ADVANCED REACTOR ROADMAP

PHASE 1: NORTH AMERICA

EXECUTIVE SUMMARY

Increased capacity for nuclear energy production could be key to helping the United States and Canada meet national energy, economic, climate, environmental, and security goals.

There is a growing consensus that both existing and advanced nuclear could play important roles in the decarbonization of the electricity grid and other parts of the U.S. and Canadian economies. Decarbonization of the electricity, transportation, and industrial heating sectors could come from large amounts of firm, carbon-free energy produced through nuclear technology.

Recent studies, like those by EPRI, DOE, and Vibrant Clean Energy, conclude that there is a large market opportunity for cost-competitive firm, clean energy sources, including nuclear energy. The nuclear energy industry is taking action to enable nuclear energy to meet the market demand through the continued operation of existing reactors and the commercialization of advanced reactors, which could be called upon to provide 60 to 400 GW of generating capacity as a carbon-free option by 2050.

The purpose of this Advanced Reactor Roadmap is to outline the critical strategies and support actions necessary for the successful large-scale deployment of advanced reactors. This will be a living document that evolves and refocuses strategies and actions as the future unfolds.

The Advanced Reactor Roadmap's intended audiences are potential customers (owners and energy off-takers), policymakers, regulators, financial institutions, public stakeholders, and industry stakeholders. The roadmap, developed through a multistakeholder process, including experts from advanced reactor developers, suppliers, utilities, researchers, and industry associations, describes an achievable path to facilitate the successful commercialization of advanced reactors, spur and support the necessary actions, and enable deployment at the levels needed.

The approach that the industry is taking to enable the value of advanced reactors to fulfill critical market needs is focused on three key things:

1. **Commercializing advanced reactor technologies that deliver the desired value**
2. **Establishing a portfolio of advanced reactor technologies to meet a diverse set of market and customer needs**
3. **Ensuring that the commercialization of these technologies is both cost-effective and on track to meet the milestones for decarbonization on time**

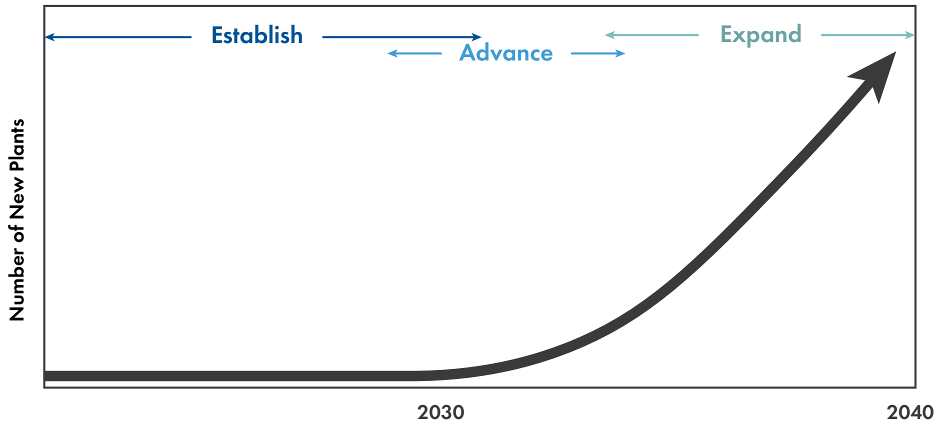
The approach relies on disruptive innovations that develop advanced reactors with benefits that deliver value to the market, including easing deployment challenges, accelerating deployments, and increasing cost-competitiveness, all while increasing safety and maintaining reliability. This requires the industry to change how it designs, deploys, and operates advanced reactors. The approach is framed to allow a realistic, phased, and risk-managed approach to deploying advanced nuclear technology. This approach of establishing, advancing, and expanding to scale (EAE) (see Figure 1) is the basis for pursuing industry priorities by setting up early wins, derisking for owners, and creating fast followers.

> "The approach is framed to allow a realistic, phased, and risk-managed approach to deploying advanced nuclear technology."

Finally, the active involvement of industry leaders has been a key driver for multistakeholder collaboration in developing this roadmap. Continued industry leadership is essential to execute and drive the strategy, promote collaboration and coordination, and ensure that actions are being completed on the roadmap, which need to be taken now to ensure that the 2050 vision can be achieved. Industry leadership must articulate a vision that builds confidence, attracts capital and investment, inspires the industry to overcome the inevitable challenges, brings technology to the market, and achieves the needed deployments. The 2050 goal is possible only if we start now.

EXECUTIVE SUMMARY

Figure 1. Establish - Advance - Expand Process



The approach to drive value to meet market demand informs the actions needed to create success in advanced reactor commercialization. These actions are divided into two areas: 1) conditions that would further enable advanced reactors to meet market needs (called enablers) and 2) the actions that the industry plans to take to deliver advanced reactors into the market.

ENABLERS

Enablers are the conditions related to policy, regulatory, and public acceptance surrounding the commercialization of advanced reactors and are key opportunities for stakeholders and the industry to enable and enhance the deployment of advanced reactors.

There are seven enablers, with a total of 15 Key Opportunities:

1. FIRST MOVER SUCCESS
2. FAST FOLLOWERS
3. REGULATORY EFFICIENCY
4. SITING AVAILABILITY AND PERMITTING
5. INDIGENOUS AND PUBLIC ENGAGEMENT
6. SUPPLY CHAIN RAMP-UP
7. WORKFORCE DEVELOPMENT

EXECUTIVE SUMMARY

ACTIONS

Actions are those the industry plans to take to deliver value in the deployment of advanced reactors. The industry actions focus on what the industry can control in delivering a timely portfolio of products with value that the market desires.

There are a total of 46 actions organized into 13 strategic elements, which are grouped into the following three action pillars:

1. **REGULATORY EFFICIENCY**
2. **TECHNOLOGY READINESS**
3. **PROJECT EXECUTION**

These actions are further prioritized to identify the high-priority actions that make the greatest contribution to delivering value to the market and other actions that could help further improve success.

Successful decarbonization efforts will depend on a host of actions, across many industries and end uses. Nuclear is expected to play a strong role in achieving this success. This roadmap is intended to be a valuable, informative asset in enabling that outcome.

ROADMAP

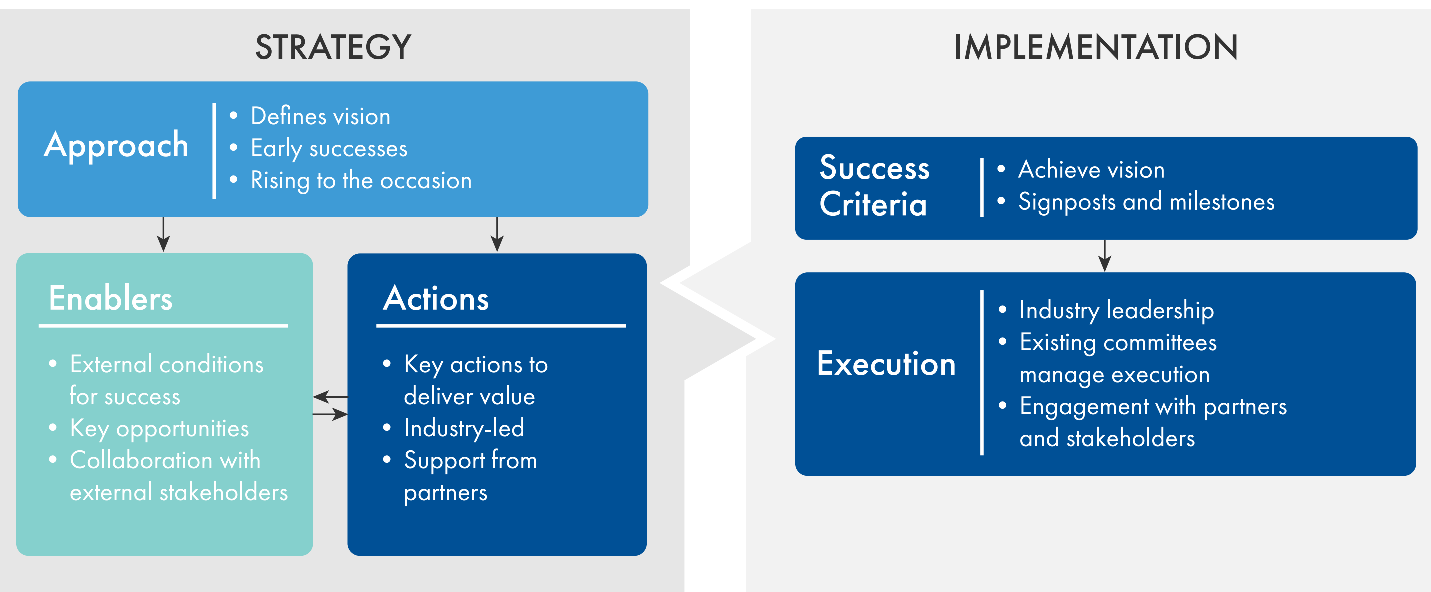


TABLE OF CONTENTS

VISION

- INTRODUCTION
- THE CASE FOR NUCLEAR ENERGY
- DRIVING VALUE TO MEET THE MARKET NEED

VISION

INTRODUCTION

The Advanced Reactor Roadmap outlines a path forward for advanced reactor technologies to help meet the market need for reliable, affordable, and zero-carbon emissions sources of energy. This early version will focus on North America and has five primary audiences:

1. **For potential owner/operators of advanced reactors –** to understand the industry plan to deliver on owner/operator (e.g., owners and energy off-takers) needs and have more confidence when making decisions to pursue advanced reactors
2. **For policymakers and regulators –** to understand the impacts of federal, state/provincial/territorial, and local policies and the policies necessary to enable deployment of advanced reactors to achieve decarbonization and other objectives
3. **For financial institutions –** to understand how advanced reactors fit in the bigger picture to deliver on society's decarbonization efforts and have more confidence in the value of and return on those investments
4. **For public stakeholders including local communities, Indigenous Nations and communities –** to understand the benefits and key attributes of advanced reactors and to have confidence that deployment and utilization of advanced reactors are done in a way that is protective of the public and the environment
5. **For industry stakeholders –** to understand the integrated path forward to create advanced reactors that deliver value to the market; to understand the opportunities and needs for developing and expanding capability and expertise; to know when those capabilities will be in demand; and to have more confidence in the return on those investments

The purpose of this roadmap is to support the successful commercialization of advanced reactors, spur the needed actions, and achieve the outcomes necessary to enable successful large-scale deployment.

