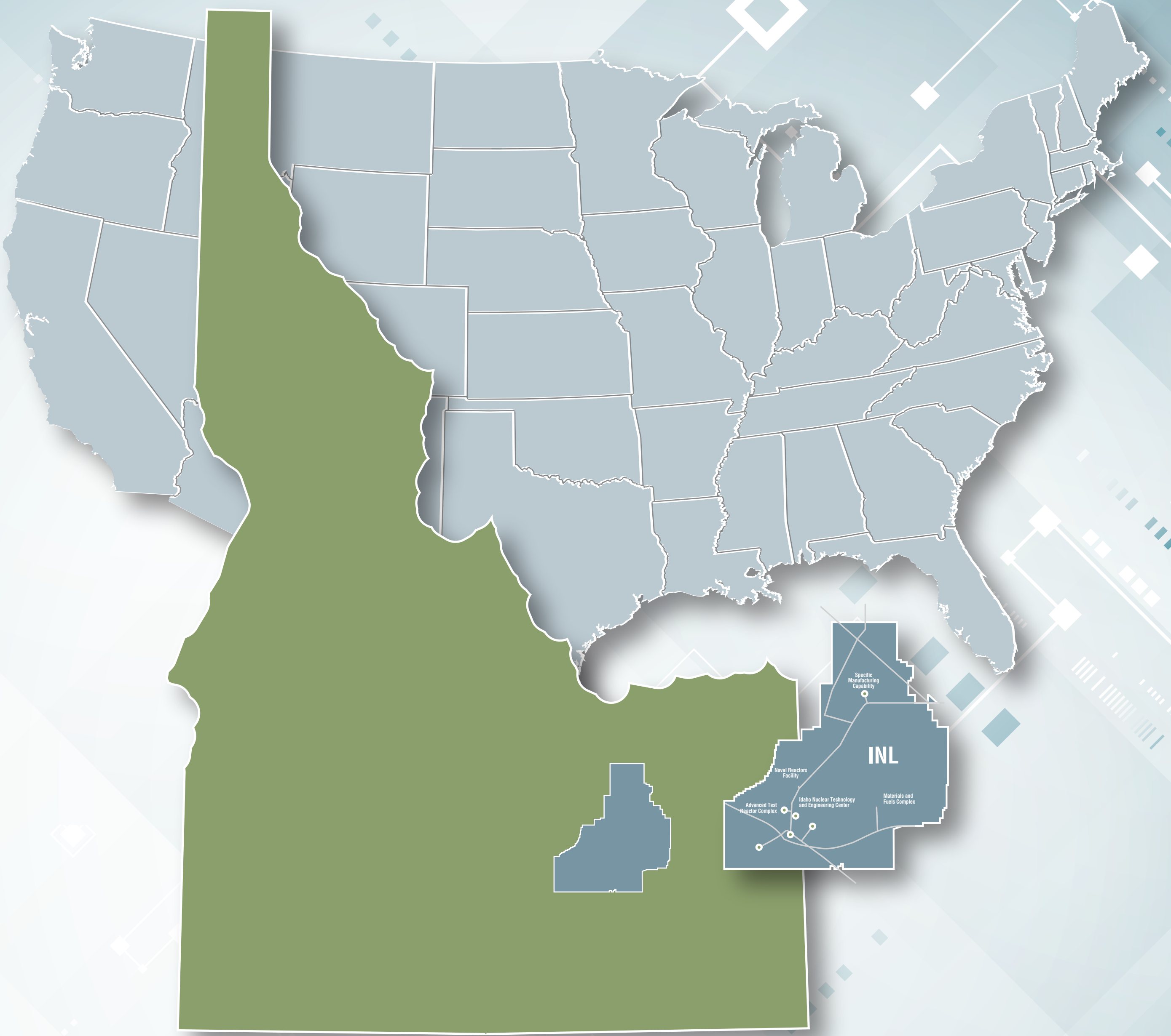

Bringing an Advanced Reactor Industry to Idaho

Idaho National Laboratory

Acknowledgments

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Executive Summary

The United States (U.S.) invented the commercial nuclear energy industry. Idaho played a major role in that effort. In fact, it's safe to say that virtually every nuclear reactor in operation today (in the U.S. and around the world) can trace some aspect of its existence to research and development conducted at Idaho National Laboratory (INL). With energy demand rising and the desire to reduce carbon emissions becoming more prominent, government and industry are increasingly interested in developing an emissions-free, power generation source that has proven safe, resilient, and dependable for more than six decades.

The world is looking to develop the next generation of nuclear reactors. This is Idaho's opportunity. Approximately 150 reactors have been ordered or are in the planning stages around the world. The market to build those 150 reactors (enough to power 115 million homes annually) is estimated at nearly $1 trillion. An additional 300 reactors are being discussed, and would add nearly $2 trillion more to the nuclear reactor market.

Idaho, with its history of nuclear reactor development, demonstration, and deployment, and INL's status as the nation's lead nuclear energy research and development laboratory, has a unique opportunity to help build a worldwide supply chain and to lead in the following areas:

1. First-of-a-kind development, demonstration, and deployment.
2. Test reactors, funded partially or in whole, by the private sector.
3. Fabrication.
4. Workforce development

Economic opportunity, and the ability to produce dependable, low-carbon electricity here at home, are powerful reasons for Idaho to help lead the development, demonstration, and deployment of next-generation nuclear reactors.

Here's another reason: national security. For more than three decades, the U.S. has chosen to be on the sidelines, slowly ceding our nuclear energy leadership to competitors, primarily Russia and China. The U.S. hasn't built a new nuclear reactor in more than three decades. Meanwhile, our high-performing reactor fleet is aging. Here's a sobering statistic: 78% of all new nuclear reactor builds across the globe involve Russia or China.

However, many people are working hard to reinvigorate the domestic nuclear energy industry. NuScale Power and the Utah Associated Municipal Power Systems (UAMPS) are working to deploy a first-of-a-kind small modular reactor at the INL site by 2026. INL is working with a variety of private-sector companies on next-generation reactor designs (including microreactors) to demonstrate in the next several years. Bipartisan support for nuclear energy development and demonstration was evident in passage of S. 97, the Nuclear Energy Innovation Capabilities Act, which instructs the U.S. Department of Energy to:

1. Establish a National Reactor Innovation Center at presumably INL, to enable the testing and demonstration of new reactor projects.
2. Determine the need for a "versatile reactor-based fast neutron source," a capability the U.S. badly needs and which now can only be accessed in Russia.

The U.S. has an obligation to lead the world into the next generation of reactor development.

Because the U.S. led development of commercial nuclear energy, our safety and non-proliferation approaches became the world standards. The U.S. knows that when a nation builds a nuclear reactor in another country, it begins a century-long relationship, a cooperative relationship that involves education, research and development, training, cyber and physical security, environmental protection, and safety and non-proliferation. When the U.S. builds a nuclear power plant in another country, we're exporting our technologies and equipment. We are also exporting U.S. values and expertise.

To have future nuclear reactors built and operated in the safest, smartest, and most resilient ways, the U.S. must lead the way. Within the U.S., that leadership has historically, and should in the future, come from Idaho. From past successes, and the current situation, the U.S. knows the following three things will help us achieve our goal of safely and securely enhancing a clean energy source that today provides 20% of America's electricity and nearly 60% of its low-carbon electricity:

1. Developing a clean energy supply chain in Idaho will require collaboration among multiple entities, including industry, academia, and local, state, and federal government officials.
2. Growing an advanced reactor supply chain should be presented in the broader context of growing a clean energy supply chain. That includes wind, hydro-electric, and solar.
3. Idaho should target two or three anchor projects that will attract other businesses and establish a nuclear supply chain.

Anchor project possibilities include:

Fuel Fabrication for Advanced Reactors

Why: Most advanced reactor designs require a new fuel production chain that doesn't exist today. If the U.S. is to establish a domestic fuel supply, INL's 890-square-mile site is ideally suited to host the facility. Idaho has the material and capability to make advanced reactor fuel, and the workforce to complete fuel separations. Shipping that material to other sites for fabrication is expensive and a security concern.

Factory Fabrication of Modules for Advanced Reactors

Why: Idaho will be the location for a first-of-a-kind deployment of an advanced reactor (NuScale). The modules should be fabricated close to the site to minimize transportation. A Blackfoot company, Premier Technology, has experience in nuclear fabrication. Idaho is developing the workforce.

Commercialization Park Adjacent to Idaho National Laboratory

Why: The nuclear industry needs to develop an advanced reactor supply chain that is cost effective and couples advances in technology and modeling and simulation with commercial business capability. An effective way to accomplish this is through a partnership between commercial business and INL to advance technology and create cost-effective advanced reactors. This would leverage federal funding and technical capability at INL.

Medical Isotope Production Facility

Why: Medical isotope production is important for the treatment of deadly diseases. It's also a multi-billion-dollar a year industry. A medical isotope production reactor in Canada recently shut down. The U.S. purchases some isotopes outside North America. Idaho has the material and workforce needed to make isotopes. Idaho also has the facilities to place a reactor.

All of this will take time, planning, and execution. However, one immediate opening arises in the area of workforce development. The nuclear community worldwide needs qualified and trained workers. A partnership between the state of Idaho, its institutions of higher learning, and industry could immediately identify workforce development needs, identify opportunities (such as tuition reimbursement), and make sure high school students throughout Idaho know about career and education opportunities in technology-related fields.

Development of advanced reactors is underway across the U.S. However, no advanced reactors are at the stage of commercial deployment, and as of yet, no orders have been placed. This may create short-term challenges for attracting businesses to participate in the advanced reactor supply chain even though long-term potential exists. Therefore, it is important to present opportunities in adjacently aligned sectors that would allow companies to easily "bridge" to a future advanced reactor supply chain future.

Bridging opportunities include: (1) attracting a clean energy industry, (2) identifying companies in Idaho that already work in a regulated industry, with quality assurance programs, and help them build nuclear quality assurance programs, (3) identifing opportunities in the global nuclear supply chain, for both existing and new plants, for businesses in Idaho, and (4) developing the businesses and/or facilities that will serve as anchor nuclear industries for Idaho. These four items would both build on existing Idaho businesses and attract new ones, thus positioning Idaho to be leaders in the advanced reactor supply chain when orders are placed.

The goal of this report is to jumpstart discussions about how Idaho can reclaim its historic leadership role and help the U.S. develop an advanced reactor supply chain. Regional partnerships will be an important part of our success and further research and discussions should explore those opportunities. Idaho should commission a future study to identify Idaho's opportunities in a clean energy supply chain.

Dr. Mark Peters
Director
Idaho National Laboratory

Opportunity and Action

The collaborators of this report have interviewed industry, research and development, and workforce development leaders to determine potential actions for attracting an advanced reactor supply chain. The table below lists the **opportunity** and suggested **action for further discussion.**

Suggested LINE Subcommittee Actions

Action	Opportunity	Timeline
	Industry Development Support	
Identify business opportunities in the existing nuclear industry worldwide for Idaho companies.	INL, industry, and the **Department of Commerce** work with partners to identify worldwide opportunities in the nuclear industry. Worldwide, the nuclear industry is a multi-trillion dollar business. Four near term opportunities for Idaho companies to compete in the global nuclear industry are: (1) extending and refurbishing major nuclear power plant life in Canada, (2) supporting U.S. nuclear power plant life extension projects, (3) supporting operation and maintenance needs of 450 operating plants worldwide, support the 450 planned new plants, and (4) providing technical expertise to support the Japanese energy plan to increase nuclear power to 25% of base source.	Near
Upgrade Idaho infrastructure to support advanced reactor supply chain.	**Idaho** establishes/enhances a fund and asks for proposals that would make investments in infrastructure upgrades to support a clean energy (nuclear) supply chain. A select group would then evaluate the proposals and make recommendations for funding. The infrastructure could support other uses. Examples of infrastructure include: roads, bridges, pipelines, and transmission lines.	Near
Establish a commercialization park adjacent to INL.	**Bonneville County** and the **city of Idaho Falls** in coordination with Regional Economic Development for Eastern Idaho **(REDI)** should explore establishing a commercialization park near the INL Research and Education Campus. Reduced lease rates could be provided to companies who are planning on collaborating with INL and/or are working in the nuclear industry. This should be structured as an accelerator as opposed to an incubator that just provides the space. An accelerator offers a range of support services and funding opportunities for startups. They tend to work by enrolling startups in months-long programs that offer mentorship, office space, and supply chain resources. More importantly, business accelerator programs offer access to capital and investment in return for startup equity.	Near

Action	Opportunity	Timeline
Industry Development Support		
Introduce legislation (or use existing legislation) to allocate funds to support identification of gaps in commercial business quality assurance programs, between their current operations and what would be needed to support the nuclear industry.	The state of **Idaho** has a number of businesses that could be suppliers for advanced reactors. The primary problem is developing a quality assurance program for the nuclear industry. The state of Idaho could establish a fund that would allow for evaluation of gaps in meeting the necessary nuclear quality assurance. Companies could submit proposals to the Department of Commerce to secure funds and have an independent company perform a gap assessment. Department of Commerce would review proposals and release funds. Funds could also be used to identify the necessary actions to close the gaps.	Medium
Set aside 20% of the INL nuclear procurement budget for a mentor-protégé program used to support regional businesses.	**INL** should develop and deploy a mentor-protégé program for local businesses interested in growing business in the nuclear industry. INL would be the facilitator of the program by supplying subcontracts to the businesses. INL could bring in an outside expert in the area to grow company NQA-1 programs (such as David Garcia at AMMI Risk Solutions). INL should review its procurement organization to identify opportunities for such a program.	Near
Identify opportunities to leverage federal funding to grow regional nuclear business.	The East Tennessee Economic Council uses resources of their region to create wealth in east Tennessee by leveraging the federal investment in the Oak Ridge National Laboratory (ORNL). ORNL works on being the bridge between federal entities and business owners. ORNL uses apprentice programs through the building trades to develop the workforce. **REDI and INL** should identify opportunities to leverage federal funding to grow Idaho's regional nuclear business.	Near

