressing multiple needs

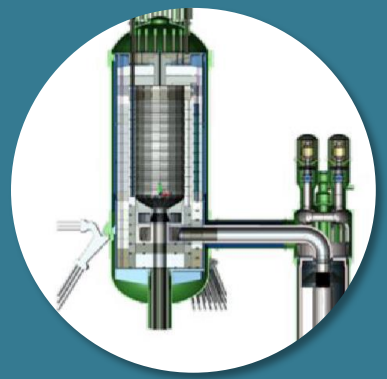
- Lower costs and faster construction:
  - Simpler designs, incorporating modular and factory construction
  - advancing innovations lower overall capital investments and operating costs
- Variable size:
  - Range from few megawatts-electric (MWe) to >1,000 MW
  - Allows owners to tailor capacity additions with energy demands and budgets, particularly important for rural electric cooperatives or municipal agencies and for isolated and distributed applications
- Meeting diverse energy needs:
  - operate at higher temperatures, process steam heat for industrial uses such as fertilizer manufacturing, petroleum refining and desalinization
  - Currently, no emissions-free sources serve these applications

Molten Salt Reactors



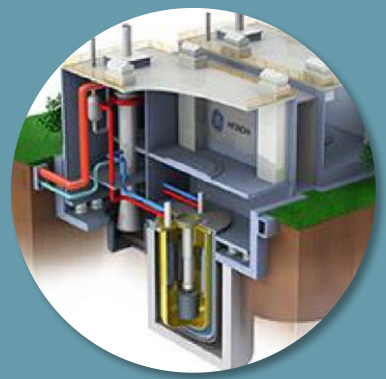
TerraPower

High Temperature Gas Reactors



X-energy

Liquid Metal Reactors



GE PRISM

SMR LWR Reactors

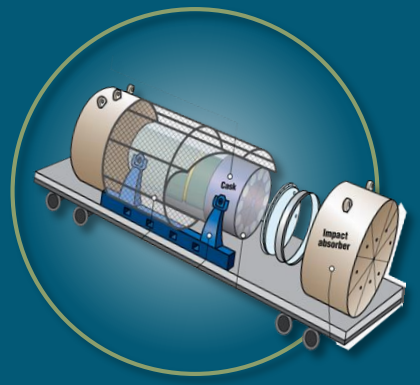
NuScale

Micro Reactors

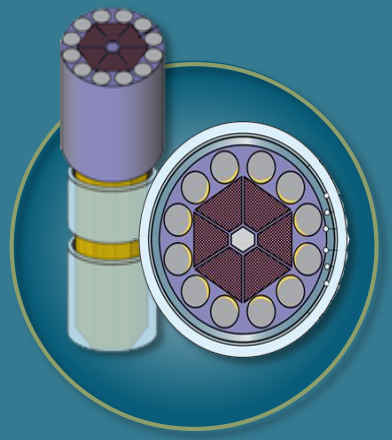
Westinghouse eVinci

Recreating the testing station:
Advanced reactor pipeline vision at Idaho National Laboratory

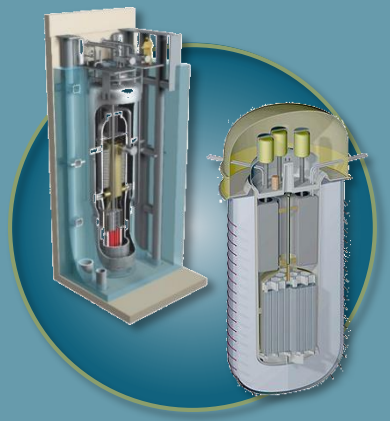
By 2021
Demonstrate first <10MW very small modular reactor (vSMR)