The roadmap includes three sections to:

1. **Describe the approach** that the industry is taking to drive the value of advanced reactors to fulfill critical market needs
2. **Discuss conditions** that would further enable advanced reactors to meet the market needs
3. **Identify actions** that the industry plans to take to deliver advanced reactors into the market

The Advanced Reactor Roadmap is initially focused on North America, with the recognition that efforts to support the industry in the United States and Canada will also support deployment of advanced reactors around the globe.

VISION

INTRODUCTION (CONT'D)

The roadmap is framed around several key attributes to enhance its value and effectiveness, including being:

1. **Integrated** – The roadmap provides an approach to facilitate the successful commercialization of advanced reactors, taking individual areas needed for success (such as fuel availability) and integrating them into an overall plan to address all areas.
2. **Recognized** – The roadmap must be communicated within and outside the industry and recognized as a common plan for successful deployment of advanced reactors.
3. **Stakeholder Supported** – The roadmap must be driven collaboratively by the industry as a whole to ensure success.
4. **Action Driven** – The roadmap is more than concepts. It includes key targets to recognize success, drive down risk, and ensure timely completion of roadmap actions.
5. **Suitable for Communication to a Wide Variety of Audiences** – The roadmap is presented in a manner that can be understood by key stakeholders internal and external to the industry.

THE CASE FOR NUCLEAR ENERGY

The world depends on vast amounts of energy to run the economy, provide security, enjoy a high standard of living, and provide the basic necessities of food, water, and health. This energy comes in the form of electricity to power homes and businesses, steam and heat for industrial uses, and liquids to fuel ships, airplanes, and cars.

As the negative impacts of carbon emissions have been increasingly recognized by the public and policymakers, there has been a significant focus on decarbonizing the energy sector. As the energy sector is decarbonized and society becomes more dependent on intermittent sources of carbon-free generation, the reliability of supply can be challenged. Nuclear power can play an important role in enhancing the reliability of energy supply while enabling deployment of greater shares of intermittent sources.

Nuclear energy has been a cornerstone of the North American electricity system since the 1970s, producing roughly 20% of the electricity in the United States and about 15% in Canada. In these countries, nuclear has a history as a reliable, resilient and affordable type of energy, available 24/7 year-round and resulting in some of the lowest-cost electricity systems over its lifetime. Nuclear energy has also been environmentally friendly, avoiding emissions of toxins and producing carbon-free energy.

The public and policymakers are beginning to understand more clearly that the transition to a zero-carbon energy system must emphasize clean, reliable, and affordable energy, not just zero-carbon emissions.

Recent passage of clean energy standards in Canada and states like Washington, as well as new federal incentives in both countries to deploy zero-carbon-emitting sources, have provided new incentives for nuclear energy.

Although most attention is on the electricity system, there is growing awareness among policymakers and the public that decarbonization of the other energy-consuming sectors is also important. The carbon emissions of the transportation and industrial heat sectors are, each, nearly the same (in the United States) or greater than (in Canada) as those of the electricity sector, meaning that even if the electric sector's carbon emissions were reduced to zero, only one-third of the carbon emissions from the energy industry will have been addressed. Although some transportation modes might be converted to electricity, many others, such as airplanes and ships, have no viable option to use electricity. Nuclear energy can be used directly for industrial uses or production of liquid fuels, including hydrogen, and can do it more efficiently than electricity to produce the heat.

VISION

THE CASE FOR NUCLEAR ENERGY (CONT'D)

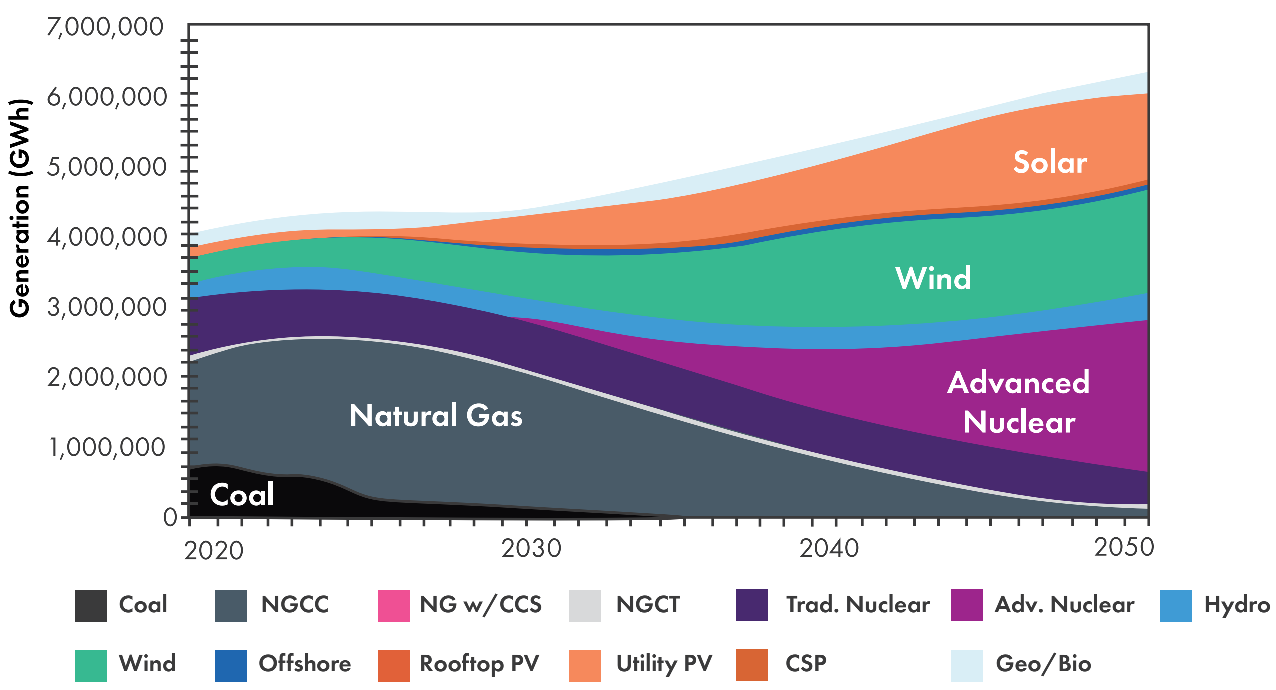
Increased capacity for nuclear energy production could be key to helping the United States and Canada meet national energy, economic, climate, environmental, and security goals. The market also now recognizes the need for more nuclear energy capacity in North America to provide a reliable and affordable path forward to meet goals for reducing carbon emissions.

Recent assessments of the energy system outlook suggest that over the next 10-20 years, the need to deploy advanced reactors in the United States and Canada will rival, and likely exceed, the scale of the entire existing operating nuclear energy capacity in North America. In Canada, Ontario's Independent Electricity System Operator's 2022 "Pathways to Decarbonization" report predicts that a doubling of the nuclear capacity by 2050 is needed to ensure the reliability of a low-carbon electricity system.

A study in the United States by Vibrant Clean Energy (VCE) found that the lowest-cost electricity system for reducing carbon would need to more than triple the nuclear capacity by 2050.[1] In another scenario involving constraints preventing large-scale deployment of new nuclear energy, the report concluded that total system costs increased by nearly a half a trillion dollars.

Figure 2, from the VCE study, shows the cumulative scale of potential advanced reactor electricity generation deployments—on the order of about 300 GWe by 2050. This lowest-cost system to provide reliable electricity and meet carbon reduction goals would need nuclear energy to increase to about 43% of the electricity generation, up from just under 20% today. The system also would need renewable sources to increase to about 50% of the electricity generation, up from roughly 10% today. Further, many energy industry leaders foresee increased demand for advanced reactors in industrial heat applications. Even with the uncertainties in these predictions, the scale of demand for advanced reactors is extremely large.

Figure 2. Potential future electricity generation landscape through 2050[1]



[2]Vibrant Clean Energy LLC. "Role of Advanced Nuclear Technologies in Decarbonizing the U.S. Energy System." NEI Board of Directors presentation, Washington, D.C., May 2022.