Action	Opportunity	Timeline
Workforce Development Support		
Introduce a bill that encourages the creation of clean energy workforce jobs, including nuclear.	Other states have used similar legislation to push green jobs and economic development.[1]	Medium
Introduce a bill or modify current bill that would provide business tax credits.	Introduce a bill or modify current bill that would provide a tax credit to each business that creates a clean energy (nuclear) job that has an annual salary of at least $50,000. Businesses can receive credits for up to 350 jobs. This mirrors legislation passed by Virginia that encourages green jobs.[2]	Medium
Provide tuition reimbursement for trades to support the nuclear industry.	The state of Idaho could consider adding language to Idaho Code Section 33-4303 that provides tuition reimbursement for community college trades that work in the nuclear industry. Two examples are nuclear qualified welders and radiation protection workers. Support could include tuition reimbursement for graduating students who work in the nuclear industry in Idaho for at least five years	Near

[1] *http://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx*
[2] *http://www.ncsl.org/research/energy/renewable-energy-legislative-update-2015.aspx#4*

Action	Opportunity	Timeline
Research and Development Support		
Support a bill that establishes a commercialization center for advanced construction and manufacturing technologies.	A recent Massachusetts Institute of Technology report[2] highlights the need to reduce the cost of new plant construction using advanced construction and manufacturing technologies. Idaho and INL could create a commercialization center for these technologies that achieves two goals: (1) reduces the costs of advanced reactors to increase the numbers deployed in the U.S. and around the world and (2) enables Idaho companies to better access for incorporating product technologies to increase competitiveness in the advanced reactor supply chain. Initially, **Idaho and INL** could commission a study to identify partners and scope of the center.	Near
Establish an organization focused on developing a nuclear industry supply chain.	**INL** should identify a dedicated lead and 2-3 additional support staff to focus full effort into working to grow a domestic advanced reactor supply chain.	Near

[2] *http://www.ncsl.org/research/energy/renewable-energy-legislative-update-2015.aspx#4*

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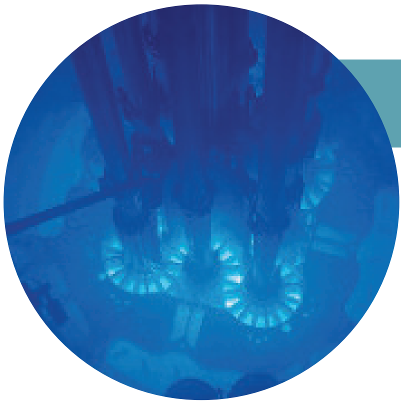



KIMTECH

Why Idaho?

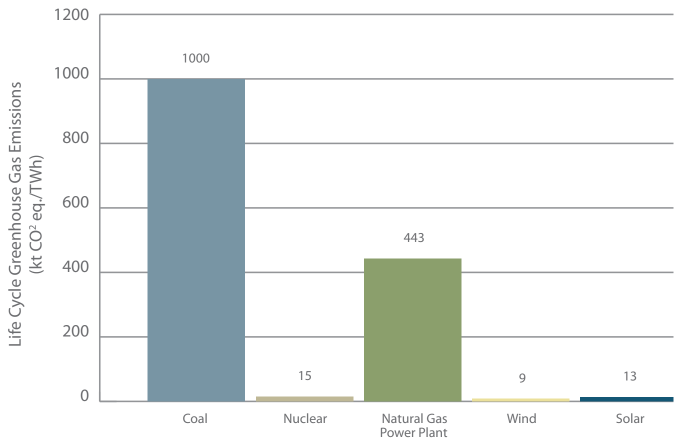
Background and Motivation

The state of Idaho and Idaho National Laboratory (INL) have a storied history of supporting the testing and deployment of civilian nuclear power across the United States (U.S.) and worldwide. Since the 1950s, INL has built, operated, and maintained 52 test reactors. Research performed using these reactors provided data used to form the safe operating envelope for the worlds light water reactor fleet. Federal funding for the construction and operation of these test reactors has provided the state of Idaho with a stable economic engine that is an important regional asset. INL's economic impact on Idaho is shown graphically in Figure 1.

Figure 1. INL economic impact on Idaho fiscal year 2018 (Jensen 2017).

More then 50 companies in the U.S. are in various stages of research, development, and deployment of a new class of reactors, termed "advanced reactors." Due to its storied history and world class workforce, INL is positioning itself to provide the testing ground for demonstration and deployment of advanced reactors. As these are deployed at INL, and later around the world, it is important that a stable supply chain be regionally available to support construction, operation, and maintenance. The supply chain should provide engineering services, materials and goods for construction, fabrication services, and workforce. The supply chain would not only support deployment of advanced reactors at INL, but would also support the nuclear industry across the world. The state of Idaho has provided support for nuclear energy through organization of Leadership in Nuclear Energy (LINE) Commission and through a recent executive order signed by the governor (Idaho 2018).

Future U.S. demand for new nuclear power plants is currently projected to be low. However, as nuclear plants are retiring early, they are being replaced with natural gas plants, increasing greenhouse gas emissions. Figure 2 shows that if natural gas replaces a coal plant, greenhouse gas emissions are cut in half. If natural gas replaces nuclear, greenhouse gas emissions go up 30 times. Nuclear power plants MUST be part of the future energy mix for the U.S. to transition to a clean energy sector.



(Gagnon et al. 2002)

Figure 2. Greenhouse gas emission life cycle.

Purpose of this Study

This report is intended to begin a discussion about growing an advanced reactor supply chain in Idaho. An analysis of current nuclear supply chain pieces is provided along with examples of what a deployed advanced reactor supply chain may look like. Finally, a series of recommended actions are provided for the state of Idaho, INL, and other stakeholders to consider. The recommendations are provided to the stakeholders and LINE Commission for further discussion.

Development of a domestic advanced reactor supply chain would accomplish: (1) establishing U.S. competitiveness in advanced reactors, and (2) strengthening Idaho and the region in advanced reactor space. The report explores involvement in three general areas that could drive the advanced reactor supply chain: (1) industry development, (2) technology development and research, and (3) workforce development. Development of the supply chain will require federal funding, state and local funding, and investment from industry.

Economic Development Reviews

Provided in this section is a brief overview of other states that have used both state and federal investment to build economic success, and lessons to be learned for Idaho. Even though many examples exist, only three are highlighted, (1) Research Triangle Park, (2) Louisiana Economic Development, and (3) East Tennessee Economic Council.

Research Triangle Park (www.rtp.org)

What is it?

The Research Triangle Park (RTP) is located in North Carolina. Its stated mission is to facilitate collaboration between three universities, promote cooperation between universities and industry, and create an economic impact for the citizens of North Carolina (www.rtp.org). RTP is a not-for-profit venture that was founded from within the state with the support of the community. Funding was raised for the park but companies were originally reluctant to move in.

ADVANCED REACTOR

GROWTH OPPORTUNITIES

Advanced reactor supply chain development will require state and federal investment in the following areas

Industry
Services, fabrication, raw materials, construction, suppliers, etc.

Research and Development
National laboratories, private sector, universities

Workforce Development
Four-year universities, community colleges, apprenticeships

Why did it work?

University researchers formed a traveling road show to highlight the research strengths to industry, forming partnerships with corporations. RTP attracted its first company, Chemstrand, the inventor of AstroTurf in 1960. Shortly thereafter, IBM came to the area with a 600,000 square foot research facility, and the future of RTP as an innovation community was assured. This worked because RTP had **community and state support** and was able to **attract an anchor industry.**

Louisiana Economic Development

What is it?

The state of Louisiana leverages its oil and gas revenue to attract business to the state. The Louisiana Economic Development (LED) creates jobs and economic opportunities for its citizens through nine integrated economic development strategies:

- Strategically improve state economic competitiveness
- Engage with local partners to enhance community competitiveness
- Forge partnerships to enhance regional economic development assets
- Expand and retain in-state businesses
- Execute a strong business recruitment program
- Cultivate small business, innovation, and entrepreneurship
- Enhance workforce development solutions
- Promote Louisiana's robust business advantages
- Attract foreign direct investments and grow international trade.

Why did it work?

LED helps businesses find the resources they need to make relocation and expansion a successful, profitable endeavor. An article from *Forbes* cites several keys to Louisiana's renaissance: comprehensive, **customized workforce training, major government reforms in ethics laws and tax policy, highly competitive business incentives,** and –above all– an innovative ability to adapt to the new global economy.

East Tennessee Economic Council

What is it?

East Tennessee Economic Council (ETEC) is an independent, regional, non-profit membership organization that supports the federal government's missions in Oak Ridge as well as encouraging new opportunities to fully utilize the highly-skilled talent, cutting-edge technologies, and unique facilities that make up the federal reservation, the University of Tennessee complex, and the Tennessee Valley Authority's region.[3]

Why did it work?

During an interview with Jim Campbell president of ETEC, Jim stated that the organization uses resources of the region to create wealth in east Tennessee by leveraging the federal investment in the Oak Ridge National Laboratory (ORNL). ORNL works on being the bridge between federal entities and business owners. ORNL **uses apprentice programs** through the building trades to **develop the workforce.**

Opportunity	Action
Identify an anchor industry and develop workforce.	Idaho in collaboration with INL and regional partners identify a few anchor industries.

[3] *https://eteconline.org/*

Other Supply Chain Process

A supply chain that delivers products on schedule, on budget, and with the appropriate quality is the key to successful projects. Over time, businesses in the U.S. have developed supply chains to support their needs. Two examples of U.S. businesses that have developed successful supply chains are the aerospace industry and Department of Defense shipbuilding. A brief overview of each is provided to provide context on what has worked and what has not worked.

Shipbuilding Industry

The Department of Defense shipbuilding industry in the U.S. has evolved from onsite construction, where keels were laid and frames constructed (bottom up construction), to Ford-class aircraft carriers utilizing extensive offsite assembly of modules in factories. The modules are then transported to the site, and joined. As the industry continues to shift to increased modularity, they are continually evolving the modular construction concept and adapting new technologies and equipment. Shipbuilders are integrating three-dimensional product models with the project schedule, work control, and management of the supply chain. As new advanced construction techniques are developed, companies are also committed to upgrading training. Construction schedules are being compressed by testing of discrete modules / sections of the ship (units), instead of testing the completed system.

From the Kennedy- to Ford-class aircraft carrier, there has been a 30% reduction in onsite construction work with 20% moved into fabrication shops. This has resulted in shorter delivery schedules and reduced cost.[4] A shipbuilding industry rule of thumb is: a task that takes 1 hour in a shop environment will take 3 hours in an assembly / outfitting area and 8 hours in-hull during final fabrication.

Some important points to note about modular construction are component changes may impact the space envelope around them in a "ripple effect," sometimes into the next ship compartment. Environmental changes (such as temperature changes) have to be accounted for when joining sections. A module built to exact dimensions in a cool shop environment in the spring may not match up perfectly out in the drydock during the summer heat. There are also numerous lessons-learned in the areas of joining.[5]

Boeing and Deployment of 787 Dreamlinear

Boeing has a global supply chain for the 787 Dreamliner aircraft. Boeing had problems with the 787 program for years. The project was originally slated to cost $8 billion but the final program cost was $32 billion.[6] However, they have optimized their supply chain and are performing the final assembly in Everett, Washington. This has led to Boeing becoming more efficient in their aircraft assembly and made the 787 program profitable.

Boeing modeled their supply chain and assembly approach after what Toyota uses in the automobile industry. Toyota uses a system that focuses the whole production process and all suppliers through joint optimization. Two important aspects of Toyota's production strategy are: (1) companies in the supply chain are only provided existing and proven technology orders and (2) Toyota invests in their suppliers.

Giving additional responsibilities to suppliers can improve the efficiency and cost. However, it is important to ensure that only proven methods and technologies are outsourced. It is important that the supplier is familiar with the prime contractor's processes and company. This is especially important in the nuclear industry where quality assurance requirements need to flow down through the supply chain. The most efficient way to achieve this is placing knowledgeable employees from the prime contractor within supplier organizations.[6]

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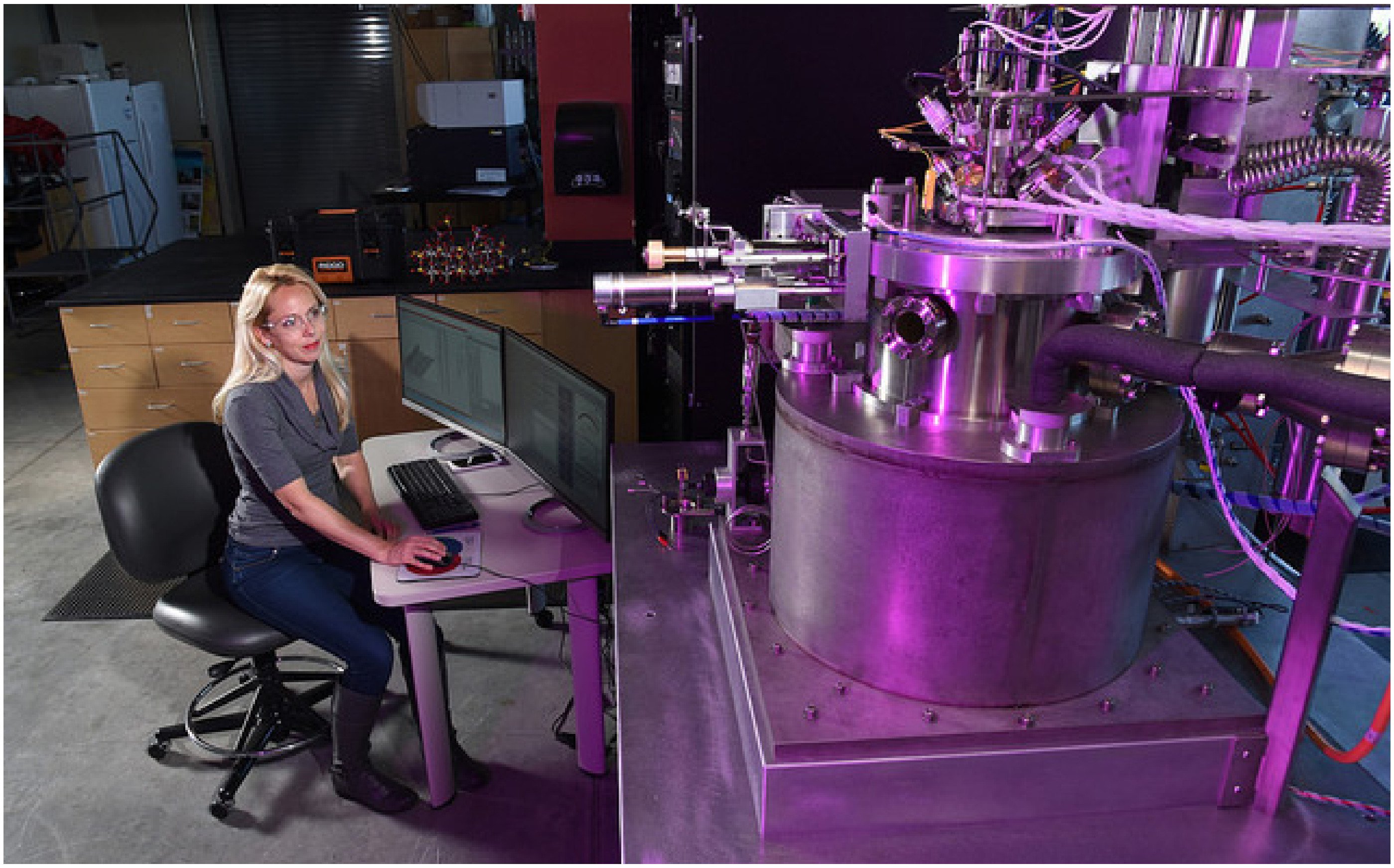
4 *https://energy.mit.edu/wp-content/uploads/2017/03/NNS-Advanced-Mfg-for-MIT-Workshop-0116-R3b.pdf*
5 *https://www.economist.com/business/2016/05/14/the-eye-of-the-storm*
6 *https://www.exsyn.com/blog/learn-from-boeing-787-production-troubles*

What is the Advanced Reactor Industry?