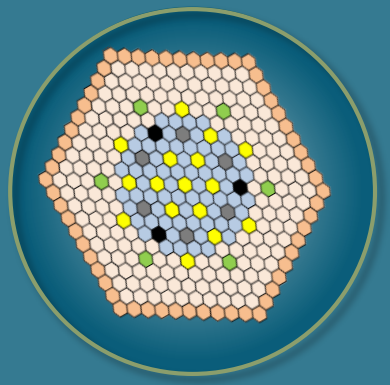
By 2025
Commercial vSMRs deployed



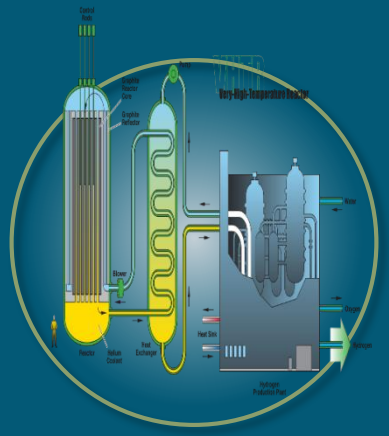
By 2026
2 SMRs operating



By 2026
Versatile Test Reactor (VTR) operating



By 2030
Non-LWR Advanced Demonstration Reactor

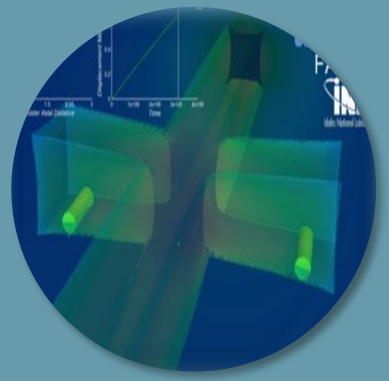


Addressing spent nuclear fuel:
Vision for effective, integrated fuel cycle solutions and SNF/HLW disposal

Research supporting management and disposition of SNF

Demonstrate real-time monitoring tools

Demonstrate cradle-to-grave M&S capabilities with MOOSE



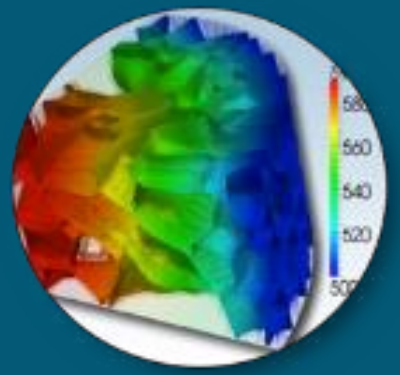
Demonstrate HALEU production by recovering HEU from naval SNF

R&D facilities to support SNF long-term challenges

Advanced Modeling & Simulation

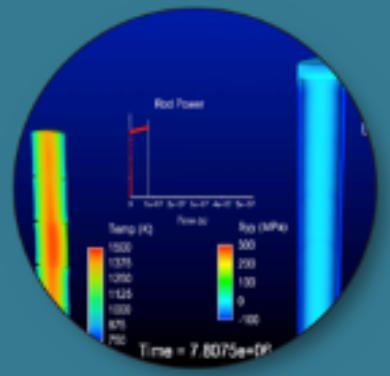
- The Multiphysics Object Oriented Simulation Environment (MOOSE) MOOSE framework is an industry-leading multiscale, multi-physics modeling platform
- MOOSE enables simulation tools to be developed in a fraction of the time previously required and makes modeling and simulation more accessible to a broad array of scientists
- MOOSE-based applications provide support for nuclear energy, materials, structural dynamics, multiphase flow, waste management, and geophysics

Risk assessment
Risk-Informed Safety Margin Characterization and advanced computational frameworks



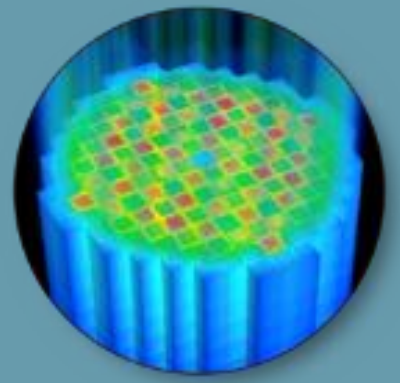
MARMOT: Microscopic changes in nuclear fuel during irradiation

Systems analysis
Advanced safety/systems analysis and predictive modeling for advanced transmutation fuels