VISION

THE CASE FOR NUCLEAR ENERGY (CONT'D)

Several important conditions have combined to create an unprecedented market need and opportunity for nuclear energy:

- Continuing, expanding, and accelerating efforts to decarbonize the energy sector, while increasing its reliability, resilience and affordability, create the need for more carbon-free technology options
- A growing understanding that an electricity system must have a diverse set of technologies, including nuclear energy, renewable energy, and storage technologies
- An emerging demand for zero-carbon-emission energy in transportation and industrial uses that will be significantly greater than the demand in the electricity system
- The growing diversity of energy applications that must be decarbonized which necessitates energy solutions tailored to the nature and size of the application

This market need creates an imperative for nuclear energy to be a significant component of a clean, reliable, resilient and affordable energy system.

VISION

DRIVING VALUE TO MEET THE MARKET NEED

The industry is taking actions to ensure that nuclear energy can meet the market needs for this clean, reliable, affordable technology.

These actions are:

- Continue to operate the existing reactors for 80 years or more
- Commercialize a new set of nuclear energy technologies

The continued operation of existing nuclear energy facilities, which account for roughly 50% of today's carbon-free power generation in the United States and 12% in Canada, is essential not only for the plants' significant benefits
to the energy system, but also because using existing plants mitigate the overwhelming challenges involved in decarbonizing the energy sector.

This roadmap focuses on the commercialization of a new set of nuclear energy technologies called advanced reactors. The industry's approach to driving the value of advanced reactors to fulfill critical market needs is as follows:

PROVIDE DESIRED VALUE

Develop advanced reactors that safely deliver the cost-effective features and benefits that the market needs from zero-carbon emissions energy sources. Most significantly, the market needs firm-clean sources (also known as baseload) that are available 24/7, 365 days a year and can withstand and/or quickly recover from disruptive events, such as extreme weather. This provides a foundation of reliable, resilient, and dispatchable power that is essential to a functional electricity grid and heat users. Furthermore, advanced reactors will ultimately enable greater deployment of renewable energy sources and storage technologies. Additional benefits of advanced reactors are their energy density, resilience, low land use, dispatchability, and contribution to energy security. Advanced reactor features for enabling flexibility to further improve the efficiency of integrating renewable energy sources into the grid will increase the reliability of the electricity system while decreasing the costs.

Advanced reactors must be cost-effective. It is important to note that, when looking at the total system cost or the cost of energy to the customer, the market does not require that advanced reactors have the absolute lowest levelized cost of electricity (LCOE). Because the LCOE does not fully consider the benefits of the energy source, the most accurate method of evaluating the cost impacts of different energy technology choices is a detailed integrated systems cost analysis that accounts for the value of each source's benefits. Analysis of costs at the system level match energy supply and demand geographically and hour-by-hour, and includes costs not included in some LCOE comparisons, such as transmission, grid stability, and intermittency.

PORTFOLIO OF PRODUCTS

Develop a portfolio of products to meet a diverse set of market and customer needs. The existing nuclear energy facilities are essentially one type of product in the market—a large energy facility most suitable to powering a large electrical grid. There will still be value in these products in the future, but the scale and diversity that the market needs to decarbonize the energy sector requires a diverse set of advanced reactor technologies with varying capabilities. There will be a need for large, medium, small, and very small (also called micro) nuclear energy facilities to meet varying sizes of the grid and customer demand. Non-electric markets, such as transportation and industrial heat, will need a wide range of temperatures and sizes. In many cases, the market will need technologies to produce both electricity and heat. Because no one design can meet all of the market need, a portfolio of products is essential.

VISION

DRIVING VALUE TO MEET THE MARKET NEED (CONT'D)

Nuclear energy has historically been used in large, baseload electric generating stations. However, demand for advanced reactors is expected to expand significantly and to include a diversity of attributes and uses, including:

- **Application:** electricity generation, industrial heat, hydrogen production, steam, and other potential energy needs
- **Size:** micro-reactors (under 50 MWe), small modular reactors (50–300 MWe), medium scale (300-600 MWe) and large-scale reactors (>600 MWe)
- **Utilization:** always on, load/demand following, or intermittent
- **Siting:** fixed or mobile
- **Technology:** light water, gas-cooled, liquid sodium cooled, lead-cooled, molten salt and potentially others
- **Energy Products:** electricity, steam, heat, hydrogen

TIMELINESS

The goal is to successfully commercialize advanced nuclear technologies through early deployments, thereby building the foundation for expanding to large-scale deployment before the mid-2030s. The market need for decarbonization, partially driven by policies, is urgent. Some policies have set decarbonization goals for as early as 2035, and nearly all have goals for zero-carbon emissions by 2050. As noted above, the VCE study concludes that if advanced nuclear energy commercialization is delayed by as little as five years (as compared to the timeline shown in Figure 2), it impacts energy system costs.

The approach to drive value to meet market demand informs the discussion on conditions that would further enable advanced reactors to meet the market needs. Planned actions to deliver advanced reactors into the market are identified in the following sections.

Successful commercialization of advanced reactors that enable the United States and Canada to meet their energy, climate, environmental, economic, and national security goals is reasonably achievable through collaborative efforts by the industry and external stakeholders.

APPROACH

- DISRUPTIVE INNOVATION
- RISING TO THE OCCASION
- ESTABLISH, ADVANCE, EXPAND
- DE-RISKING PROJECTS FOR OWNERS
- EARLY SUCCESS TO BUILD A FOUNDATION & CONFIDENCE

APPROACH

DISRUPTIVE INNOVATION

Capturing the benefits of advanced reactors on the needed timeline requires an emphasis on "disruptive innovation" for deployment and utilization of the technology.

Advanced reactors build on the safety record of existing nuclear power facilities to provide even safer risk profiles. This risk reduction, coupled with modern monitoring and control technology, provides the opportunity to reshape how nuclear technology is developed, regulated, deployed, and operated. Changing how advanced reactors are pursued and viewed is important to achieve leveraged benefits—including easing of deployment challenges, accelerating deployments, and increasing cost-competitiveness, all while increasing safety and reliability.

The opportunities to change the game in advanced reactors are related to the elements listed in the preceding section, but they are also important strategic enablers themselves. Most importantly, changing the game involves shifting industry paradigms and practices in a sustained manner that encourages innovation, further strengthens the industry, and increases the benefits and utilization of advanced reactors.

Important opportunities to change the game and enable the deployment of advanced nuclear technologies include:

IN THE DESIGN AND ENGINEERING OF ADVANCED REACTORS

Increased standardization in designs, achieving the goal of "design and license once, use many;" a limited portfolio of designs each tailored to needed use-cases, reducing the need for use-specific design and licensing, and improving the business case for the application; large and ample design margins that facilitate and enable wide deployment envelopes, both for potential sites and potential uses; a risk-informed approach to quality assurance that avoids undesired bleed over of detailed nuclear quality requirements into the non-nuclear systems and equipment; and importantly, the design, licensing, and operational separation of the nuclear energy portion of a facility supplying energy from the non-nuclear portion using that energy, enabling significant cost savings and increased operational flexibility.

IN THE REGULATORY REVIEWS AND LICENSING OF ADVANCED REACTORS

Increased efficiency of regulator reviews through risk-informed approaches; effective and agile reviews of diverse technologies and use-applications; and NRC review schedules that reliably and predictably support mission objectives. The U.S. goal shall be to license advanced reactors, that have previously been approved, in 12 months or less from submittal to approval (that is, no longer than 12 months for both the safety and environmental reviews), with the understanding that initial applications of a design and early applications may take longer as the regulators streamlines their processes. Canada continues to work on streamlining their regulatory approval process.

IN THE DEPLOYMENT OF ADVANCED NUCLEAR TECHNOLOGY IN THE FIELD

Shift from an approach of "procure and construct" complex facilities to "manufacture and assemble components, then install them in a constructed structure"; implement a risk-informed and graded approach to oversight and quality assurance; and inculcate a culture that embraces the value of project management and risk mitigation rather than simply being activities that are done on the project.

IN THE OPERATIONS AND MAINTENANCE (O&M) OF ADVANCED NUCLEAR TECHNOLOGIES

Greatly reduced facility staffing levels and maintenance costs; streamlined qualification requirements for staff through a graded and risk-informed approach; and maintenance philosophies consistent with industrial facilities for comparable systems and components, that still deliver required levels of equipment reliability.

IN THE OWNERSHIP AND BUSINESS MODELS FOR ADVANCED NUCLEAR TECHNOLOGIES

Enabling and delivering to benefit "new to nuclear" owners; reducing the hurdles to ownership of an advanced reactor facility; and creating the opportunity for "energy as a service."

Capturing these disruptive innovations to create opportunities and "change the game" are requisites for success. Without achieving these big picture and cultural shifts as part of the near-term and mid-term deployments, long-term success and large-scale deployments (that is, "expand") are unlikely.

APPROACH

RISING TO THE OCCASION

The success of advanced reactors relies on evolving, strengthening, and sustaining industry culture. The industry's pursuit of operational excellence has served the industry well; excellence is needed across the activities required for successful commercialization and the high levels of safety and reliability, which are hallmarks of the industry, must be maintained. To achieve the vision of success, leverage the benefits of advanced technology, and build confidence and credibility, some elements of the culture must continue to evolve.