Existing U.S. nuclear power plants are retiring earlier than expected due to cheap natural gas (Haratyk 2017). While the outlook for existing plants and Generation III+ large light water reactors looks dim in the U.S., the worldwide outlook is bright (World Nuclear 2018). This provides an opportunity for the nuclear industry in the U.S. to continue its participation in the world-wide nuclear supply chain.

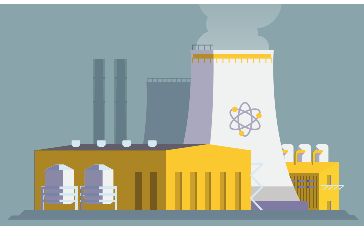
As the nuclear community struggles for a path forward to stabilize the existing industry, including new-build plants in the Southeastern U.S., more than 50 companies are in various stages of developing advanced reactors (Freed 2015). Advanced reactors provide an opportunity to improve the economics of new-build nuclear plants in the U.S. However, these are paper designs and the promised economic case for these reactors are not yet proven. A brief description on the different classes of advanced reactors is provided in Figure 3.

For the purposes of this report, the term advanced reactor refers to those nuclear reactors that are currently in the design, development, and/or demonstration phase and are applying novel approaches to increase modularity and passive safety. This definition could include deployment of the AP1000 into a new nuclear environment such as India. A report published by Third Way states there are nearly 50 advanced reactor developers today, with nine unique advanced reactor types (Freed 2015). The nine types outlined are: molten salt reactors, sodium-cooled fast reactors, lead-cooled fast reactors, gas-cooled fast reactors, supercritical water-cooled reactors, very high temperature reactors, small modular reactors, microreactors, and fusion reactors. A more detailed description of each reactor type is provided in Appendix A.



Advanced Reactors Industry Overview

"Remote Arctic Community", Nuclear Reimagined
https://www.thirdway.org/blog



ADVANCED REACTOR TYPES

- Molten salt reactor
- Small modular reactor
- Microreactor
- Lead-cooled reactor
- Sodium-cooled reactor
- Very high temperature reactor
- Gas-cooled reactor

UNIQUE SUPPLY CHAIN NEEDS

- Special materials that can operate at elevated temperatures and in corrosive environments
- Fabrication and welding procedures for these materials
- Qualified workforce in working with these materials

Advanced Reactor Types	Maturity	Market	Deployment in Idaho
Molten salt reactor	Late 2020s[1]	US, Global	Yes
Light water reactor	Mid 2020s	US, Global	Yes
Microreactor	Mid 2020s	US, Global	Yes
Lead-cooled fast reactor		Global	No
Sodium-cooled fast reactor	Mid 2020s[2]	US, Global	No
Very high temperature reactor	Late 2020s	China, US	Unknown
Gas-cooled fast reactor		US, Global	Yes

[1] Deployment timelines for the first of a kind are in the 2020s (Nanalyze 2017).
[2] Prototype of traveling wave reactor technology for mid 2020s, likely in China (TerraPower 2018).

● Yes ○ No ▲ Unknown

Figure 3.Advanced reactors industry overview.

Advanced Reactor Supply Chain

A supply chain, as defined by the American Production and Inventory Control Society,[7] is a system of organizations, people, technologies, activities, information and resources involved in moving materials, products and services all the way through the manufacturing process, from the original materials supplier to the end customer. Generally, the supply chain for an advanced reactor will require many of the same components, but with some noticeable differences. Some of those differences include: advanced reactors will have a different fuel fabrication supply chain (this will be identified as an opportunity for Idaho later), advanced reactors will require more modular construction capability since the concept is to build modules in factories and deploy them to the site, and special materials for high temperatures or highly corrosive environments will be needed for advanced reactors. An item that is consistent is the quality assurance requirements.

Figure 4 provides a high-level overview of the stakeholders and the tiers in the advanced reactor supply chain. An example of what would be involved at each tier is provided for a nuclear steam supply system.

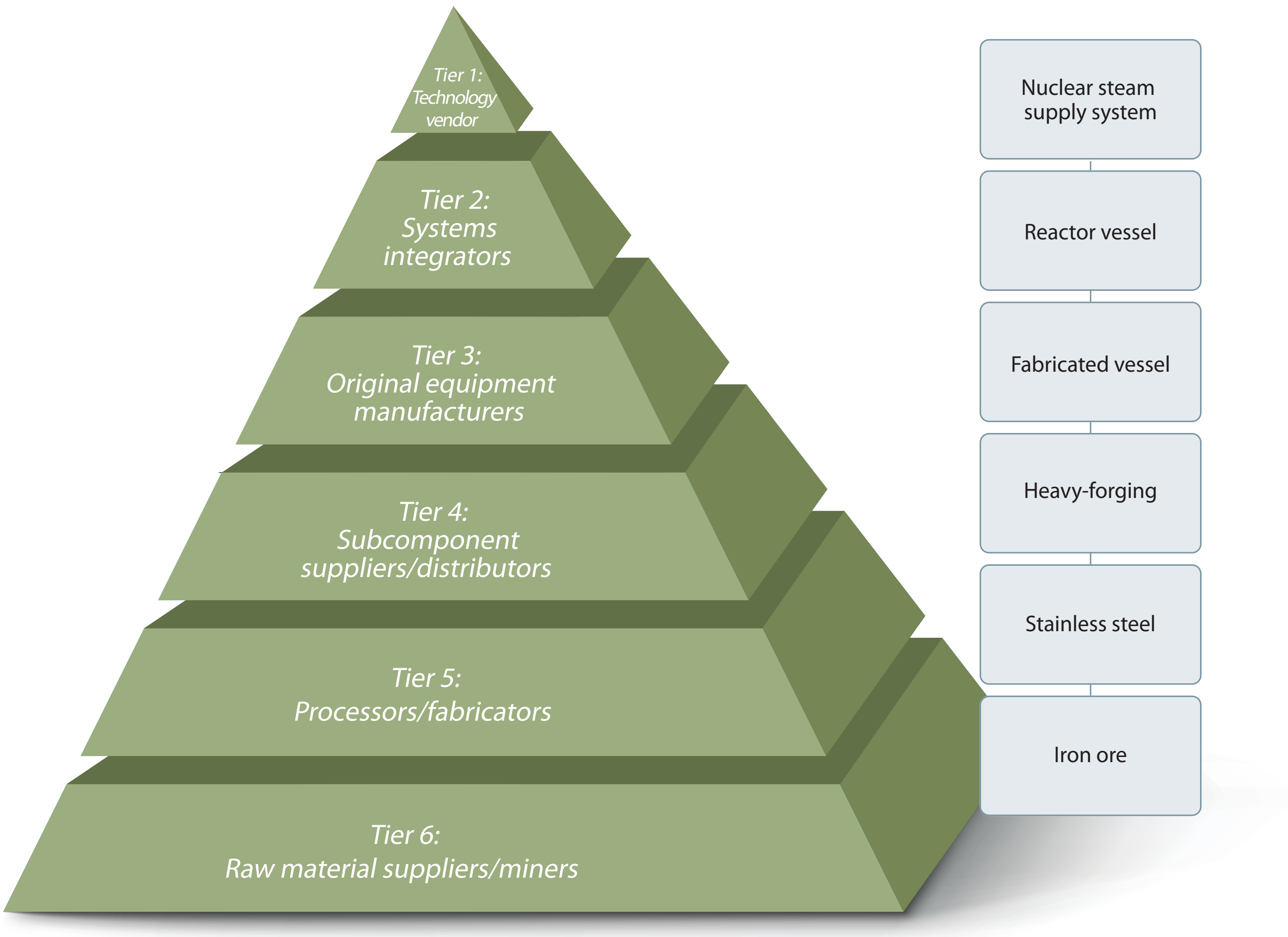


Figure 4. Nuclear supply chain (World Nuclear Association 2014).

[7] http://www.apics.org/

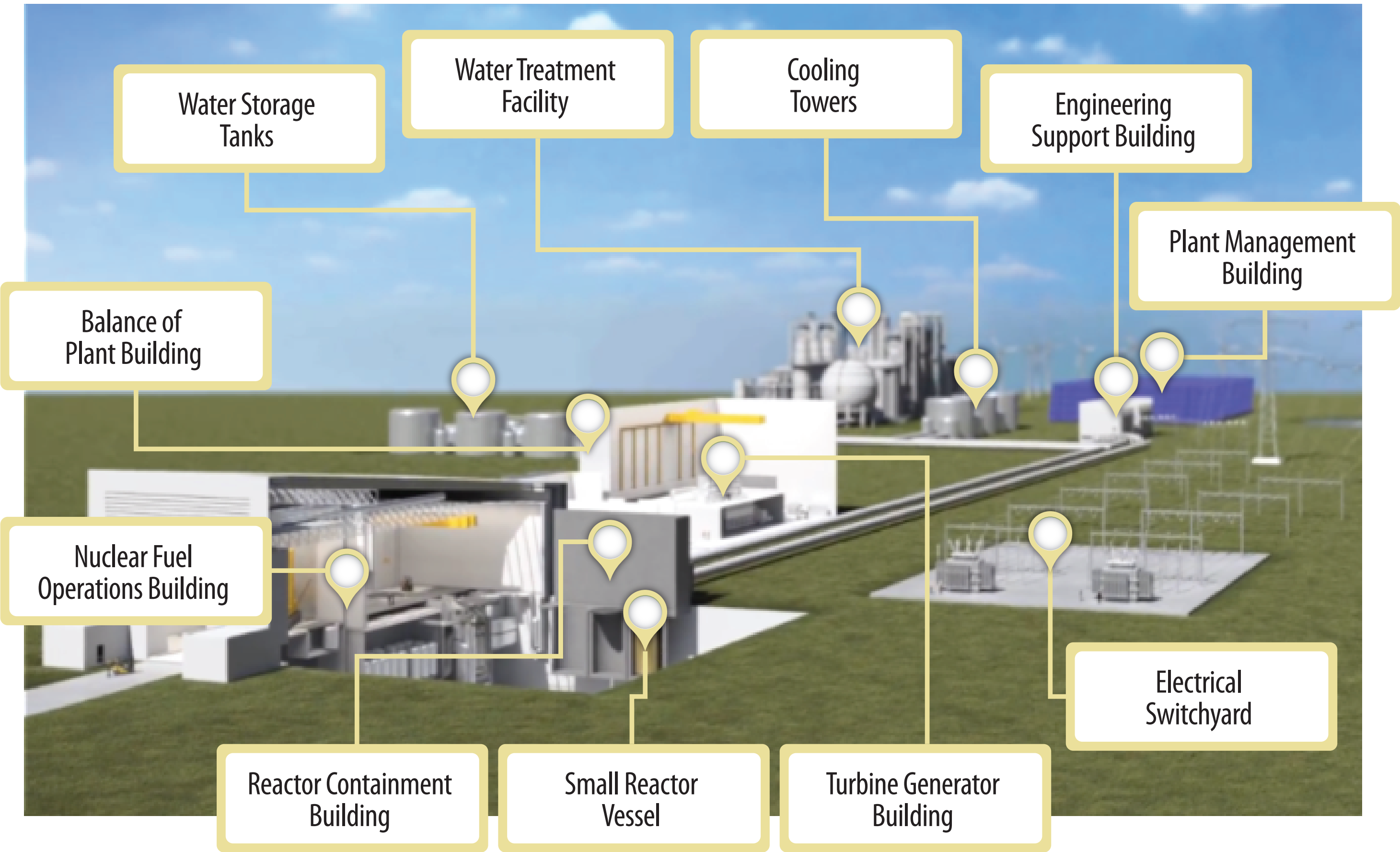


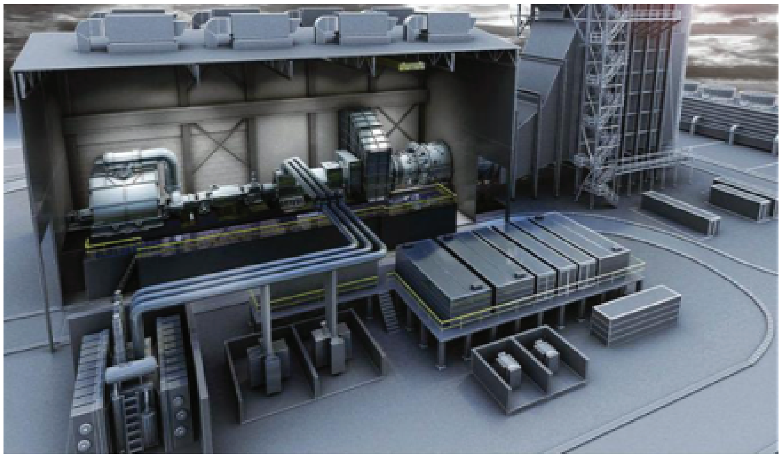
Figure 5. Physical segments of a generic advanced reactor.