BISON: Nuclear fuel pellet surface simulation

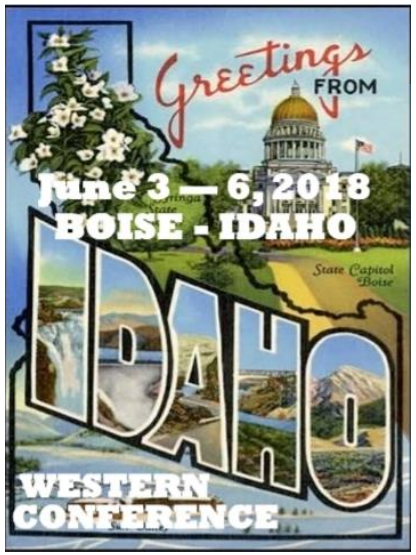
Multi-scale modeling
Multi-scale nuclear fuel performance modeling & simulation



MOOSE: Advanced reactor full-core multiphysics modeling

Douglas Little

Deputy Assistant Secretary for Intergovernmental and External Affairs, US Department of Energy

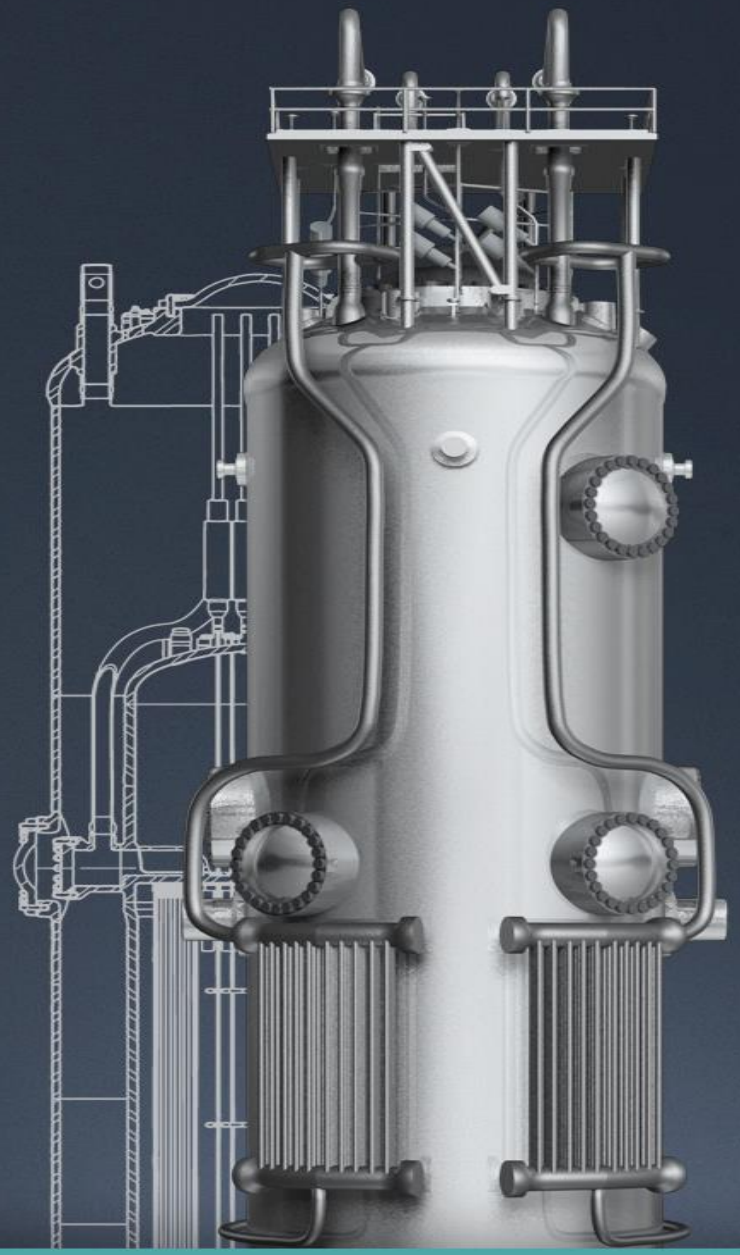


June 4, 2018

NuScale Overview

José N. Reyes, Jr.
Chief Technology Officer and Co-founder

2018 Western Conference of Public Service Commissioners



Who is NuScale Power?