Examples of evolution that will enable enhanced effectiveness include:

- Being able to separate the scope of nuclear safety and radiological hazards from normal industrial activities and apply the rigor and levels of quality assurance appropriate to each. Shifting from a model of building large "one-off" plants on site, to assembling factory made plants
- Shifting from an attitude and culture of "constructing nuclear power plants" to "assembling industrial facilities with radiological hazards"
- Being unrelenting in driving the industry to be risk-informed and technology-inclusive with the regulator
- Understanding that external stakeholders can have very different perceptions and views of nuclear technology than industry participants
- From an education and communications perspective, having a proactive posture in engagements with external stakeholders and the public and sharing the contributions and accomplishments of nuclear energy and the industry team, and the larger impacts offered by advanced reactors
- Truly achieving the objective of standardization of nuclear technology designs without continual refinement and modification
- Recognizing the value and importance of government support to accelerate commercialization with policies that are equitable for nuclear and other clean energy sources
- Avoiding overpromising or underperforming. The industry cannot tolerate either, and history suggests that it is vulnerable to both in the deployment of advanced reactors

These culture evolutions are needed to achieve success; enabling and sustaining the changes is a fundamental role of industry leadership.

ESTABLISH, ADVANCE, EXPAND

To enable and ensure the needed timeliness and to build both capability and the needed confidence, the industry's commercialization plans must be framed to allow a realistic, phased, and risk-managed approach to deploying advanced nuclear technology.

More specifically:

- **Establish** wins on early mover and early finisher deployments (both first-of-a-kind [FOAK] and fast followers) to build a firm foundation and increase stakeholder confidence
- **Advance** from the established foundation to include multiple projects, deployments, and uses of advanced nuclear technology
- **Expand** to deliver at needed scale to meet the demands of the future energy landscape

This EAE strategy provides important benefits, including:

- Helping to ensure the most important accomplishments are achieved on the needed timelines
- Prioritizing industry efforts and actions
- Assisting in managing stakeholder expectations of what will be accomplished and when
- Most importantly, avoiding an early "all in" approach of attempting too much, too soon, and at the same time

APPROACH

ESTABLISH, ADVANCE, EXPAND (CONT'D)

A primary focus is on the industry first establishing a firm foundation, and while establishing it, to pursue a level of simplicity such that wins can be captured and the first deployments will occur as planned. Attempting to take on too many complexities or attempting to expand too widely prior to establishing the foundation of capability and the wins that build confidence threatens delays and costs to the individual projects. These delays jeopardize the overall industry deployment and raise the likelihood of missing the needed time window for deployments. The EAE strategy is intended to provide the framework to enable sustained and large success.

Although the high-level EAE approach has a clear end goal of deployments to meet the demands of 2050, the phased EAE strategy and approach also apply to lower-level accomplishments and workstreams that the industry must advance to achieve those deployments. Examples include:

- **Scale of deployment:** Transitioning from FOAK and early-mover projects with offset intervals, to multiple projects in parallel to widespread deployment of a design

- **NRC and CNSC processes:** In the U.S, using the known Part 50 and Part 52 processes, crafting with the NRC an optimized Part 53, and realizing the expected and needed predictability of NRC reviews. In Canada, applying the CNSC risk-informed, graded-approach, and alternative approaches that are possible within the regulatory framework, but which to date have not been applied to advanced reactors, and addressing timing challenges with the Impact Assessment Act

- **NRC and CNSC throughput:** Increasing the efficiency and throughput of regulatory reviews, advancing from FOAK applications to multiple applications (or fleet application) of previously approved designs, to predictable reviews of many different types of technologies at multiple application volumes

- **Design standardization:** Creating FOAK designs that balance the speed to market and market coverage, and after deployment of a large number of standard, first-series of the designs, then consider enhancing the design

- **Regulatory alignment:** NRC and CNSC collaborating on aligning the regulatory review processes to enable expedited reviews and capacity to accept and utilize each other's work

While moving through the EAE phased approach for these discrete topics, the industry must also be continually strengthening and expanding its capacity—in the spirit of the EAE strategy—in important areas identified in the roadmap, such as project management performance, supply chain robustness, and recruiting and training the needed workforce of the future.

Finally, while executing the roadmap, the industry must always look beyond the current phase and proactively address the needs of subsequent phases. It must also focus on advancing the lower-level workstreams, not simply the high-level achievements.

APPROACH

DE-RISKING PROJECTS FOR OWNERS

Customers are moving cautiously to make deployment decisions as advanced reactor programs mature. This can create an expected rapid increase in the demand for advanced reactors after success on the initial deployments.

The parallel goals of accelerating initial deployments, flattening the demand peak for new reactors at a sustainable level of new plants coming online each year, and enabling an early foundation for success will require the industry to achieve near-term and mid-term successes that build the confidence of key stakeholders internal and external to the industry and establish a record of success that the industry can deploy advanced reactors to meet customer expectations.

Customers of advanced reactors will remain cautious until a firm foundation is established and early mover and early finisher successes strengthen industry expertise and capability. Prior to the first projects being completed, customers, investors, and other stakeholders will need to gain confidence through the reduction and mitigation of first-mover risks. Developing advanced nuclear project deployment plans that achieve an equitable sharing of risk among customers, suppliers, contractors, financial institutions, and other stakeholders, including financial targets and models that result in cost-competitive products, along with defining the companion project execution and governance models, is a critical need. Extensive numbers of lessons learned from evaluations, reports, and recommendations from previous deployment of nuclear technology are available to owners, technology vendors, constructors, contractors, and other stakeholders. These recommendations were all developed with the mission to derisk future projects. It is imperative in the strategy that industry and owners use these valuable resources.

EARLY SUCCESS TO BUILD A FOUNDATION AND CONFIDENCE

To ensure more opportunities for and delivery on wins, increased confidence in the industry's ability to deliver among stakeholders and customers is critical. To build this confidence, the industry needs to deliver on the work it is doing, which, realistically, will occur only if wins have been achieved (and orders received).

The solution to this chicken-and-egg challenge (need work to build stakeholder confidence, but do not have opportunity to do work without stakeholder confidence) necessitates the strategy to build wins and strengthen the industry in a sequential, incremental manner that also continually derisks projects for owners. This confidence factor and how it is developed are also key in evolving the culture of the industry to succeed and thus in the successful delivery of nuclear technology.

Increasing stakeholder confidence is particularly important from a business case and project definition perspective. By building increased confidence, there will be more orders and investment in advanced reactors, more projects will move through the deployment cycle and provide important lessons, more challenges will be overcome, and the industry will be best positioned and prepared to meet its full potential.

Securing early and frequent "wins" is a fundamental need for establishing a foundation of industry success.

ENABLERS

- FIRST MOVER SUCCESS
- FAST FOLLOWERS
- REGULATORY EFFICIENCY
- SITING AVAILABILITY AND PERMITTING
- PUBLIC ENGAGEMENT
- SUPPLY CHAIN RAMP UP
- WORKFORCE DEVELOPMENT

ENABLERS

Driving the value of advanced reactors to fulfill critical market needs can be enabled by several conditions related to policy, regulatory, and public acceptance surrounding the commercialization of advanced reactors. The following enablers, with associated key opportunities, provide a valuable framework for focusing the solutions and actions that will enable large-scale deployment success.

Key Stakeholders

FIRST MOVER SUCCESS	FAST FOLLOWERS	LICENSING EFFICIENCY	SITING AVAILABILITY & PERMITTING	INDIGENOUS & PUBLIC ENGAGEMENT	SUPPLY CHAIN RAMP-UP	WORKFORCE DEVELOPMENT
• Industry • Federal • States/ Provinces • Regulators	• Industry • Federal • Regulators	• Industry • Federal • Regulators	• Industry • Federal • States • Regulators	• Industry • Federal • States/ Provinces • Public • Indigenous	• Industry • Federal • States/ Provinces	• Industry • Federal • States/ Provinces • Regulator • Universities • Trade Unions • Trade Schools

FIRST-MOVER SUCCESS

As with any new technology, the deployment of the first advanced reactors will include many new and unfamiliar complexities, and first-customer adoption can be slow for new technologies.

Recognizing these conditions, the U.S. Congress has provided incentives for the deployment of new clean energy technologies, including advanced reactors. These include the U.S. Department of Energy (DOE) providing direct support to first deployments of several advanced reactor designs, the Inflation Reduction Act providing tax incentives to spur market adoption, and loan guarantees. State support for the adoption of nuclear energy is also important to first-mover success, and many states are beginning to pass incentives to spur market adoption. In Canada, the recent Federal Budget announced several tax incentives and other measures that build on previous government support for the adoption of advanced reactors that will help to ensure that these technologies are available in the market and capable of making significant contributions to achieving the decarbonization and energy security goals. The industry is focused on deploying advanced reactors in a manner that minimizes risk and enables rapid learning because future deployments rely on their success.

The key opportunities to enable first-mover success are:

Government Policies

Governments are establishing policies to meet energy and climate goals, and these policies can either enable or discourage advanced reactor adoption in the market. Established policies with stable and reliable funding of programs enable the industry to make and even accelerate business decisions that lead to the timely deployment of the first projects.

Deployment Best Practices

The actions include the development of construction and project best practices, and the implementation of these best practices for advanced reactor projects. These are especially important for the first projects that will encounter new and unfamiliar complexities. Experience has shown that government policies that establish arbitrary deadlines or other unnecessary burdens on industry can also incentivize practices that do not implement all of these best practices. Therefore, government policies that support the industry's implementation of best practices will enable market adoption by enabling the industry to minimize cost, schedule, and risk.