A list of physical segments of a generic advanced reactor are provided in Figure 5. This generic layout could differ depending on the advanced reactor coolant, plant layout, and plant size. One important item to note is that large quantities of concrete are needed and this will be sourced near the construction site.

Figure 6 provides a list of items used in the construction of an advanced reactor, and thus highlights industry needed for an advanced reactor supply chain. Included are mechanical systems, materials, specialty equipment and services, electrical distribution, and instrumentation. This list would allow private companies to identify opportunities for selling their supplies or services to the prime contractor in an advanced reactor project. Information on estimated quantities for a NuScale 12-pack is provided in Appendix B.

Mechanical

- Rebar and grid systems
- Carbon steel plates
- Carbon steel piping
- Stainless steel plates
- Stainless steel piping
- Unistrut, wire rope, cables
- Piping supports
- HVAC, filtration systems
- Process filtering skids
- Anchors, fasteners
- Valves
- Tanks, vessels, drainage vessels
- Cranes, hoists, lifts
- Water recovery systems
- On-site fabrication



Electrical 120VDC to 345KV

- Motors-DC
- Motors-AC
- Motor generators
- Emergency generators
- Switchgear
- Breakers
- Battery banks
- Inverters
- Chargers
- Conduit
- Wiring, wiring boxes
- Fuses
- Distribution panels
- Lamps, lightbulbs
- Cable trays

Materials

- Concrete/aggregate
- Paint, sealants, coatings
- Resins, polymers, adhesives
- Industrial use chemicals
- Chemical ion exchangers
- CO^2, halon, industrial gases
- Scaffold systems, ladders
- Welders, weld rod, brazing
- Grout, caulks
- Nuts, bolts, anchors
- Lumber, plywood
- Siding, roofing, paneling
- Earthwork equipment

Specialty Equipment & Services

- Fire protection
- Fire suppression
- Paint and coatings
- Insulation-stainless
- Normal lighting
- Emergency lighting
- Hydrogen storage
- Oils/lubricants
- Oil filtration systems
- PA/communicaitoins
- Audio/visual systems
- Cranes, hoists, lifts
- Crating ropes, cables
- Cameras
- Elevators
- Doors
- Hatches
- Absorbents
- Tool Boxes
- Hand tools
- Powered tools
- Signage
- Safety equipment
- Barricades, barriers
- Material testing services
- Quality and inspection
- Safety and health
- Admin/human resource services

Instrumentation

- Sensors
- Meters
- Transmitters
- Power supplies
- Low voltage wiring, terminals
- Testing equipment
- Circuit boards
- Alarms
- Ground detection equipment
- Solenoids
- Relays

Figure 6. Construction pieces for an advanced reactor.

Quality in the Supply Chain

Quality assurance in all aspects of nuclear power plant activities is a necessity. A supplier, service provider or contractor maintains compliance to the regulations of 10 CFR 50, as defined by the Nuclear Regulatory Commission, with their internal processes, procurement methods, procedures, training, and capabilities. The standard approach is a well-defined quality management system that ensures compliant execution of process within defined guidance documents, procedures, and work instructions to industry standards and certifications, such as ASME, API, and ISO.

The advanced reactor industry will have a graded approach to ensuring quality. The three quality levels are: safety-related (Q), non-safety related (non-Q), non-Q – regulatory treatment of non-safety systems (NSR-Q, note that this is still in a validation process). Advanced reactors will likely need less safety-related (Q) components than traditional large light water reactors, which may make it easier for suppliers to enter at a lower quality assurance level. However, quality in the supply chain is critical to the success of the project. Therefore, it is important that all stakeholders in the process are integrated and collaborating in the supply chain along the entire process. Opportunities exist for local manufacturing and procurement of both safety and non-safety class components when possible.

Construction

One of the primary advantages of advanced reactors over traditional large light water reactors is the ability for modular assembly in a factory. Four opportunities for factory module assembly capability for advanced reactor fabrication are: (1) structural steel construction, (2) reactor/containment vessel, (3) electrical and instrumentation and control modules, and (4) equipment modules. Equipment modules will require multi-discipline assembly teams since they will use piping, ducting, cabling, process equipment, electrical, and instrumentation and control. A general rule of thumb used in the defense shipbuilding industry is the 1:3:8 rule (see Figure 7, Moody 2010). Where a task/fabrication in a shop/factory environment takes one hour to accomplish, the same task would take three hours to accomplish in an assembly area, and eight hours at a construction site.

An ideal process would be to assemble modules at the factory, join them into super modules, and then lift and install the super modules at the construction site. The assembly area can also be used to increase integration and testing activities that will reduce in situ construction activities. Processes can be monitored and improved, waste can be reduced, lessons can be learned, and close tolerances can be controlled.

Local suppliers are important to the success of an advanced reactor project. These are typically located within a 500-mile radius of the site being constructed (U.S. Nuclear Industry Council). The first site to build an advanced reactor (i.e., Utah Associated Municipal Power Systems/NuScale at INL) will have a manufacturing opportunity advantage over others in terms of becoming a global supplier.

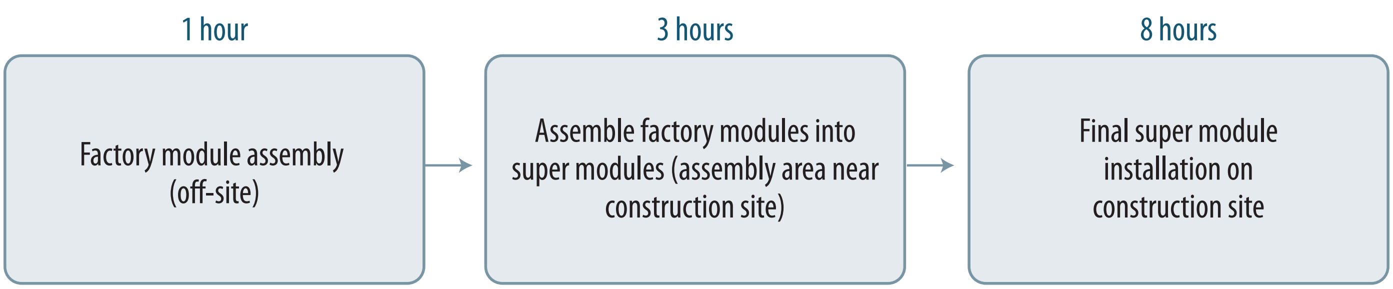
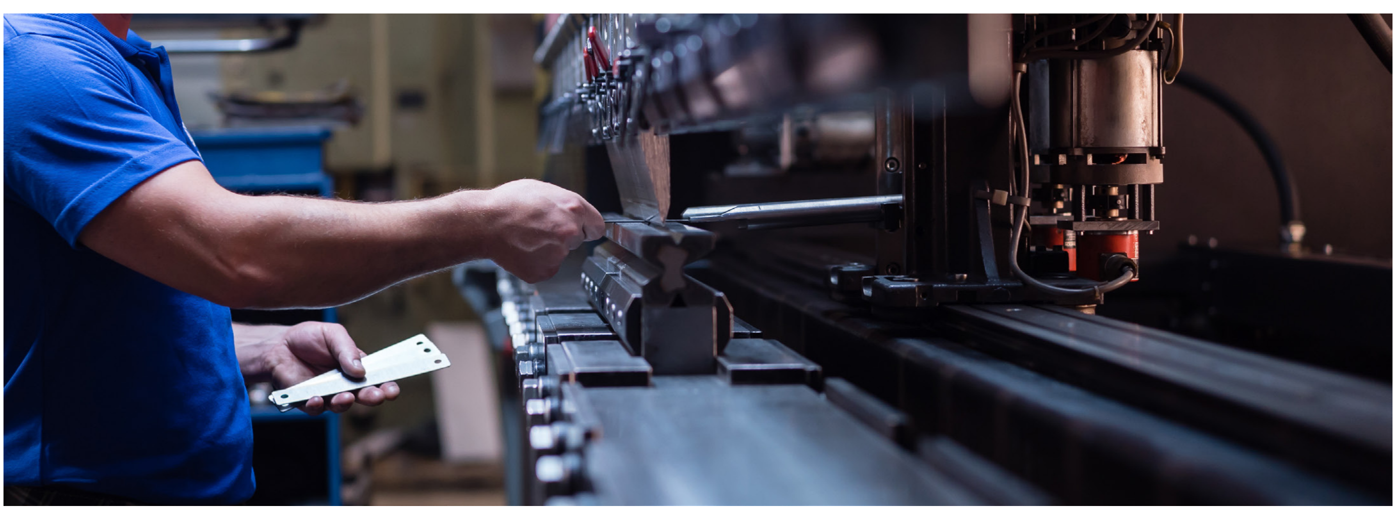


Figure 7. Ideal module assembly process for advanced reactors.



Advanced Reactor Development Needs

Additional development is needed for advanced reactors to meet their full potential in modular factory fabrication, assembly area work, and construction site installation. Resources at both national laboratories and commercial industry could be used to help address the needs in technology development, codes and standards, and unique designs. Identified needs include:

- Development of methods for advanced reactor modular assembly, other industries such as chemical and food processing already have established methods for modular fabrication.
- Design of equipment and capabilities at a factory to support module assembly.
- Design and testing of modular components before installation.
- Process for design and assembly of super modules and plant systems (this would be done in the assembly area) that can be installed on the construction site.
- Fuel fabrication facility for advanced reactors. Advanced reactors will need a high-assay low-enriched uranium fuel facility (NEI 2018).
- Ability to increase U.S. forging capability and capacity.
- Common language allowing suppliers to support multiple advanced reactor designs.
- Integrated configuration management standards.

Opportunity	Action
Support industry development to supply worldwide nuclear industry	Idaho works with industry and consultants to identify worldwide opportunities

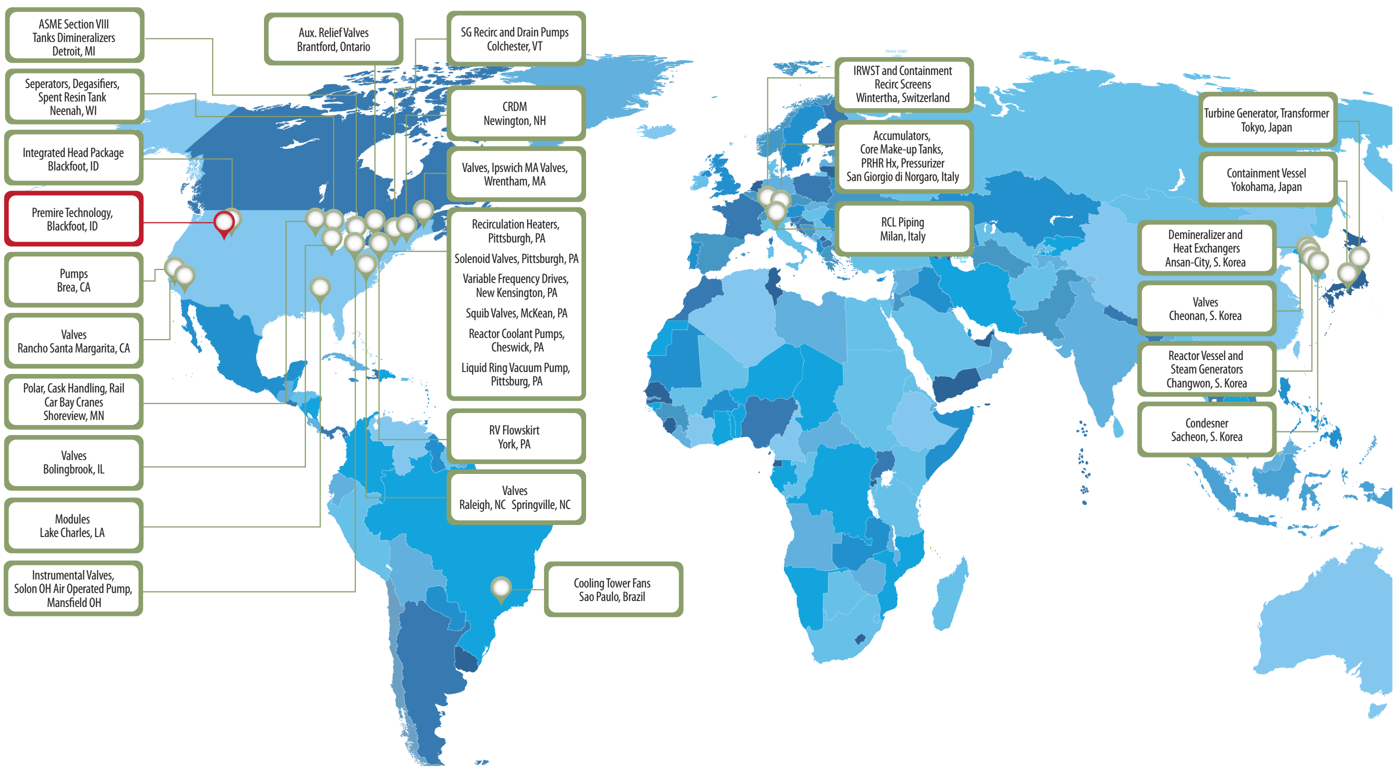


Figure 8. Global supply chain for fabrication and construction of AP1000.