- NuScale Power was formed in 2007 for the sole purpose of completing the design and commercializing a small modular reactor – the NuScale Power Module™.
- Initial concepts had been in development and testing since the 2000 (U.S. DOE) MASLWR program.
- Fluor became lead investor in 2011.
- In 2013, NuScale won $226M in matching funds in a competitive U.S. DOE Funding Opportunity.
- >366 patents granted or pending in 20 countries.
- >800 people have worked on the project with 6 offices in U.S. and 1 office in London.
- Design Certification Application was completed in December 2016 and accepted for U.S. NRC review in March 2017.
- Total expenditures ~$720MM to present.
- DOE Award June 2018, $40M matching funds
- First plant COD planned at INL in 2026

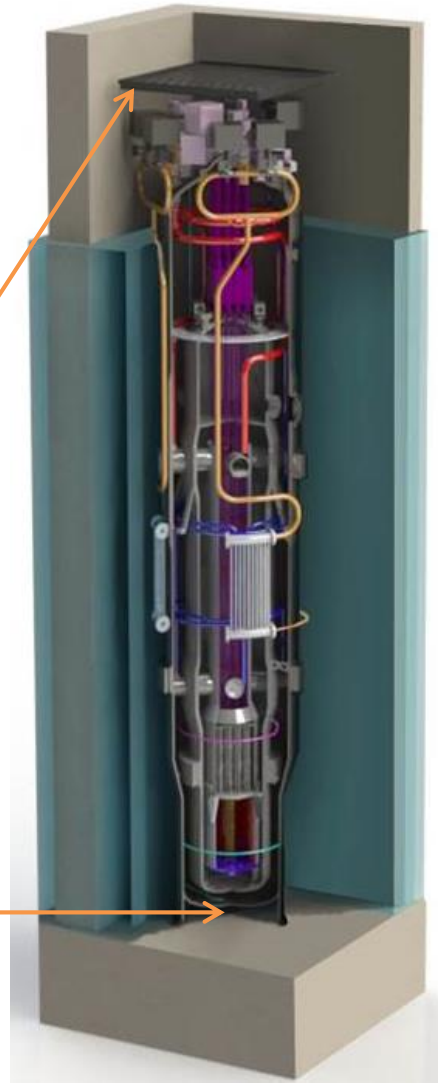
NuScale Engineering Offices Corvallis

One-third scale NIST-1 Test Facility

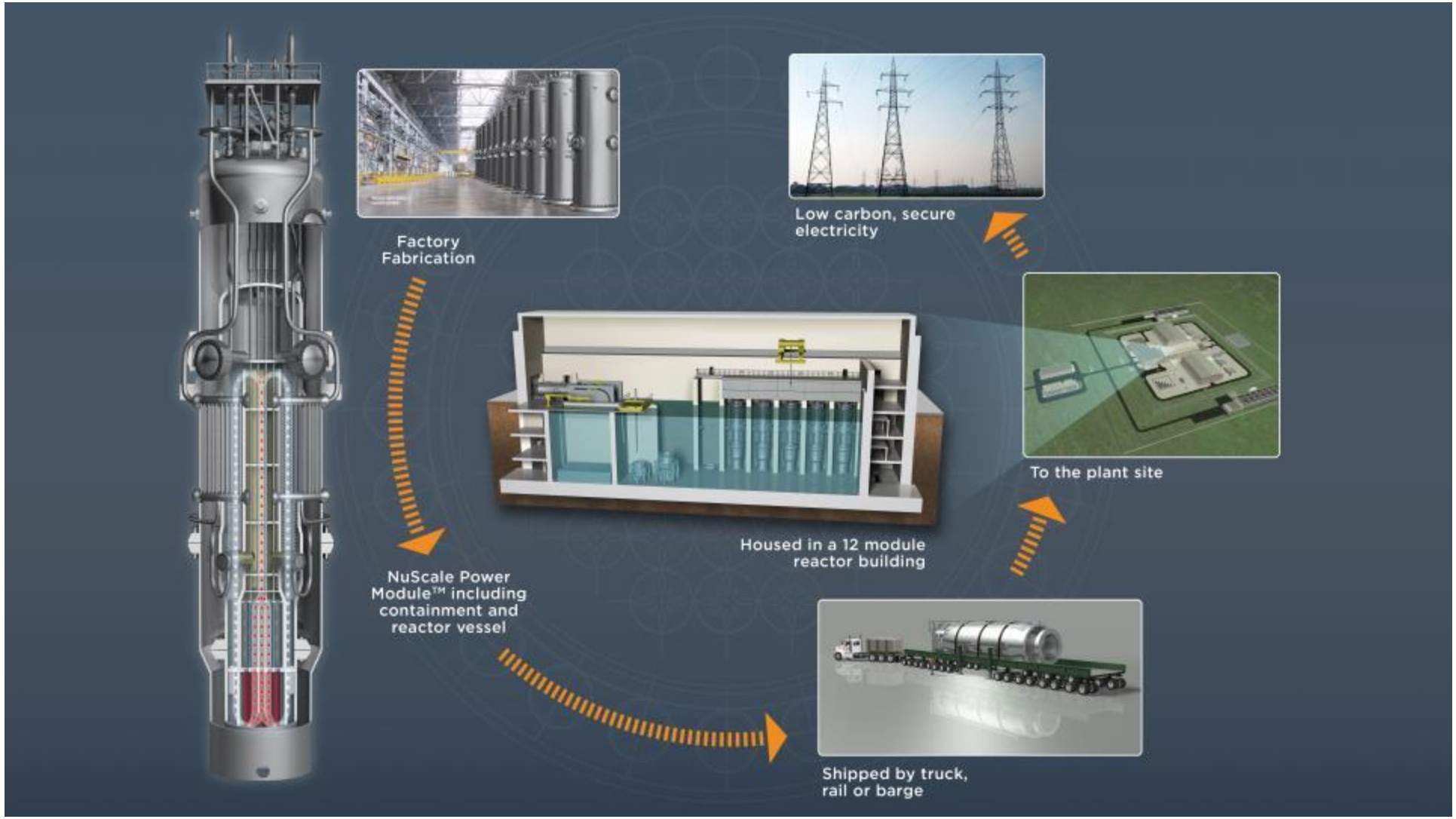
NuScale Control Room Simulator

What is a NuScale Power Module?