Investments

It has been several decades since a large number of nuclear reactors have been built in the U.S. and Canada, so the investment community is relatively unfamiliar with the financial structuring of new nuclear build projects. The pricing of risk for first-of-a-kind new nuclear build projects, and the uncertainty of whether nuclear energy qualifies in environmental, social and governance financing could be a disincentive to some investors. Building education and comfort in the investment community is needed to enable a healthy supply of investment in new nuclear projects.

ENABLERS

FAST FOLLOWERS

Customers who are hesitant to be the first to adopt new technologies prefer to wait until the products are adopted by the first movers.

These "followers" are seeking to better understand the costs and schedule of advanced reactors so that they can more accurately factor the risks into their business decisions. However, if these followers wait until the first projects are completed, market adoption will be too slow to enable large-scale deployment of advanced reactors in the timeframe that the market needs to achieve national decarbonization goals. Enabling "fast followers"—those who proceed with projects soon after the first projects start and with reduced risks similar to having waited until the first project is completed—will allow the industry to meet the needs for clean energy between now and the mid-2030s, while also establishing the foundation for large-scale deployment through 2050.

The key opportunities to enable fast followers are:

De-Risking

The industry is developing a framework for reducing the risks for fast followers so that they are similar to the risks of having waited until the first projects are completed. This framework aligns the lead project deliverables and milestones that significantly reduce risk, in the areas of design, licensing, procurement, and construction, with the milestones of the fast follower projects. The outcome is that the fast followers benefit from the lower risks so that business decisions for moving forward can be made, in some cases reducing the timespan between the first and second project from five years to less than two years. Stakeholder support for the first projects to achieve these derisking milestones and for the fast followers to benefit from the first project's successes in their decision making will enable these fast followers to accelerate the deployment of advanced reactors. Examples of support include government policies, investment decisions, and public support.

Streamlining

The industry is pursuing design standardization and partnerships around individual designs of developers, customers, and suppliers that will streamline the deployment of the first wave of advanced reactors. This enables a process of learning that is well established to rapidly reduce the cost, schedule, and risks. Stakeholder support for streamlining advanced reactor deployments, by resisting the temptation to pursue major design or partnership changes for each project, and for encouraging risk sharing among the partners, will enable the industry to accelerate the deployment of advanced reactors.

REGULATORY EFFICIENCY

The market need for advanced reactors to enable the United States and Canada to meet their decarbonization goals will result in innovative designs that regulators have not previously approved and at a volume of licensing applications that far exceeds the NRC's or Canadian Nuclear Safety Commission's (CNSC's) current capacity.

Current regulations and key policy and technical positions in the United States and Canada have been established based on existing technologies—light-water reactors (LWRs) in the United States and heavy-water reactors in Canada. While some progress has been made to update the regulatory framework, the current regulatory framework is not efficient for advanced reactor technologies. If not updated, the regulatory framework may discourage the innovation necessary for providing valuable benefits to the market. It is understood the first time a new design undergoes a review it will take longer than later applications.

In fact, the current regulatory framework cannot process applications at a sufficient pace, even for those technologies on which it is based. The historical schedule for NRC approvals is four to eight years. The NRC review fees, which have historical cost of $28–$42 million and continue to grow exceeding $70 million in some estimates for future applications, is both cost and schedule prohibitive to achieving the scale of advanced reactor deployment that is necessary to meet the market need.

Although both the U.S. and Canada have already embarked on initiatives to revise or update regulations or regulatory documents and standards and to implement policy and technical positions that consider advanced reactor technologies, these efforts have been slow to reach completion and have not included all aspects of the regulatory processes and framework that must be updated or re-aligned to address the urgency of the climate change crisis.

A recent letter from NEI to the NRC states that the NRC could have as many as 60 applications in the licensing process at one time by 2030. In Canada the largest concern about the regulatory process relates to the federal Impact Assessment Act (IAA), which has long timelines and has not been tested for nuclear projects. The regulatory framework in both countries will also need to be updated to align with the innovations in advanced reactors. Although the NRC and CNSC have made progress, there is much work to be done, and the first advanced reactor applications are already in progress.

ENABLERS

REGULATORY EFFICIENCY

The key opportunities to enable regulatory efficiency are:

Regulatory Review and Reform

Regulatory reform by the NRC and in Canada by the CNSC and by the Federal government on the IAA would establish regulatory frameworks to facilitate the efficient and timely approval and licensing of innovative and safe advanced reactors. This regulatory reform would support deployment of the first advanced reactors and fast followers, and set the foundation for large-scale deployment in the early 2030s. Regulatory reform includes the following:

- Efficient and timely licensing of advanced reactor licenses in less than 12 months from docketing of the application to issuance of the license in the U.S. (Note that additional time will be necessary for the first regulatory review of a design.)
- Resolving key policy and technical issues (for example, emergency preparedness, environmental reviews, security) prior to the submittal of applications to minimize the need for subsequent design changes that prevent the streamlining of fast followers
- Updating the regulatory framework to align requirements with the advanced reactor technologies
- Collaboration between the NRC and CNSC to minimize the duplication of regulatory reviews of designs that are commercialized in both countries and also to enable standard designs between the two countries

Policy

The U.S. Congress and the Canadian Parliament can enable and encourage both nations' regulators to pursue the needed regulatory reforms that enable deployment of advanced reactors at the scale necessary. Regulatory reform is in the national and public interest because there is a market need for advanced reactors to achieve national energy, climate, environmental, economic and national security goals.

SITING AVAILABILITY AND PERMITTING

Site selection for nuclear energy facilities has historically been limited to locations based on population density, natural weather and geological conditions, and access to resources like a local water supply or rail spur.

However, advanced nuclear reactors are being designed with innovative features that eliminate or at least reduce these siting constraints. Enhancements to safety enable siting in areas with more extreme weather and geological conditions and closer to population centers where the power is needed. Enhancements to safety also enable advanced reactors to be used in island mode (separated from the grid) and for black start (the generation relied on to restart the grid after an outage). More efficient operations and smaller size can make dry cooling more economically feasible, eliminating the need for drawing water from a local body of water. Innovations that make advanced reactors smaller and easier to operate enable them to be located in remote areas, and even to be periodically relocated for humanitarian and disaster relief.

These features as well as standardization of designs will maximize the areas in which advanced reactors can be located. This is essential because the scale of advanced reactor deployment to meet the market need is not limited to a small scope of siting conditions, but will be wide and varied, just as the market and customer needs are diverse.

The key opportunities to enable siting efficiency are:

Permitting

Numerous stakeholders have roles in the siting availability of advanced reactors. Federal, state/provincial/territorial, municipal, and Indigenous governments will be involved in decisions for site permitting and, in some cases, making available public lands for siting advanced reactors. Local communities and the public will be involved in the process for deciding on the sites for advanced reactors. Industrial end-users of power, steam and

SITING AVAILABILITY AND PERMITTING (CONT'D)

heat will also be significant stakeholders in site selection. Regulators, market operators, investors, and insurance companies will also influence these decisions. Supportive engagement by these stakeholders with rapid decision making will enable the acceleration of the deployment of advanced reactors to meet the diverse set of market and customer needs.

Design Flexibility

The variability of site conditions across North America creates an incentive for advanced reactor designs to be tailored to each site to minimize costs and maximize performance. However, such an approach would not enable the efficiencies that come from design standardization. On the other hand, design standardization creates a natural tension between minimizing costs and maximizing the range of acceptable sites. To address this, the industry will need to develop flexible designs that are both standardized and adaptable to a range of site conditions. The industry needs regulators, customers, and other external stakeholders to make decisions that enable it to pursue this type of design flexibility.

INDIGENOUS AND PUBLIC ENGAGEMENT

Indigenous peoples and the public have a vested interest in the policies to meet energy, climate, environmental, economic, and national security goals. They also have a vested interest in the technologies that are commercialized to meet these goals and the plans for deployment to meet the market needs.

There are numerous opportunities for Indigenous peoples and the public to engage in the government processes for establishing policies and making regulatory decisions, including decision making related to specific project decisions, such as siting, safety, and environmental impact. In some instances, engagement of these parties happens late in the process, posing potential delays in the deployment of advanced reactors.

It is recognized that, in many cases, the public is not well informed about the opportunities to engage with the industry or government on decisions about energy and climate policies, technologies pursued to meet market needs, or projects to deliver value to the market. Establishment of programs by third parties or the government that enable communities and the public to more effectively engage with the industry and government can lead to deployment of advanced reactors.

In Canada, Indigenous peoples and community consultation (an accountability of the Crown, as represented by both Federal government and Provincial government agencies); early, ongoing and meaningful engagement by nuclear project proponents and licensees; incorporation of Indigenous knowledge into projects; benefits agreements or agreed-upon value (potentially equity); and potentially some form of Free Prior Informed Consent (FPIC) in recognition of the UN Declaration of the Rights of Indigenous Peoples (UNDRIP), are necessary (but not necessarily sufficient) requirements for successful nuclear deployment in Canada.

The key opportunities to enable public engagement are:

Public Engagement

Government processes that enable early engagement of the public in the process for establishing policies and making regulatory decisions can significantly reduce risks for advanced reactor projects, enabling deployments. Such processes would need to reach final decisions early in the timeline of the industry's business decision making to avoid delays that come when policies and regulatory positions change late in an advanced reactor project.

Community Engagement

The industry desires a strong, positive relationship with local communities and the public, one built on the fair treatment of all communities regarding industry operations and activities. This commitment includes fostering and sustaining inclusive, trust-based, and mutually beneficial relationships with local and disadvantaged communities. The industry is pursuing a path forward on advanced reactors that would lead to early and frequent engagement with potential host communities and others in the public that have equity in a potential advanced reactor project.