Advanced Reactor Stakeholders in the Supply Chain

The current supply chain for new build nuclear plants is global. Westinghouse developed a global supply chain for fabrication and construction of the AP1000 (shown Figure 8). The figure shows major pieces in the AP1000 supply chain from turbine generators to valves, piping, tanks, and vessels. Premier Technology (Blackfoot, Idaho) is part of the Westinghouse supply chain. This presents an opportunity for the region and state to build on Premier's nuclear fabrication capability to help establish Idaho as a worldwide supplier in the advanced reactor supply chain. The advanced reactor supply chain may also be global, although it is possible for the U.S. to establish a completely domestic supply chain for advanced reactors, with investment.

Figure 9 identifies major stakeholders in an advanced reactor supply chain and provides descriptions of each. These stakeholders have an important role in the design, procurement, and construction process. Appendix C provides an overview of how each stakeholder fits into the life cycle of advanced reactors from design to construction to decommissioning. The state of Idaho should work to identify companies in Idaho that are interested in working in the nuclear supply chain, then work to fill gaps in their businesses to become nuclear supply chain providers. One important gap to close is nuclear quality assurance.

Advanced Reactor Stakeholder/Supplier	Description	Idaho Opportunities
Owner/License Holder	Plant license holder authorized to operate the facility within the requirements of the plant design basis. Responsible for plant design, operation and fiscal decision making over life of facility. An example would be UAMPS for the NuScale project	State works with potential license holder to provide tax breaks or incentives to come to Idaho
Prime Design Engineer	Design engineer enterprise with final facility design authority. Typically be a large design engineering organization with many years of experience in the nuclear industry on an international scale. An example would be AREVA or SNC Lavalin.	Design firms in Idaho could partner with Prime Design Engineer.
Directing Project Management Provider	Overall Project Management enterprise. May be a division of Prime Design Engineer or separate firm with capacities for large scale capital project controls. An example would be Faithful & Gould or AECOM.	AECOM is part of the BEA contract.
Regulatory Compliance Authorities	Independent agencies and organizations with legal and industry regarded authority to assign, monitor and enforce enterprise compliance to regulations. Examples are the is NRC, EPA and state-specific authorities.	State of Idaho will have regulatory oversight.
Procurement Management of Supplied Goods	Overall authority chartered to define and establish procurement processes and infrastructure. May be Prime internal function or specialized service and technology provider working on behalf of Direct Project Management provider.	Department of Commerce could identify businesses in Idaho interested in this business
Prime Fabricator and Assembler	Tier 1 or centralized fabricator / fabrication facility where majority or bulk fabrications and component / sub assembly occurs for fully integrated product line. including advanced manufacturing. Examples are established nuclear supplier, such as AREVA or large fabricator with diverse and complex experience, such as Boeing.	Idaho could help develop suppliers in this area or help companies build relationships with Tier 1 fabricators. Premier Technologies is an example. Workforce development is important.
SSC Sub-suppliers and Service Providers	Tier 2 and below providers whose goods and services support the overall product line and are integrated into production and products within the Prime Fabricator location or supply chain. Examples include local to international suppliers.	Idaho could help develop suppliers in this area. Workforce development is important. Premier Technologies serves this role for AP1000 builds
Specialty Suppliers and Service Providers	Provide advancement of design, solutions in process and methods and enable First of a Kind / Prototyping capacities in controlled environments, such as laboratories, machining centers, materials and process development centers.	Could be the specialized nuclear fuels fabrication. Idaho/INL should explore a fuel fabrication facility as an anchor industry. Could be a public private partnership.
Logistics and Transportation Authorities	Experienced in standard and complex shipping and cartage requirements for large scale, global distribution support. Maintain design and nuclear safety protection through shipping-specific applications and compliance to the plant license specification.	Department of Commerce could identify businesses in Idaho interested in this business
Warehouse and Storage Providers	Experienced in storage, crating and warehousing processes. Work in collaboration with the fabricators, end clients and logistics and transportation authorities to assure products and goods maintain design and quality compliance.	Department of Commerce could identify businesses in Idaho interested in this business
Commodity and Facility Construction (Prime Constructors)	Contracted supplier and service provider with responsibility for facility and commercial construction to support the advanced reactor fabrication facility, the overall power plant facility or other supporting facilities for both.	Department of Commerce could identify businesses in Idaho interested in this business
Facility Operation and Maintenance -Modification	Responsible for post commissioning power plant operations, maintenance and overall management. This may be an Owner responsibility or contracted service provider, such as Fluor or other smaller emerging enterprises.	If FOAK reactors are built at INL a local firm in Idaho, or a larger firm with local presence could support this.
Regional Education Program Providers (Service Only)	Critical resource channel to support a large scale advanced technology initiative where workforce development, trades training, industry specific qualifications and education will be necessary to develop a local workforce and staff for all facilities within the project;	State could work with community colleges and state universities to provide tuition reimbursement for those interested in degrees specific to advanced nuclear industry. Also need to identify critical development areas.

Figure 9. Advanced reactor stakeholder and supplier list.

Figure 10 is an example of how some of the stakeholders would interact for factory module production. First, the order will be placed and modular factory fabrication will begin. Once the modules are fabricated in the factory, they will be shipped by truck, rail, or barge to the project site. The modules will be assembled into super modules in the assembly area and then craned into place on the construction site.

For instance, if the first-of-a-kind advanced reactor is deployed in Idaho, there are companies that could support the project. As illustrated in Figure 11, Idaho has nuclear suppliers and service industries. For instance, digital instrumentation and control systems could come from Boise (home to HP and Micron), electrical equipment supply from Pocatello (D&S Electric), pumps and valves from Idaho Falls (Curtis-Wright), module fabrication in Blackfoot (Premier Technology), nuclear grade concrete (Idaho Falls), and a workforce from all over the state.

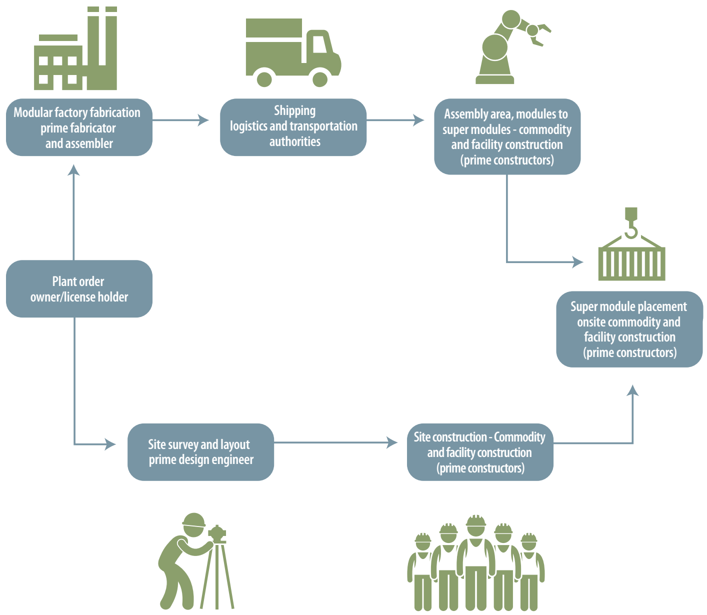


Figure 10. Stakeholder interaction during factory module production.

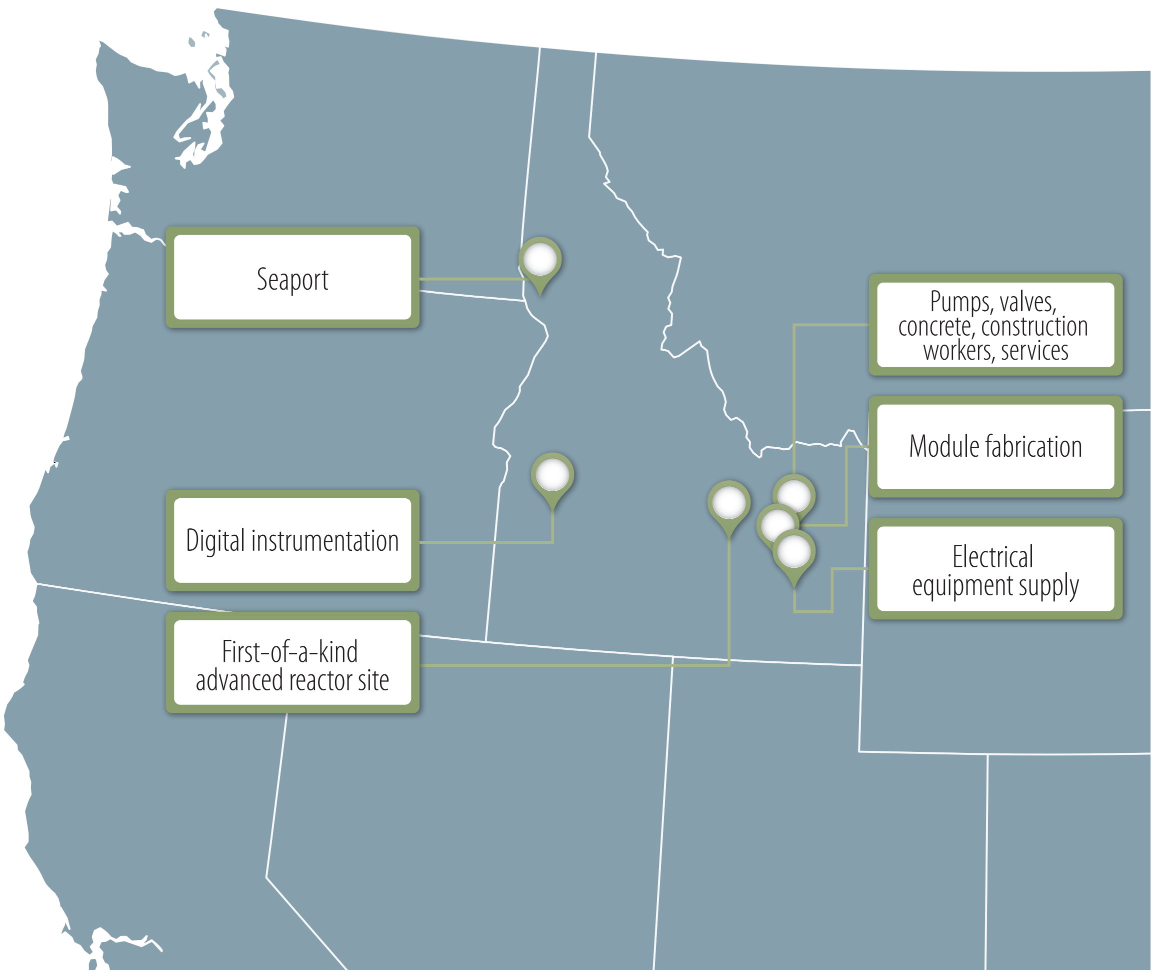


Figure 11. Idaho nuclear supplier and service industries.

What are Idaho's Opportunities?

Development of advanced reactors is underway across the U.S. However, no advanced reactors are at the stage of commercial deployment, and as of yet, no orders have been placed. This may create short-term challenges for attracting businesses to participate in the advanced reactor supply chain even though long-term potential exists. Therefore, it is important to present opportunities in adjacently aligned sectors that would allow companies to easily "bridge" to an advanced reactor supply chain future.

Bridging opportunities include: (1) attracting a clean energy industry, (2) identifing and working with companies in Idaho that already work in a regulated industry with quality assurance programs, (3) identifying opportunities in the global nuclear supply chain, and (4) designating businesses or facilities that would serve as an anchor to the nuclear industry. These four items would build on existing Idaho businesses, and help attract new businesses, thus positioning Idaho for participating in the advanced reactor supply chain when orders are placed. Another important item is for the state of Idaho to develop a workforce in the clean energy and advanced reactor supply chain.

Successful projects need resource, workforce, predictability, and stability.

Even though this report is focused on the advanced reactor industry, it is important for the state of Idaho to embrace the concept of being a supply chain provider for the broader clean energy industry. Clean energy is projected to have the largest growth of any other energy sources over the next 20 years. Other clean energy technologies such as hydro-electric, wind, and solar have quality assurance standards, while not as strict as nuclear, that would still build company capabilities in that area.

Industry Development

The state of Idaho already has companies that work in regulated markets who could participate in the nuclear supply chain with help updating their quality assurance programs. These companies likely already have quality assurance programs and a safety culture that could be used to more easily implement a nuclear quality assurance program such as NQA-1. The state of Idaho should identify companies in Idaho that work in regulated markets who could participate in the nuclear supply chain.

Industrial sectors in Idaho that provide products that meet quality standards are:

Aerospace in Idaho

160 Establishments
2,300 Jobs
$63,000 Average Yearly Earnings
35% 10-Year Projected Growth Rate

The aerospace industry: https://commerce.idaho.gov/site-selection/key-industries/aerospace/

Energy in Idaho

2,300 Establishments
29,000 Jobs
$91,000 Average Yearly Earnings
14% 10-Year Projected Growth Rate

Energy industry: https://commerce.idaho.gov/site-selection/key-industries/idahos-energy-industry/

Food Production in Idaho

2,000 Establishments
43,000 Jobs
$44,000 Average Yearly Earnings
9% 10-Year Projected Growth Rate

Food production: https://commerce.idaho.gov/site-selection/key-industries/food-production/

Advanced Manufacturing in Idaho

1,500 Establishments
40,000 Jobs
$77,000 Average Yearly Earnings
16% 10-Year Projected Growth Rate

Advanced manufacturing: https://commerce.idaho.gov/site-selection/key-industries/advanced-manufacturing/

The state of Idaho also has geographical advantages that position it uniquely for opportunities in a global supply chain. Geographical opportunities include:

- Shipping access to the rest of the world through the Columbia River in Lewiston
- Existing federal land at INL that could be used as a demonstration reactor park to establish a public-private partnership with companies in the nuclear industry.

Research and Development

From state universities to INL, Idaho has supported nuclear research and development for over 50 years. As advanced reactors start to utilize modular construction to improve their economics, opportunities exist for technology research and development. One of the biggest needs is joining modules into super modules, placement on site, and welding and joining of advanced materials. There is an opportunity for a collaborative effort with industry, INL, community colleges, and universities to establish a commercialization center for advanced construction and manufacturing technologies. The focus would be on joining, welding, material development, and large-scale testing.