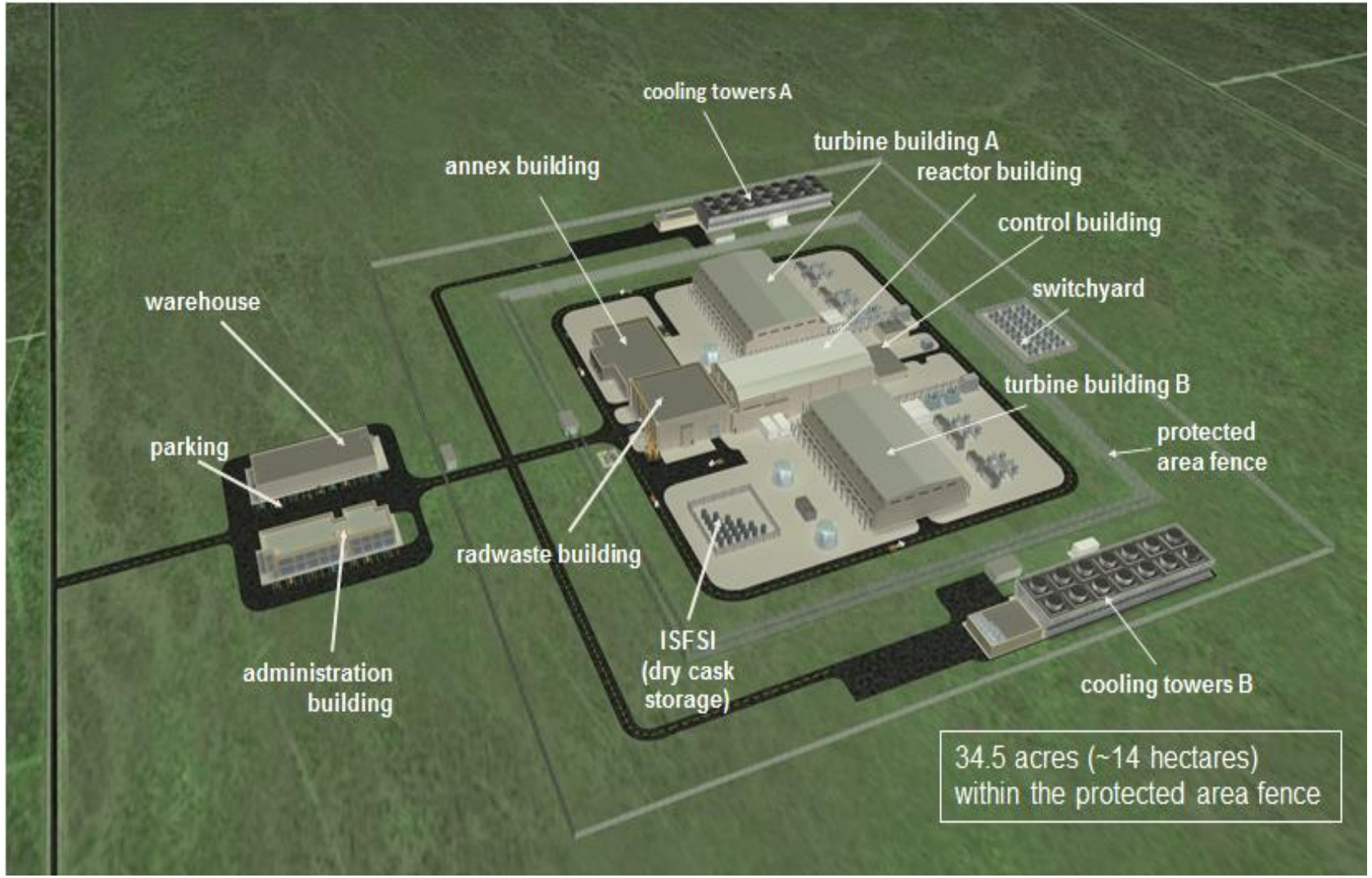
- A NuScale Power Module (NPM) includes the **reactor vessel, steam generators, pressurizer** and **containment** in an integral package that eliminates reactor coolant pumps and large bore piping (no LB-LOCA)
- Each NPM is 50 MWe and factory built for easy transport and installation
- Each NPM has its own skid-mounted steam turbine-generator and condenser
- Each NPM is installed below-grade in a seismically robust, steel-lined, concrete pool
- NPMs can be incrementally added to match load growth - up to 12 NPMs for 600 MWe gross (~570 net) total output



A New Approach to Construction and Operation



Site Layout



Licensing Status

- Design Certification Application (DCA) completed at end of 2016. Submitted January 2017.
  - *43,000 NRC review hours, and participation in 119 Formal Meetings and in an NRC DCA Readiness Review. 12,000+ pages*
  - *14 Topical Reports*
  - *>2 million labor hours*
  - *>800 people worked on the project across 5 Offices in U.S.*
  - *>50 supplier/partners*
  - *Over $500M in Design development and testing*
- DCA accepted for docketing in March 2017.
- Received ~1500 RAIs with average NuScale response in < 60 days
- Phase 1 of NRC Review is Complete

Lessons:

- Pre-Application Review
- Regulatory Gap Analysis
- Design Specific Review Standard
- Key Topical Reports
- NRC DCA Readiness Review

A New Level of Plant Resiliency

NuScale design offers unparalleled resilience

- **Island Mode/Loss of Offsite Power** - Single module can power entire plant. (Island mode). NuScale plant does not require operator or computer actions, AC/DC power, additional water or grid connection for safety.
- **Black-Start Capability** - A NuScale Plant can start up from cold conditions without external grid connections using small onsite back-up generators. Exploring nuclear heat start-up.
- **First Responder Power** – On loss of offsite grid, all 12 modules can remain at full power or be ramped down while rejecting 100% steam to its condensers.
  - Able to provide grid power in 50 MWe increments upon grid restoration.
- **Resilience to Natural Events** – Modules and fuel pools located below grade in a Seismic Category 1 Building.
  - Can withstand a Fukushima type seismic event
  - Can withstand hurricanes, tornados, and floods
- **Resilience to Aircraft Impact** – Reactor building withstands aircraft impact as specified by NRC aircraft impact rule.
- **Cybersecurity** – NuScale Plant protection systems are non-microprocessor systems (i.e., field programmable gate arrays) and software-free and therefore not vulnerable to internet cyber-attacks.