Indigenous Engagement

It is recognized that in Canada the CNSC has community and public engagement processes in place, as well as a significant Indigenous consultation program. As well, the Canadian federal government has established an Indigenous Advisory Council for the SMR (advanced reactor) Action Plan. Project proponents will engage Indigenous peoples to achieve the outcomes above for the public and community engagement outlined above as well as potential partnerships.

ENABLERS

SUPPLY CHAIN RAMP UP

The United States and Canada have deployed only a few new nuclear energy facilities in the last several decades.

Projects like the AP1000 at Vogtle 3 and 4 and the refurbishments of the CANDU reactors in Canada continue to maintain a domestic supply chain. However, much of the new nuclear supply chain is located outside of North America. Policies for domestic content drive the need for an increase in the U.S. and Canadian supply chains. Advanced reactor technologies also incorporate new materials and innovative components for which there is little experience in manufacturing. The shift from in-field construction to factory manufacturing of advanced reactors enables larger-scale deployment, but it also makes the need for a strong domestic supply chain even more essential to meeting the market need.

The key opportunities to enable supply chain ramp-up are:

Fuel Enrichment

Fuel enrichment from Russia, once a significant contribution to the worldwide supply, is no longer a desired option for advanced reactors. Increasing development of nuclear facilities around the world mean that there will be growing demand for the existing enriched fuel supplies. Potential scarcity of supply and desire for fuel security have both Canada and the U.S. considering their options for domestic supply. The time and investment needed for the industry to expand or develop new enrichment facilities requires clear government policies. Some advanced reactors will also use enrichments at higher levels than are commercially available. Although the industry could establish supply of this new enrichment level, the same factors—uncertain government policies and unclear timing and scale of market demand—discourage investment. Rapid implementation of the currently authorized and funded HALEU Availability program is essential to the success of many Advanced Reactor developers. Significant government investment would catalyze industry build-out of needed HALEU production capacity. In cases where the timelines for adding new fuel enrichment capacity do not support near-term need, government policies that provide the needed enrichment will ensure that first projects and fast followers are not delayed.

Canada and the U.S. government are collaborating to explore options to secure supply, both through import and fuel enrichment in the U.S. Developing enrichment capacity in the near term will be an important step to ensuring energy security in both countries.

Component Manufacturing

The industry is pursuing the expansion of the supply chain for advanced reactors; however, uncertainty in the timeliness and scale of advanced reactor deployment is likely to suppress the investment needed in the supply chain. Government support for the expansion of domestic supply chains will enable the industry to use the benefits of government policies, depending on use of the domestic supply chain. Furthermore, innovative advanced reactor designs with novel components will have longer lead times and are more prone to early design changes, putting at risk the ability to standardize the design, which is important to fast followers, regulatory efficiency, and cost reduction in progressing to "nth of a kind." Government support would enable the prototyping of novel components early in the design, so that any design changes that improve the value of advanced reactors can be made before applications for the first movers are submitted to the regulators. These novel elements might include advanced manufacturing methods and commercial standards to meet nuclear-grade quality requirements.

ENABLERS

WORKFORCE DEVELOPMENT

Workforce challenges are being experienced today, not just in the nuclear and broader energy industries, but across the economic sectors worldwide. This challenge is fueled by an aging workforce, which leads to staffing reductions through retirements and a change in work culture amongst the younger generations.

Cultural differences between the existing workforce and younger generations entering the workforce could also be factors. For instance, younger workers are less inclined to pursue jobs with significant travel, untraditional hours, or in remote situations. There has also been a long-term decline in the number of skilled craft workers that will be essential in the manufacturing, construction, and operation of advanced reactors. The industry action plan describes the path forward to ensure a stable and sufficient workforce for the deployment of advanced reactors as well as to support the long-term operation of the current fleet.

The key opportunity to enable workforce development is:

Training and Recruitment

The industry's plans for workforce development include programs to create a pipeline of sufficient qualified workers in all areas, including engineering and design, technical knowledge (such as O&M, radiation protection, and chemistry), skilled trades for manufacturing and construction, legal and regulatory affairs, communications, and human resources. These programs are designed to attract, train, and retain the workforce for advanced reactors. These workforce issues will also impact the regulators and other government agencies that have actions necessary to support the commercialization of advanced reactors. Government programs that attract individuals into the trade schools and colleges to study in areas that develop the skills and knowledge needed by the nuclear industry will enable the deployment of advanced reactors.

ACTIONS

- REGULATORY EFFICIENCY
- TECHNOLOGY READINESS
- PROJECT EXECUTION

ACTIONS

The actions that industry plans to take to deliver advanced reactors into the market are built on the strengths of today's high-performing nuclear power industry, using those assets to develop and apply innovative and enabling solutions.

The industry actions focus on what the industry can control in delivering a timely portfolio of products with benefits to the market. A cross-section of industry subject matter experts, leaders, and stakeholders engaged to develop an informed assessment of the key opportunities and the actions needed to address those opportunities within the context of wide-scale deployment of advanced reactors in the 2030s. This assessment included deep dives into multiple strategic elements (see Figure 3) in three primary pillars:

1 **Regulatory Efficiency –** informing the regulators as they prepare to accept, review, and approve the required volume of applications on the needed timeline, including applications for new technology and FOAK applications

2 **Technology Readiness –** the readiness of the nuclear industry to deliver needed advanced reactors that are reliable and perform to customer expectations and needs, and the associated supply chain providing supporting components, equipment, and materials

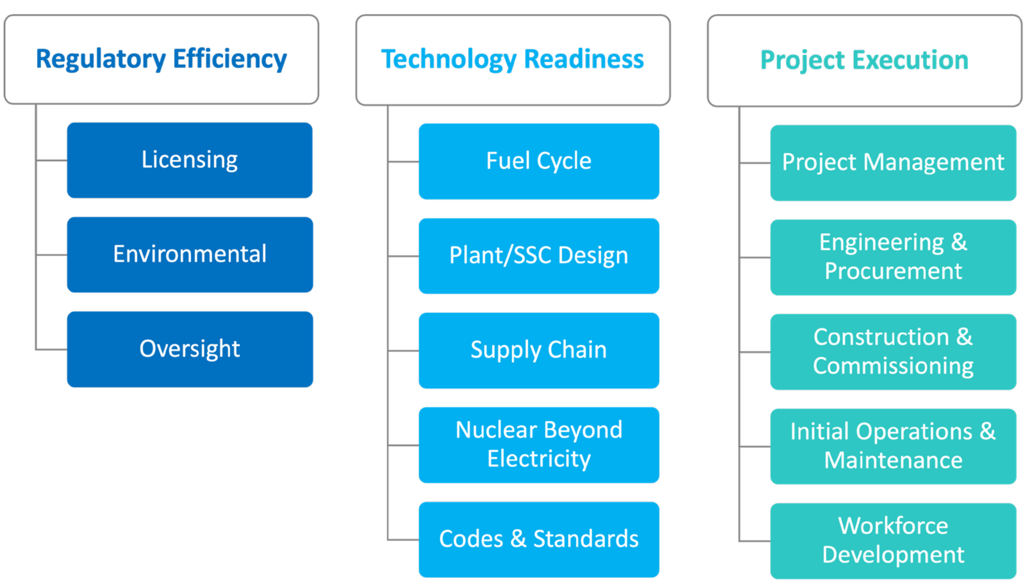
3 **Project Execution –** the ability of the nuclear industry to deliver advanced reactor projects on schedule and budget, and the readiness to operate the delivered facilities reliably and safely

There are a total of 46 actions. These actions are prioritized to identify those actions that make the greatest contribution to delivering value to the market (Priority 1) and other actions that could help further improve success (Priority 2).

Note that for actions where Canada is already, or is planning to address these issues, the Canadian Nuclear Association (CNA) has been listed as the place holder action owner for Canadian entities that are/will take on these actions alone or jointly with United States counterparts. As the CNA further develops and rolls out its Nuclear for Net Zero Strategy in the coming months, collaboration with the NEI and EPRI on the Advanced Reactor Roadmap and the actions it reflects will grow and better reflect the activities already underway, and those planned, for the Canadian nuclear energy industry.

The analysis identified opportunities for investments, expanded capability, and progress across all pillars and the spectrum of scope areas and infrastructure to design, license, deploy, and operate advanced reactors, all with the expected outcome to strengthen the industry. Collectively, these opportunities, along with the associated actions, represent the action plan for key accomplishments by industry and partner stakeholders.

Figure 3. Strategic Elements



REGULATORY EFFICIENCY
LICENSING

To reach the objective of deploying a large fleet of advanced reactors during the 2030s, licensing must be predictable, timely, efficient, and cost-effective to facilitate the regulator's throughput of applications needed for large-scale deployment. Advanced reactor regulations, guidance, and licensing must take advantage of lessons from licensing the existing North American fleet and then move forward based on the enhanced margins of safety.

KEY ISSUE: LICENSING TIMELINES

NRC and CNSC review schedules for new reactor reviews can delay deployment of new and advanced reactors that are critical to achieving the nation's environmental, economic, and national security goals.

Although more time might be needed for FOAK reviews, reviews of previously approved designs should take no longer than 12 months from submittal to approval (that is, no longer than 12 months for both the safety and environmental reviews).