Workforce Development

A qualified workforce is the biggest barrier to expanding existing industries and attracting new ones. The LINE subcommittee on workforce development has provided background in this area (LINE 2012). To help students overcome the cost of college and increase their potential, Idaho established the Opportunity scholarship.

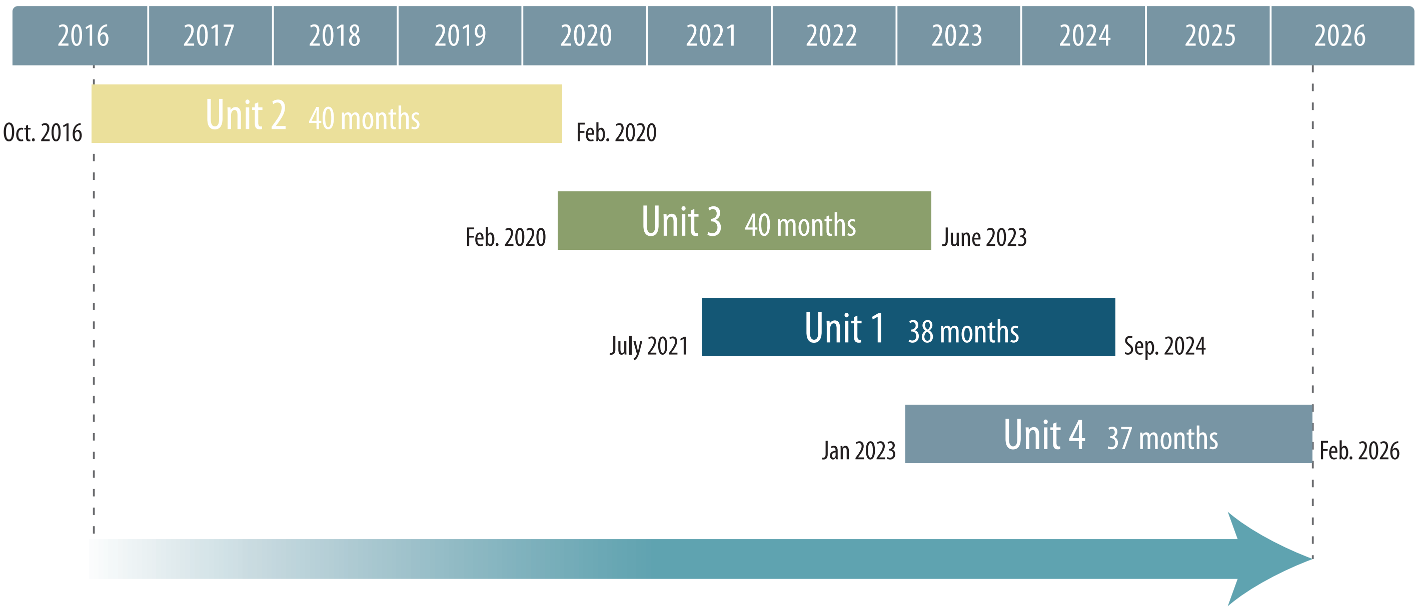
Similar to Tennessee, Oregon, and Oklahoma Promise programs around the country, Idaho Opportunity provides last-dollar financial aid to qualified students based on GPA, satisfactory progress, and family contribution. Opportunity works; program participants experience retention rates of 86%. An increase of 14% from non-Opportunity peers. When considering that Idaho's taxpayers receive $2.30 on every dollar spent on community colleges, the program's benefits become even more apparent. Individuals with associate's degrees benefit personally, enjoying higher annual wages than the statewide median. For example, a radiological technologist working at INL with an associate's degree has a median annual income of $51.6k–significantly higher than Idaho's average of $40.5.

The predominant share of Opportunity awards go to bachelor's students. Out of the 1,500 new awards disbursed in 2016, only 256 went to community college students (16.7% of total awards). Additionally, based off percentages of total viable population, the awards per-capita are lower for community college students. They are relatively less likely to receive an award than their four-year degreed peers.[8]

The real opportunity here is to identify high demand skilled labor positions in the energy industry, develop curriculum with community colleges to support those positions, and educate K-12 students on the opportunities. Tuition reimbursement for these in-demand energy industry fields should be considered through the expansion of Idaho's Opportunity scholarship investment.

[8] *https://boardofed.idaho.gov/resources/opportunity-scholarship-report-2017/*

Current Opportunities in the Nuclear Industry



Canada – Darlington/Bruce (OPG)

Term: 2010-2026 – First site start 2016

Plants: Four nuclear sites

Scope: Major refurbishment and life extend

- Reactor components
- Nuclear fuel handling systems
- Bridge cranes and tooling
- Turbine generator and auxiliaries
- Steam generators, instrumentation
- Service water piping systems
- Digital control system
- Associated valves, motor, and controllers.

U.S. Nuclear Life Extension > 40 to 60 years

Term: Ongoing - current

Plants: 85 NRC granted plant extensions in place

Scope: Equipment replace/repair for life extend

- Main turbine and support systems
- Heat exchangers, valves, and support systems
- Service water system piping systems
- Condenser tubing
- 4160 V cabling, breakers, and panels
- Main generator, rotors, and regulators
- Fire protection systems
- Digital and protective scheme controls.

Global New Nuclear Plant Build Status – 08/2018

Term: Ongoing - current

Plants: 450 operating units worldwide
50 plants under construction
150 plants ordered/planned
300 additional being proposed

Scope: Green field construction in entirety

- All systems, subsystem, and components
- Support engineering and design
- Specialty and new innovations
- Construction services
- Steel, logistics, and shipping
- Project management services.

Japan – Energy policy recovery

Term: Increase nuclear to ~ 24% base source

Plants: 40+ shutdown units/post Fukushima

Scope: Establish safety/quality condition pre start up

Needed components, supplies, and materials:

- Seismic and fire compliance
- U.S. standards assessments
- Licensing impact assessments
- Reduce energy imports
- Achieve environmental goals
- Assess restart of new plant builds
- Launch replacement modifications.

Three near-term opportunities to attract businesses looking to have a presence in the U.S. exist. INL currently has a point of contact who is working with these companies and is aware of their interest in establishing operations in the U.S. Business opportunities are adjacent to regulated industries that could also support the advanced reactor supply chain.

Project Snapshot

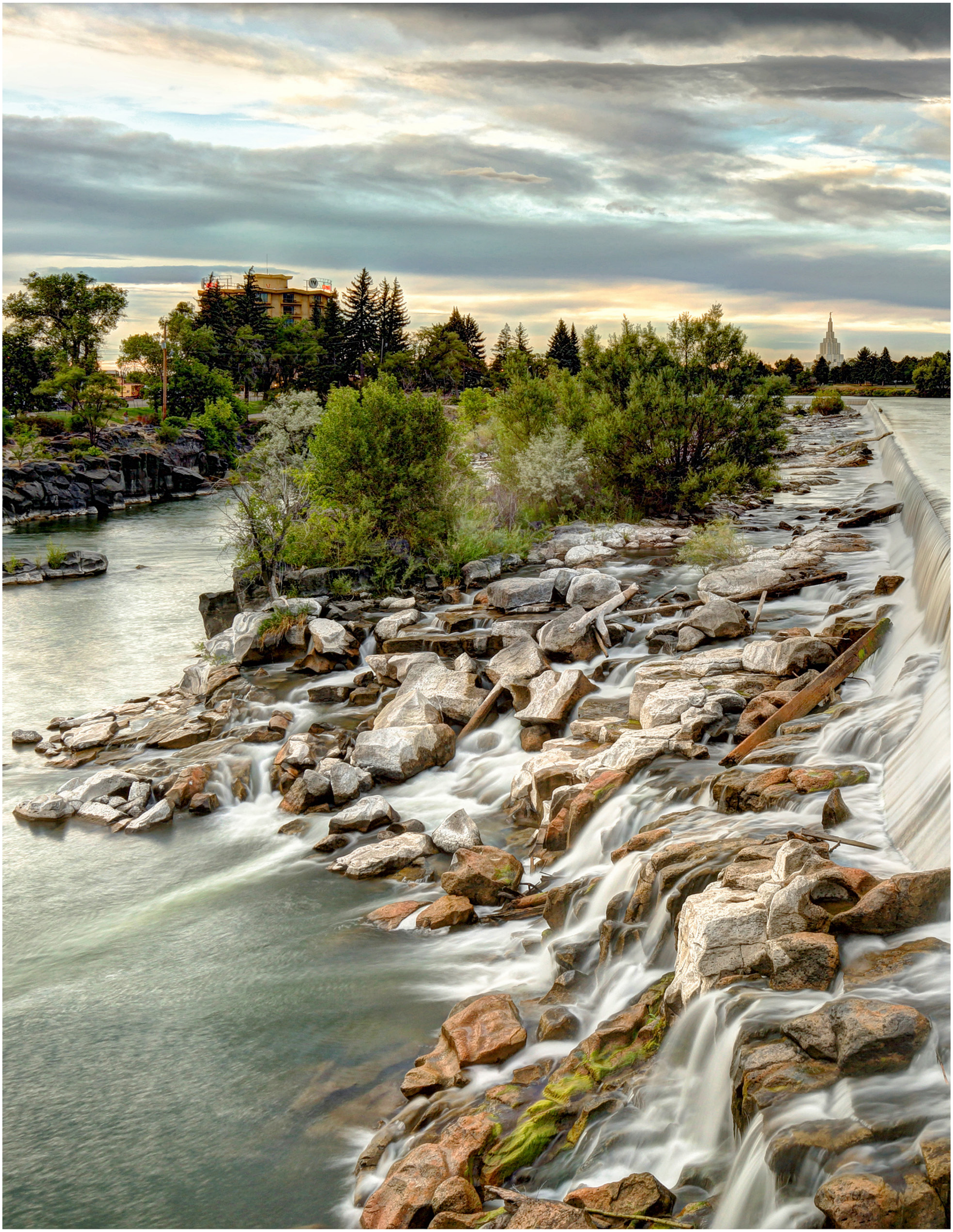
- Robotic fire-fighting equipment fabricator seeking U.S. location for distribution
- No commercial channels to U.S. interests
- Leveraging alternative procurement service channels for match making and project facilitation.

Project Snapshot

- Large scale stainless piping fabricator with global business
- Seeking regional partnerships for cost and freight reductions to North American region
- Leveraging alternative procurement service channels for 'match making' and project facilitation.

Project Snapshot

- Global population of large nuclear forgers is low
- New reactor deployment targets will strain current supplier base
- Long term, high demand opportunity.



Anchor Opportunities

There are opportunities for the state of Idaho to attract commercial business(es) that will serve as an anchor to the community and attract additional business around them. Four of these opportunities are highlighted (1) fuel fabrication for high-assay low-enriched uranium, (2) commercialization park adjacent to INL, (3) factory fabrication of modules for the advanced reactor industry, and (4) medical isotope research and development and production.

Fuel Fabrication Facility

Most advanced reactor designs require a new fuel production chain that doesn't exist today. Many will require higher enrichments, and fuel forms very different from those manufactured for the current light water reactors. The current generation of light water reactors uses fuel enriched to less than 5% uranium-235. However, many advanced reactor designs require enrichments between 5-20%, called high-assay low-enriched uranium fuel. There is an immediate opportunity for Idaho to purse a public-private partnership to enable the enriching of material to between 5-20% and for a facility to fabricate advanced reactor fuel. INL has material and enrichment capability. INL could work to provide land to a private company to build a fuel fabrication plant adjacent to the INL facility. This partnership would establish a first of its kind facility in the U.S. and would support many advanced reactor designs. The need for this capability was highlighted at a March 8-9, 2018 symposium hosted by GAIN (INL 2018).

Commercialization Park Adjacent to INL

Business parks (commercialization parks) can be an economic engine of a community. One example of this is The Development Corporation (TDC) of Knox County, Tennessee.[9] TDC is involved in the acquisition, development, and management of property for business park use. They ensure that the business parks have the necessary utilities and other infrastructure.

Bonneville County and the city of Idaho Falls (in coordination with the Regional Economic Development for Eastern Idaho [REDI]) could provide a business park setting similar to TDC. They could purchase a block of land in Idaho Falls near the INL Research and Education Campus, put in the necessary utilities and infrastructure and zone for heavy industry and commercial business. Reduced lease rates would be provided to companies who plan to collaborate with INL and/or work in the nuclear industry. This would also leverage a research and development initiative within INL to fast track advanced reactor technology that could make future nuclear projects more affordable.

Factory Module Fabrication

Idaho is poised to be the location of the first-of-a-kind advanced reactor, NuScale, in the U.S. Therefore, Idaho will have a manufacturing opportunity advantage over others in terms of becoming a global supplier.

Local suppliers are important to the success of an advanced reactor project since these are typically located within a 500-mile radius of the site being constructed. While the scale of the NuScale advanced reactor modules are relatively small compared with large light water reactor vessels, they are still large (72-ft. long by 15-ft. diameter).[10] Ideally, these first-of-a-kind modules will be fabricated in a factory close to the construction site. The factory constructed for these first-of-a-kind modules can also supply to the world as more advanced reactor orders are placed. The modules could be shipped by rail to the Lewiston seaport or by rail to a seaport in Washington.

[10] *http://www.knoxdevelopment.org/TDCHome.aspx*

[11] *https://www.nuscalepower.com/en/technology/technology-overview*

Medical Isotope Research and Production Facility

The medical isotope production industry is multiple billions of dollars per year. Half of that business is in the U.S. Medical isotopes are used in both scans and treatments with emerging isotopes targeting cancer cells without "poisoning" the rest of the body. The most commonly used isotope for scans is molybdenum-99 and it must be produced nearly continuously to assure availability. The most mature and reliable means of producing technetium-99m/molybdenum-99 is in a reactor. None of the technetium-99m/molybdenum-99 used is produced in the U.S. With the shutdown of the Canada's National Research Universal reactor in 2018, molybdenum-99 production continues only in Belgium, Netherlands, South Africa, and Australia. In addition, there is a more lucrative local opportunity for the facility to produce shorter-lived isotopes and distribute these to regional cancer centers such as Huntsman Cancer Institute.