Regulatory Approval of Innovations Related to Plant Resilience

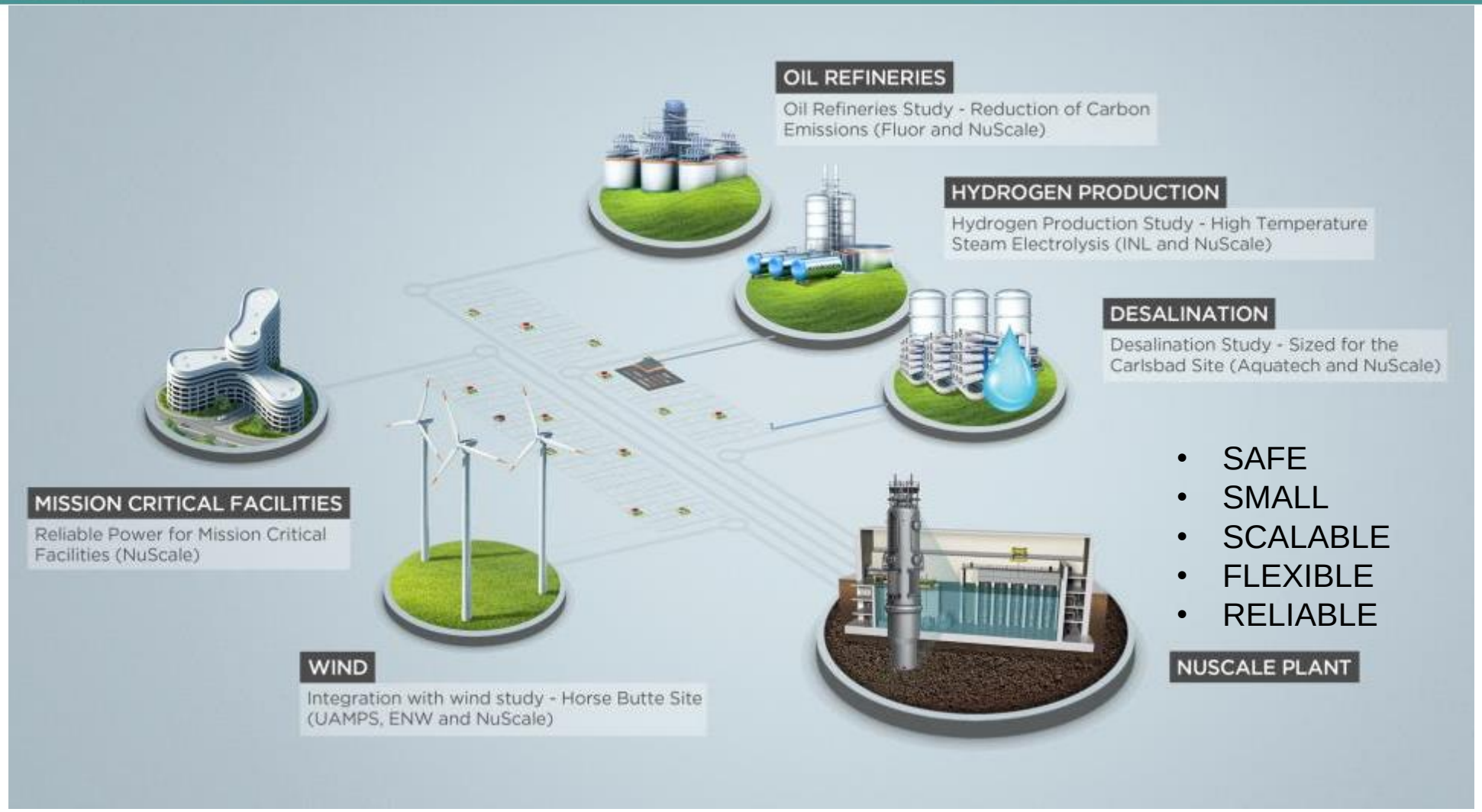
NuScale Digital I&C Platform (HIPS) Approved by NRC (July 2017)

- The Highly Integrated Protection System (HIPS) Platform is a protection system architecture jointly developed by NuScale Power and Rock Creek Innovations.
- It uses field programmable gate array technology that is **not vulnerable to internet cyber attacks.**

NRC approves NuScale Approach for no 1E Power (December 2017).