ACTION:

Priority 1

Develop recommendations for enhancements to licensing processes: Recommendations will be established that would enable more timely and efficient reviews and approvals of advanced reactors.

Action owner: NEI and CNA

Need Date: 2024

KEY ISSUE: EMERGENCY PREPAREDNESS

The existing regulatory framework for emergency preparedness does not take into consideration the innovative design features, smaller source terms, and safety characteristics of advanced reactors. These designs are disadvantaged because they cannot scale their emergency planning zone and emergency response based on their safety profile.

ACTION:

Priority 2

Develop emergency planning methodologies: Methodologies will be needed for implementing the new NRC rule and guidance (pending approval) that can be used to establish the emergency planning zone distance. For Canada, technical justifications will be needed for appropriately sized emergency planning zones meeting Canadian requirements and expectations.

Action Owner: Advanced reactor vendors

Need Date: 2023

REGULATORY EFFICIENCY

LICENSING

KEY ISSUE: SECURITY

The existing regulatory framework for physical security does not take into consideration the safety and security characteristics of advanced reactors. These designs are disadvantaged because they cannot scale their security organization and response based on their ability to protect against radiological sabotage without the need to interdict and neutralize the threat.

ACTION:

Priority 1

Provide industry input into the regulator rule making on security: Ensure that the new rule and guidance appropriately reflect advanced reactor technology safety and security features.

Action owner: NEI and CNA

Need Date: 2023

KEY ISSUE: REGULATORY EFFICIENCY AND ALIGNMENT

Canada and the United States recognize the need to collaborate on addressing a series of issues that can be addressed through regulatory alignment between the two nations.

ACTION:

Priority 1

Provide joint recommendations to regulator and CNSC on regulatory alignment: Review and develop recommendations for enhancing alignment of regulatory processes and requirements to facilitate the efficient approval and licensing of advanced reactors in both countries.

Action Owner: NEI and CNA

Need Date: 2024

KEY ISSUE: OPERATOR STAFFING

The existing regulatory framework for all aspects of operation does not take into consideration the features of advanced reactors. Alternative approaches, which still maintain the level of protection to the safety of the public provided by existing reactors, are needed so that the business case for new reactors is not disadvantaged.

ACTION:

Priority 2

Develop industry recommendations for NRC guidance on operator staffing: Recommendations will be established to implement operator requirements appropriate for advanced reactor technologies.

Action Owner: NEI and CNA

Need Date: 2023

REGULATORY EFFICIENCY

LICENSING

KEY ISSUE: PART 53 (U.S. ONLY)

The current regulatory framework for technical requirements is prescriptive and inefficient for the regulation of advanced reactor technologies. A rule is needed that reflects a technology-inclusive, risk-informed, and performance-based regulatory framework, thereby providing an efficient and adaptable approach that enables applicants to meet their needs for schedule, cost, and predictability.

ACTION:

Priority 1

Provide industry feedback and recommendations on Part 53: Establish and communicate detailed feedback and recommendations for enhancing the NRC's Part 53 rulemaking to enable rules and guidance that are technology-neutral, performance-based, and risk-informed and efficiently reflect the safety and security features of advanced reactors.

Action Owner: NEI

Need Date: 2024

KEY ISSUE: PART 50 AND 52 (U.S. ONLY)

NRC plans to address lessons learned with the experience of the first applicants and licensees to use 10 CFR Part 52 and update 10 CFR Part 50 for technical consistency with Part 52, which does not clearly include key lessons learned as identified by the industry. The outcome of the rulemaking should be that the Part 50 and 52 regulatory processes do not impose undue risks and delays in licensing and construction of new reactors.

ACTION:

Priority 1

Provide industry input into the NRC rule making for Parts 50 and 52: Ensure that the new rule and guidance appropriately reflect advanced reactor technology safety and security features.

Action Owner: NEI

Need Date: 2024

REGULATORY EFFICIENCY

ENVIRONMENTAL & SITING

Over time, implementation of the National Environmental Protection Act (NEPA) in the United States and the Impact Assessment Act (IAA) in Canada have both become unjustifiably complex and time-intensive, with reviews frequently spanning several years or more and requiring massive resource expenditures. Maintaining the status quo will hinder the timely licensing of the advanced reactors. To achieve widespread deployment of advanced reactors, the implementation of NEPA and IAA must be streamlined to achieve efficient and timely environmental reviews. The NEI 2020 white paper "Recommendations for Streamlining Environmental Reviews for Advanced Reactors" provides recommendations for how this might be accomplished in the United States. Canadian industry is working diligently with government and Indigenous peoples and other stakeholders to streamline the IAA process to facilitate efficient approvals while maintaining environmental and human health safety.

KEY ISSUE: CATEGORICAL EXCLUSIONS (U.S. ONLY)

Current NRC regulations (10 CFR 51.20(b)) require the NRC to prepare an environmental impact statement (EIS) for specific categories of actions, including permits/licenses to construct and operate a nuclear power reactor or testing facility under 10 CFR Part 50 or Part 52. This requirement does not reflect consideration of the innovative design features, smaller source terms, and safety characteristics of advanced reactors, which are expected to result in even smaller site preparation/preconstruction, construction, and operation-related impacts relative to current large LWRs. Also, as relevant to DOE-funded, NRC-licensed projects, DOE's categorical exclusion regulations at 10 CFR Part 1021, Subpart D, do not fully account for the novel characteristics and reduced impacts of advanced reactors.

ACTION:

Priority 1

Enable NEPA exclusions: Develop input to the NRC that enables the implementation of proposed categorical exclusions under NEPA and 10 CFR Part 51 for advanced reactor licensing and/or operation.

Action Owner: NEI

Need Date: 2025

KEY ISSUE: ENVIRONMENTAL ASSESSMENTS

Current NRC regulations (10 CFR 51.20(b)) require the NRC to prepare an EIS for specific categories of actions, including permits/licenses to construct and operate a nuclear power reactor. This requirement does not reflect consideration of the innovative design features, smaller source terms, and safety characteristics of advanced reactors, which are expected to result in even smaller site preparation/preconstruction, construction, and operation-related impacts relative to current large LWRs. In Staff Requirements Memorandum (SRM)-SECY-21-0001 (April 19, 2022), the NRC noted that their staff may "further explore the idea of preparing environmental assessments to meet NEPA requirements for some categories and subcategories of license applications presently falling within the scope of 10 C.F.R. § 51.20(b)."

For Canada, to have one project, assessment, and decision, it will be key to coordinate federal reviews between the two agencies involved (the CNSC and the Impact Assessment Agency) along with the provincial or territorial environment assessment process. Reviews of second-of-a-kind and fleet deployments need to take credit for assessments of safety performed in FOAK deployments and focus instead on the site-specific project differences.

ACTION:

Priority 1

Enable environmental assessments in place of EIS: Develop input to the NRC that enables the future use of environmental assessments in lieu of more detailed environmental impact statements for the licensing of certain advanced reactors.

Action owner: NEI

Need Date: 2025

REGULATORY EFFICIENCY

ENVIRONMENTAL & SITING

ACTION:

Priority 1

Streamline the Canadian Impact Assessment Act and CNSC Environmental Assessment for Advanced Reactors. Specifically:

- Short term: Ensure no delays at the regulator end to the legislated or regulated assessment timelines. Drive for Tailored Impact Statement Guidelines that have appropriate scope for nuclear projects.
- Medium term: Revise implementing regulations to streamline the process and shorten timelines, especially as applied to Nth-of-a-kind and fleet deployments, to require only assessment of site-specific aspects, not reassessment of aspects addressed at other sites.
- Revise federal acts and provincial legislation to recognize the climate-change imperative and environmental benefits of nuclear power. Revise legislative requirements appropriately to enable faster, more predictable deployment of energy sources that do not emit greenhouse gases.

Action Owner: CNA working with the Canadian federal government and provincial agencies

Need Date: 2023, sustained

KEY ISSUE: GENERIC ENVIRONMENTAL IMPACT STATEMENT (GEIS) (U.S. ONLY)

In September 2020, the NRC approved their staff's development of an advanced reactor GEIS and future codification of the GEIS in the NRC's Part 51 regulations. In November 2021, the NRC staff issued SECY-21-0098, seeking NRC approval to publish for public comment a proposed rule that would amend Part 51 to codify the findings of the Advanced Reactor GEIS. By allowing applicants for advanced reactors that meet the performance measures and assumptions in the GEIS to reference the GEIS in their applications, the GEIS is expected to simplify and expedite advanced reactor environmental reviews.

ACTION:

Priority 1

Support the successful implementation of GEIS: Participate in the NRC rulemaking process and provide technical and legal input to ensure that the agency's final advanced reactor GEIS, associated rule, and implementing guidance meet its objective to "streamline the time and effort needed to complete environmental reviews under NEPA for most advanced nuclear reactors."

Action owner: NEI

Need Date: 2025

REGULATORY EFFICIENCY

ENVIRONMENTAL & SITING

KEY ISSUE: POPULATION SITING (U.S. ONLY)

The existing population-related siting guidance is prescriptive and based on large LWR technology. NRC guidance and expectations for population-related siting of advanced reactors should appropriately consider their smaller source terms and safety characteristics through the use of technology-inclusive, risk-informed, and performance-based criteria.

ACTION:

Priority 2

Develop technical input to siting criteria: The industry will provide technical input to support the NRC's preparation of guidance on technology-inclusive, risk-informed, and performance-based criteria for the policy on siting away from population centers that will increase the number of allowable sites for advanced reactors in comparison to current guidance while still controlling societal risks.