The anchor opportunity is a reactor for producing medical isotopes located on the INL reservation for both research and distribution purposes. A reactor of known design could be privately financed and located within a federally-owned INL facility at the end of its mission. The facilities that could be used at INL are the CPP-666 fuel storage pools and the CPP-684 Remote Analytical Laboratory.

Action	Anchor Opportunity
Establish fuel fabrication capability for advanced reactors.	**INL** through a **public-private partnership,** establishes a capability to up or down blend product. **INL** then gives the material to an adjacent facility (private) to make the necessary fuel for advanced reactors. The **state** could work on infrastructure to support supplying the high-assay low-enriched uranium material out of state. The State also works with regional partners to identify material transportation.
Encourage factory fabrication of modules for advanced reactors.	If **INL** is the place to deploy advanced reactors, the **State** requires that a portion of the business is spent with Idaho businesses.
Establish a commercialization park adjacent to INL.	The **county and city in coordination with REDI** should explore establishing a commercialization park near the INL Research and Education Campus. Reduced lease rates would be provided to companies that are planning on collaborating with INL and/or are working in the nuclear industry.
Explore a medical isotope research and production facility.	**INL** should explore a **public-private partnership** to establish a research, separations, and production facility for the medical isotope industry. INL should establish a partnership with **medical university partners.** The **state** could provide tax breaks to bring in companies that manufacture and ship these radiopharmaceutical isotopes.

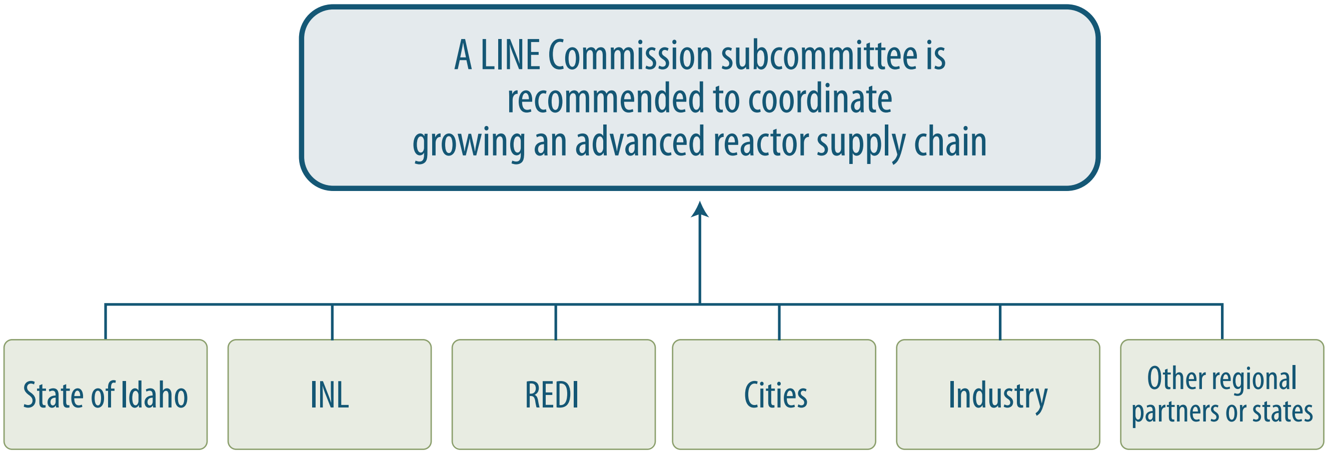


Figure 12. Recommendation and key players.

Partnership Collaboration

Developing an advanced reactor supply chain will require collaboration among all interested parties including INL, REDI, State of Idaho, industry, cities, and other regional partners or states (see Figure 12). Each partner will have a single point of contact and these will be integrated with a central point of contact that is yet to be defined.

Each partner plays an important role in industry development, research and development, and workforce development. Potential activities for these partners are discussed as follows and listed in Figure 13.

State of Idaho

Idaho should actively work to grow the advanced reactor supply chain by supporting work force development, helping to improve infrastructure (such as road, rail, other), and providing tax breaks or incentives. The most critical piece is the workforce. Growth of the workforce starts at the high school level where Idaho should have programs in welding and fabrication. Development of the workforce also needs to occur at the community college level and in apprentice programs. The state should work with the advanced reactor industry, INL, and others to identify workforce development opportunities. Idaho could offer tuition reimbursement for graduates of community college or apprentice programs that stay and work in state for a given number of years.

Growing an Advanced Reactor Supply Chain

	Workforce Development	Research & Development	Industry Development
State of Idaho	Support infrastrucure development specific to growth. Identify existing industries who are interested in nuclear supply chain work. Require companies to source at least a percentage of the project cost in Idaho for new nuclear builds. Tie it to tax breaks."	Establish State of Idaho research and development park adjacent to the INL Research and Education Campus in Idaho Falls.	Provide tuition reimbursement for training in careers that support the nuclear community.
INL	Set aside funding specific to placing subcontracts that would support local businesses in the supply chain.	Form a supply chain/technology development group, coordinating with external stakeholders and develop INL's strategy to lead in technology development to support an advance reactor supply chain. INL must dedicate funding for this group. Coordinate with local and regional centers such as Seattle, Silicon Valley, and others. Work with advance reactor industries and adjacently aligned supply chains (Department of Defense shipbuilding and aerospace) to identify opportunities for technology development.	Identify workforce needs and provide funding to support curriculum.
REDI	Work with local businesses to identify businesses interested in advance reactor supply chain. Market the strength of local advance reactor suppliers. Attract new businesses.		
City	Improve airport services to select hubs (Seattle, San Francisco, Boston).		
Industry	Invest in their business to grow capability in the supply chain.	Identify workforce needs and provide funding to support curriculum.	Identify workforce needs and provide funding to support curriculum.

Figure 13. Potential activities to grow an advanced reactor supply chain.

Idaho National Laboratory

INL's role is in the technology development, demonstration, and deployment of advanced reactors. In this research and development space, the lab should better understand the advanced reactor business by placing out plant assignments to the current centers of venture capital investment in the advanced reactor industry, Silicon Valley, Seattle, and Boston. These out plant assignments should attempt to build relationships with investors and advanced reactor companies, establish the value proposition for these companies, and determine how Idaho and INL can support them in being successful. It is recommended that INL establish an organization to focus on identifing technology development needs in the advanced reactor supply chain, building the value proposition for why companies should be located in Idaho Falls, and working with other local, state, and regional partners.

Regional Economic Development for Eastern Idaho

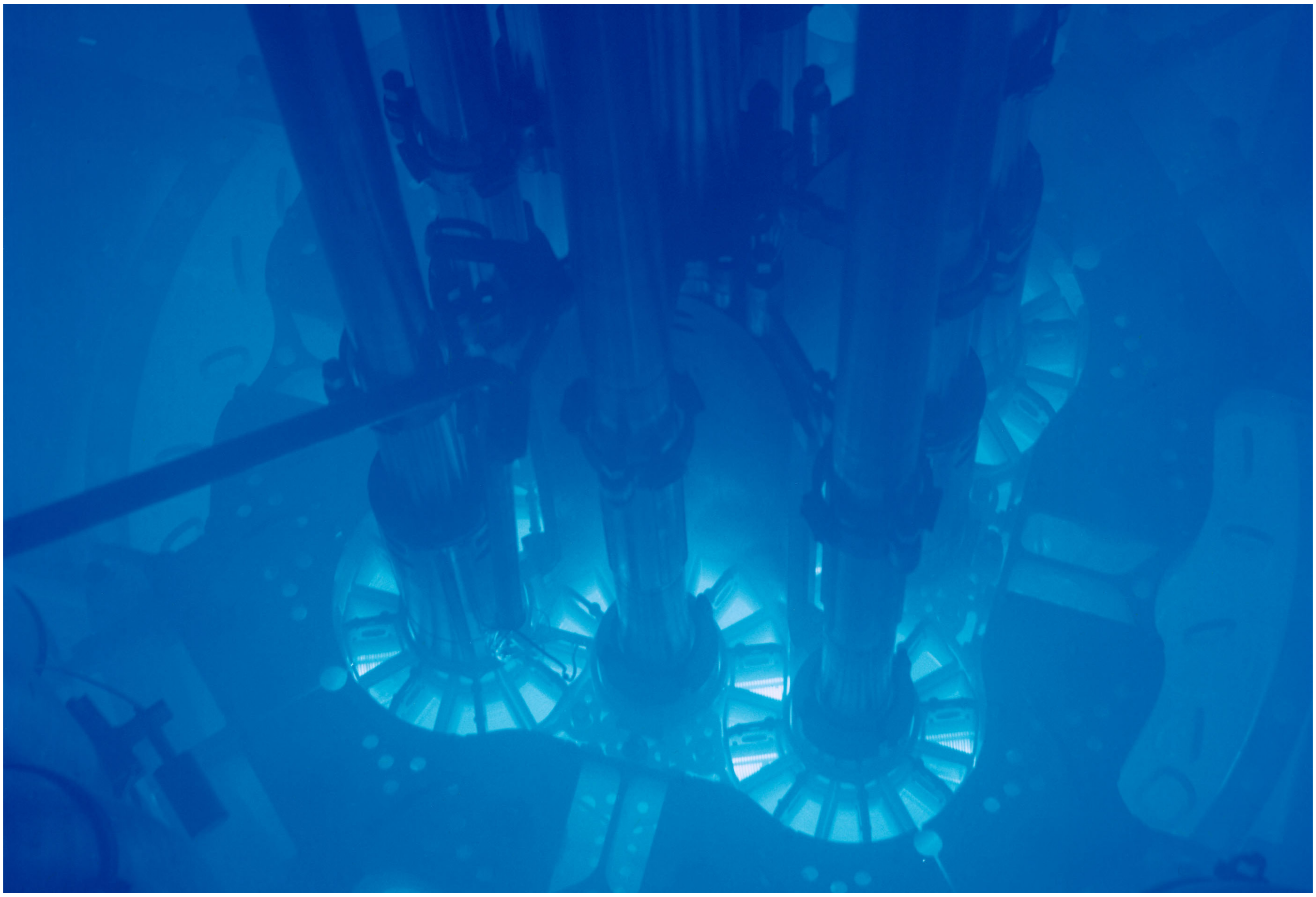
Our regional economic development center can help identify businesses interested in working in the nuclear and advanced reactor industry, identify gaps in those businesses, and help them close the gaps. REDI can also help market the strengths of these businesses to the nuclear and advanced reactor industry.

City of Idaho Falls

Direct access to Idaho Falls by commercial aircraft remains a potential impediment to industry locating in Eastern Idaho. Continued effort by the City of Idaho Falls and regional/state entities to establish additional flights could help attract the advanced reactor supply chain.

Industry

Industry can identify workforce development needs and work with the other partners to development curriculum to fill those needs.



References

Alemberti, A., Smirnov, V., Smith, C. F., and Takahashi, M. (2014). "Overview of lead-cooled fast reactor activities." Progress in Nuclear Energy, 77, 300-307. https://doi.org/10.1016/j.pnucene.2013.11.011

Freed, J., Brinton, S., Burns, E., Robson, A. (2015). "Advanced Nuclear 101." T. Way, ed.Third Way.

Gagnon, L., Belanger, C., and Uchiyama, Y. (2002). "Life-cycle assessment of electricity generation options: The status of research in year 2001." Energy Policy, 30(14), 1267-1278.

Haratyk, G. (2017). "Early Nuclear Retirements in Deregulated U.S. Markets: Causes, Implications and Policy Options." M. C. f. E. a. E. P. Research, ed.MIT, MIT.

Idaho (2018). "Executive Order No. 2018-07." Establishing a Policy for Nuclear Energy Production and Manufacturing in Idaho, State of Idaho.

INL (2018). "Enabling Advanced Reactors for the Market Symposium Summary Report," INL/EXT-18-45586, Gateway for Accelerated Innovation in Nuclear.

Jensen, W. (2017). "Idaho National Laboratory Economic Summary." R. B. Center, ed. INL.

LINE (2012). "Education & Workforce Subcommittee Final Report & Recommendations," https://line.idaho.gov/wp-content/uploads/sites/12/2016/07/Education-Workforce_FINAL.pdf.

Moody, J., (2010). "Affordable small modular reactors – effective integration of modular design, manufacturing and construction techniques," Presentation to Platt's Small Modular Reactor Conference, June.

Nanalyze (2017). "When Will We Have a Working Molten Salt Reactor?", https://www.nanalyze.com/2017/02/molten-salt-reactor-when/.

NEI (2018). "Addressing the Challenges with Establishing the Infrastructure for the front-end of the Fuel Cycle for Advanced Reactors, January 2018.

Neutron-Bytes (2017). "China Expands Uses & Markets for Its HTGRs." https://neutronbytes.com/2017/03/18/china-expands-uses-markets-for-its-htgrs/.

Next-Big-Future (2018). "Terrestrial Energy USA has MOU for siting a molten salt nuclear reactor in Idaho." Next Big Future, https://www.nextbigfuture.com/2018/04/terrestrial-energy-usa-has-mou-for-siting-a-molten-salt-nuclear-reactor-in-idaho.html. (6-12-2018, 2018).

Sofu, T. (2015). "Sodium-cooled Fast Reactor (SFR) Technology Overview."