- This novel safety design approach eliminates the need for class 1E power, the regulatory standard set for the design of safety-related nuclear power plant electrical systems, which are currently required of all nuclear plants in the U.S.

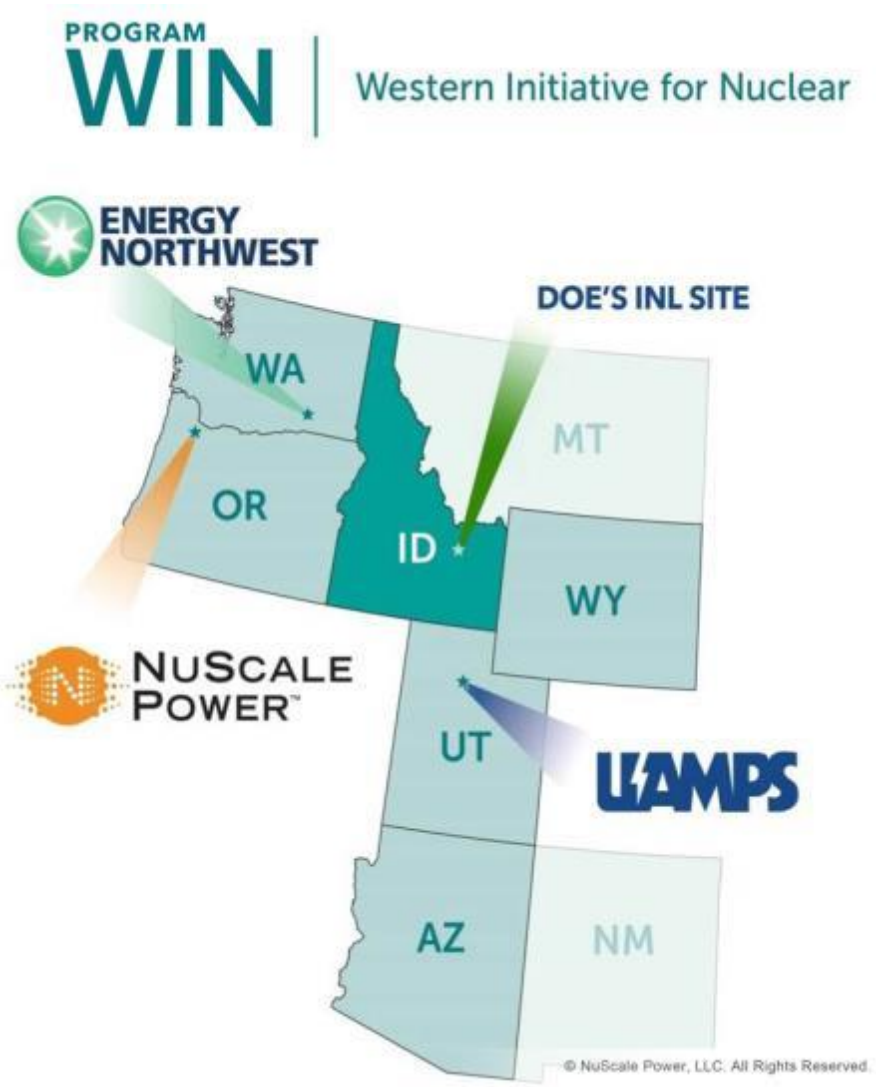
NuScale Diverse Energy Platform (NuDEP) Initiative



- SAFE
- SMALL
- SCALABLE
- FLEXIBLE
- RELIABLE

Progress with 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 license application to NRC
- 2026 commercial operation
- Power Sales Contracts *(UAMPS)*
  - Target is 150 MW by August 2018.



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Nuclear reactors of the future