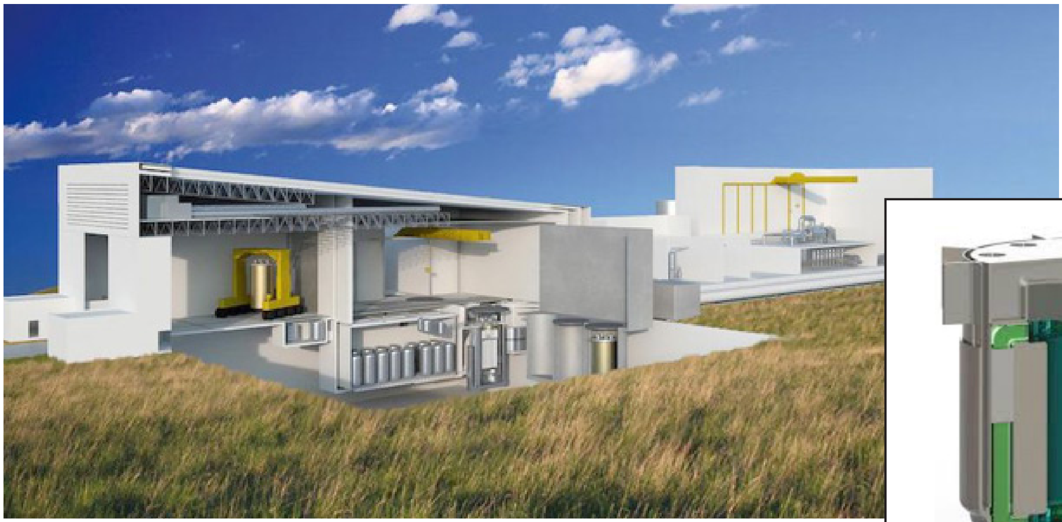
TerraPower (2018). "TWR Technology: Preparing Nuclear Energy for Global Growth." http://terrapower.com/technologies/twr. (6-12-2018, 2018).

World Nuclear Association (2014). "The World Nuclear Supply Chain – An Overview," presentation by Greg Kaser, March 11, 2014.

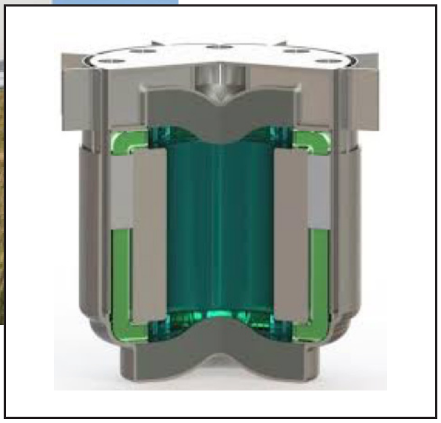
World Nuclear (2018). "Plans For New Reactors Worldwide." http://www.world-nuclear.org/information-library/current-and-future-generation/plans-for-new-reactors-worldwide.aspx. (07/16/2018, 2018).

Appendix A: Advanced Reactor Description

Molten Salt Reactors



Terrestrial Energy MSR Concept



TerraPower MSR Concept

Description

Liquid metal coolant that uses liquid salt with operating temperatures around 650°C. Operated at or near atmospheric pressure. Depending on the concept the fuel is either dissolved in the liquid coolant or placed in metal rods. Conceptual sizes range from 40 – 1000 MWe.

Benefits

Walk away safe. No human intervention or active safety systems needed to control the reaction.

Unique Supply Chain Needs

Special materials that can operate at elevated temperatures and corrosive environments. Fabrication and welding procedures for these materials. Qualified workforce in working with these materials.

Maturity

Deployment timelines for first of a kind (FOAK) are in the 2020s (Nanalyze 2017).

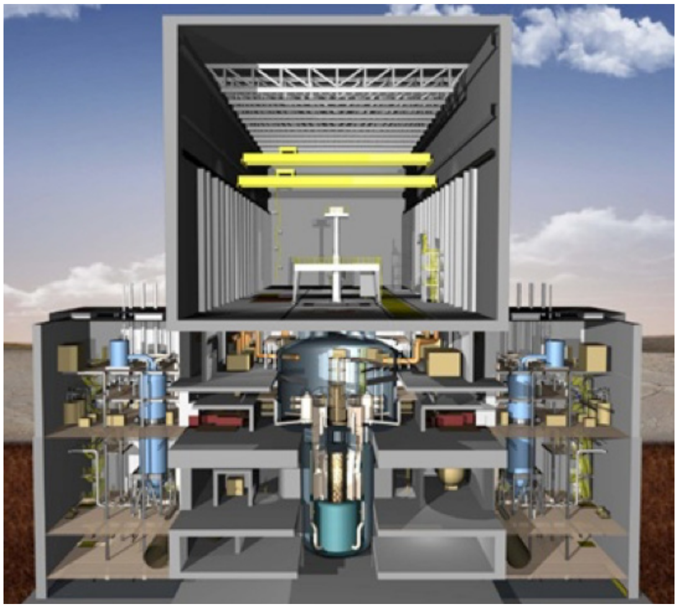
Targeted Market

U.S. and international

Possible Deployment in Idaho?

✔ Yes, Terrestrial Energy USA is looking at FOAK at INL (Next-Big-Future 2018).

Sodium-Cooled Fast Reactors



Terrapower TWR-P

EBR-II

VTR VERSATILE TEST REACTOR

Description

Liquid metal coolant that uses liquid salt with operating temperatures around 500°C. Operated at or near atmospheric pressure (Sofu 2015). Depending on the concept the fuel is either dissolved in the liquid coolant or placed in metal rods. Conceptual sizes range from 40 – 1000 MWe.

Benefits

Helps the fuel cycle by enabling use of uranium and plutonium from spent fuel as its fuel.

Unique Supply Chain Needs

Special materials that can operate at elevated temperatures. Fabrication and welding procedures for these materials.

Maturity

Prototype of TWR technology for mid-2020s (TerraPower 2018), likely in China

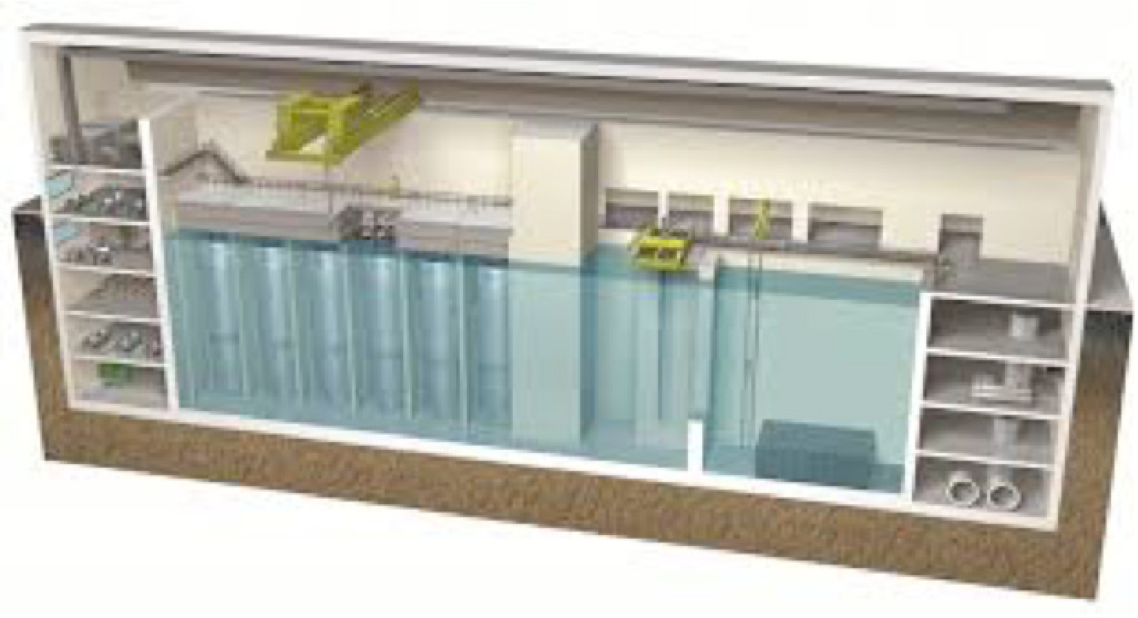
Targeted Market

International and U.S. First plant(s) built outside of the U.S.

Possible Deployment in Idaho?

INL is the site for the proposed versatile test reactor.

Small Modular Reactors



NuScale

Description

The term SMR is generally used for those reactors less than 600 MWe and using light water reactor fuel. Because this technology uses light water reactor fuel, the projected time to market is less than other advanced reactor technologies. NuScale is an example of an SMR.

Benefits

SMRs typically require fewer active safety systems then traditional LWRs (commercial plants operating in the U.S. today).

Unique Supply Chain Needs

Supply chain that can factory fabricate those modules.

Maturity

Mid 2020s

Targeted Market

Initial deployment in the US.

Possible Deployment in Idaho?

Yes.

Microreactors

KAIST micro-reactor concept

Westinghouse micro-reactor concept

Description

A short term victory for the advanced reactor industry. Modular and deployable to remote locations including military bases, mining facilities, and villages in remote locations. Typically between 1 – 10 MWe.

Benefits

Easy to move as one unit and therefore easily deployable. Will allow the advanced reactor industry to start rebuilding a nuclear supply chain in the U.S.

Unique Supply Chain Needs

Supply chain that can factory fabricate the unit.

Maturity

Deployment in the early 2020s.

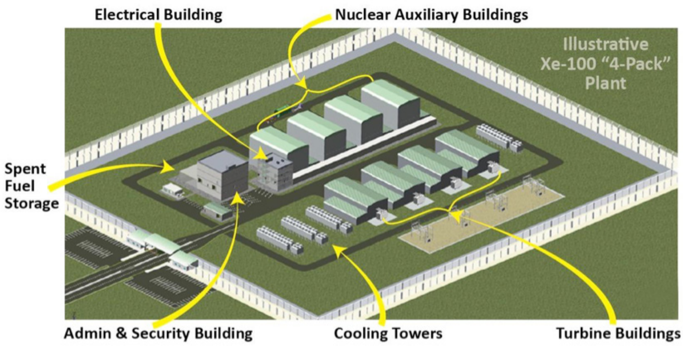
Targeted Market

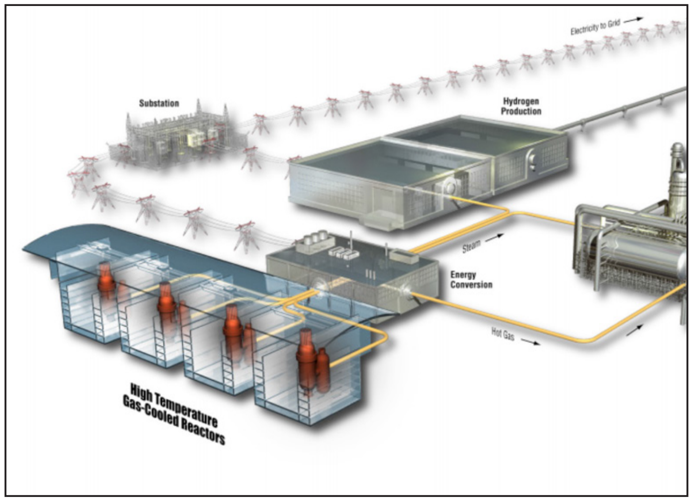
Remote sites in the U.S.

Possible Deployment in Idaho?

✔ Yes.

Gas-Cooled Fast Reactors





Description

Helium is generally used as the coolant at temperatures of 650-850°C. Conceptual sizes range from 20 – 600 MWe.

Benefits

Helps the fuel cycle by enabling use of uranium and plutonium from spent fuel as its fuel.

Unique Supply Chain Needs

Advance materials still require more testing. Would require the ability to work with these materials including forging and welding

Maturity

Targeted Market

International and U.S. first plant(s) built outside of the U.S.

Possible Deployment in Idaho?

✔ Possible. Even if they are not deployed supporting nuclear facilities could be built in Idaho such as a fuel fabrication facility.

Lead-cooled fast reactors

Description

Heavy liquid metal coolant that uses lead with operating temperatures around 500°C. Operated at or near atmospheric pressure.

Benefits

Can generate electricity without producing spent fuel that could be turned into weapons-grade materials that posed a proliferation risk. Relatively chemically inert and refueling cycles of 15-50 years.

(Alemberti et al. 2014)

Unique Supply Chain Needs

Special materials that can operate at elevated temperatures and corrosive environment. Fabrication and welding procedures for these materials.

Maturity

Still a number of research and development hurdle to overcome including testing of special materials for use in the lead environment.

Targeted Market

First plant(s) built outside of the U.S.

Possible Deployment in Idaho?

Not currently.


ADVANCED TEST REACTOR

Appendix B: Supply Chain Information

Components Needed for a Nuclear Power Plant

- Supplies
- Basemat concrete (6,000m^3)
- Steel (6,100t)
- Forgings (4,000t)
- Pumps (~200)
- Valves (5,000+)
- Piping (~210 km)
- Cabling (2,000km+)
- Welding seams (50,000+)
- Exceptional quality required from "nuclear-grade" components (higher than normal "industrial or commercial grade")
- Safety-related items – performance testing required
- Safety-significant items – reasonable assurance of performance required
- Engineering: civil, mechanical, electrical, software.

NuScale Needs (per 12-module plant)

- Concrete (170,000 cy)
- Steel (5,000 t)
- Piping (150,000 ft)
- Cabling (7 million linear ft)
- Conduit (1.5 million linear ft)
- Cable tray (48,000 liner ft)
- Instruments (12,000)
- Electrical equipment (over 500 items including switchgear, MCCs, PDCs, inverters, VFDs)
- Mechanical equipment (over 900 misc.)
- Module protection system cabinets (36)
- Reactor trip breakers (48)
- Ion exchangers (36)
- Heat exchangers (1 to 42 Mbtu/hr)
- 480V variable frequency drives (55)
- 5 to 85,000 gpm pumps (334)
- 25 to 300,000 tanks (82)
- 370 to 50,000 cfm HVAC units (158)
- B/U diesel – 480V 1,650kW/2,063KVA (2)
- Steam turbine generator package 45-50MW
- Main power transformer (4) – 112 MVA @ 13.8kV/345kV
- Unit auxiliary transformer (8) – 16.7 MVA @ 13.8/4.16
- Reactor building crane (1) – 750 tons, 44 ft lift, 69 ft span
- Feedwater heaters (36) 1,100 gpm, 24 ot 42 Mbtu
- Condensate pump (36) – 575 gpm at 370 ft
- Feedwater pump (36) – 575 gpm at 1,200 ft
- Circ water pump (6) – 85,000 gpm at 80 ft
- Cooling tower (2) – 260,000 gpm