Action Owner: NEI

Need Date: 2024

KEY ISSUE: SITE SELECTION AND EVALUATION (U.S. ONLY)

The site selection process requires the collection of significant safety and environmental information and detailed analysis that must be supplied to the NRC to support an applicant's siting decision. A site must meet NRC regulatory requirements for construction and operation (that is, requirements related to site suitability and radiological health and safety). An applicant also must comply with environmental review requirements under NEPA and 10 CFR Part 51 for the consideration of alternative sites. Some requirements might be outdated or inapplicable due to advancements in reactor technologies and analytical methods as well as expected new non-electric applications of advanced reactors (such as process heat).

ACTION:

Priority 2

Develop guidance for site selection and evaluation: The guidance will focus on simplifying and streamlining the site selection and site suitability evaluation processes for advanced reactors, including reactors that might be sited on former coal-fired power plant sites.

Action owner: NEI and EPRI

Need Date: 2025

KEY ISSUE: INCREASINGLY STRINGENT PERMITTING PROCESS

Population growth, climate change, pollution, and aging water delivery systems have created an increasing array of challenges with water supply, water quality, ecological impact, and infrastructure. As a result, many states' permitting agencies have been adopting increasingly stringent water quality standards and thermal discharge limitations that make permitting closed-cycle wet cooling plant designs increasingly difficult, if not impractical.

ACTION:

Priority 2

Utilize best waste heat cooling technologies in order to ease permitting process: Develop guidance on available cooling water technologies and cooling water system design options to help applicants using water-cooled advanced reactor technologies avoid or mitigate challenges related to cooling water availability and permitting.

Action owner: Owner with guidance from EPRI

Need Date: 2023

REGULATORY EFFICIENCY
OVERSIGHT

This section is primarily focused on the regulatory and safety oversight of the construction and operations of advanced reactors. This includes external stakeholders such as electrical grid and service area authorities. Other forms of oversight, for example, project execution, are consolidated into those sections.

KEY ISSUE: MODERNIZE REGULATORY OVERSIGHT

The strong oversight processes, which have evolved over the past 40 years, have contributed to the high levels of safety and reliability achieved by the operating fleet. Innovative design features and safety enhancements of advanced reactors must be met with further evolution of these oversight processes to improve efficiency and effectiveness.

ACTION:

Priority 2

Develop guidance on modernizing regulatory oversight: The guidance will modernize the oversight of advanced reactors during the construction and operation phases. The focus will be to reduce unnecessary burden and gain efficiencies while retaining elements necessary to achieve outcomes related to safety and reliability.

Action Owner: NEI, CNA, EPRI

Need Date: 2024

KEY ISSUE: EXTERNAL ENGAGEMENT

History has shown that the success or failure of an infrastructure project is heavily influenced by the level of support garnered from all facets of a community. The successful deployment of advanced reactors will require commitment and attention to external engagement on par with the robust business and engineering practices that the industry already implements. It is in the best interest of the industry as a whole to share experiences, options, and best practices for external engagement.

ACTION:

Priority 2

Engage external stakeholders: For each advanced reactor deployment project, implement an Indigenous, community and public engagement plan consistent with the industry's commitment to environmental justice principles, community engagement best practices, and a just transition to a decarbonized energy economy.

Action Owner: Owner/operators, Institute of Nuclear Power Operations (INPO) and dedicated energy users with support from NEI

Need Date: Prior to the selection of site

TECHNOLOGY READINESS
FUEL CYCLE

KEY ISSUE: ADVANCED REACTOR FUEL QUALIFICATION & TESTING

Most of the advanced reactor developers are using fuel different than what is used in the current fleet. All these fuel designs will require qualification and testing. Specifically, some advanced nuclear fuel fabricators and advanced reactor developers are planning to rely on existing benchmark data to qualify their HALEU fuels up to 20%. However, these data might be outdated or not applicable. Therefore, it is expected that approval of HALEU fuels used in the core of advanced reactors will require in-pile testing.

ACTION:

Priority 2

Qualify Advanced Reactor Fuel: The qualification conditions for advanced fuels should be defined, a test plan for each advanced fuel should be developed, and a gap analysis to determine needs and develop new equipment should be performed. Additionally, the use of existing testing facilities should be coordinated and the need for new testing capacity determined.

Action Owner: Advanced reactor vendors, EPRI

Need Date: 2024 (First commercial reactors)

KEY ISSUE: USED FUEL HANDLING AND STORAGE STRATEGY

The back end of the fuel cycle for advanced nuclear fuels is not well defined and will likely present significant variability, depending on the advanced reactor design, both in the United States and Canada.

ACTION:

Priority 2

Develop spent fuel handling and storage strategy: A technology-neutral acceptance criteria for long-term storage repository will be established, spent fuel handling technologies for advanced fuels will be evaluated, and a cost-benefit analysis of fuel storage options will be performed. The Canadian Nuclear Waste Management Organization (NWMO) and the U.S. DOE will continue to collaborate on option development.

Action Owner: EPRI, CNA, Advanced reactor vendors

Need Date: 2024

KEY ISSUE: ADVANCED REACTOR FUEL AVAILABILITY

With the shortages in low enriched fuel and with many advanced reactor developers relying on High Assay Low Enriched Uranium (HALEU) to fuel their reactors, it is imperative that a trusted supply chain of domestic (that is, North American) enrichment is brought to market at the earliest opportunity. Government support is needed to create sufficient domestic enrichment of Low Enriched Uranium (LEU) and HALEU fuel for advanced reactors.

ACTION:

Priority 1

Government Support for Domestic Commercial Fuel Enrichment: Advocate for and employ government funding and/or offtake agreements to catalyze rapid private sector investment and build-out of domestic LEU and HALEU production capacity.

Action Owner: NEI, CNA, advanced reactor developers, owner/operators

Need Date: 2024

TECHNOLOGY READINESS
PLANT/SSC DESIGN

The plant and SSC design strategic element includes the design of advanced reactors and systems, structures, and components (SSCs). Because a significant amount of time has passed since the current operating fleet of LWRs and CANDU reactors was designed, and due to the different features of advanced reactors in terms of coolant, size, and type of fuel, design of advanced reactors will present unique challenges.

KEY ISSUE: MATERIALS BEHAVIOR

A complete understanding of the behavior of materials selected during the design under relevant conditions might not be available during the design phase. Because some advanced reactor designs are intended to operate at much higher temperatures than the currently operating LWRs, design practices need to account for the "time-dependent" behavior of materials in various coolants for safety and life-cycle analyses.

To fill this gap, the materials roadmap developed by EPRI should be updated, vendors' needs should be collected and prioritized, and the needed tests should be performed with a timeline that meets advanced reactor designers' needs.

ACTION:

Priority 1

Capture material data and close data gaps necessary for deployment of advanced reactors: Identify the materials needed for advanced reactor designers in both the near- and mid-term and ensure that materials testing is performed for on-time qualification. The materials roadmap developed by EPRI should be updated, vendors' needs should be collected and prioritized, and the needed tests should be performed with a timeline that meets advanced reactor designers' needs. In addition, Canada should ensure sufficient laboratory facilities are available for Canadian testing and data development requirement.

Action Owner: EPRI, CNA, advanced reactor vendors

Need Date: 2028 for first mover, 2030–2035 for mid-term needs

KEY ISSUE: INSUFFICIENT DATA AND ANALYTICAL TOOLS

Computer codes and risk assessment tools needed during design to predict the behavior of systems and components might not be qualified for advanced reactor conditions. To qualify the analytical tools needed for design, the experimental data needed and the analytical tools that require verification and validation (V&V) should be identified and V&V qualification for the required analytical tools should be completed.

ACTION:

Priority 2

Develop and Qualify Analytical Tools for Advanced Reactor Design: Survey advanced reactor vendors to identify analytical tools needed for optimal design. Create an action plan to develop and/or qualify tools as needed.

Action Owner: EPRI/advanced reactor vendors

Need Date: 2024 for action plan

TECHNOLOGY READINESS
PLANT/SSC DESIGN

KEY ISSUE: RELIANCE ON LEGACY DESIGNS

New reactor designers often rely on the idea that almost every conceivable type of reactor technology has already been tried out in the past and use this as a basis that proven designs exist. However, design drawings and manufacturing details are often not available, so past experience might not be readily available. Also, the subsequent problems found during operation might not be captured and/or understood.

Furthermore, the modes and mechanisms of operation from the historical technology experience might not be the same as those planned for advanced reactors. These different operational challenges may not be understood through historical precedent. To fill this gap, a guide on how to use past designs should be developed, including the identification of past designs that can be useful for advanced reactors. The guide should be endorsed by the regulators.

ACTION:

Priority 2

Develop Guide on Leveraging Legacy Reactor Experience: Identify best-practices uses of legacy advanced reactor demonstration experience and data, while providing guardrails based on their shortcomings.

Action owner: EPRI

Need Date: 2024

TECHNOLOGY READINESS

SUPPLY CHAIN

The supply chain has been identified as a strategic element because advanced reactors employ fuels, coolants, technologies, deployment models, and other attributes and capabilities that extend beyond those of the current operating fleet of LWRs and CANDU reactors. The scope of the supply chain strategic element includes basic commodities (raw materials, steel, concrete, rebar, pipe, and so on), manufacturing (alloys, casting, forging, modularization, and so on), non-light water technology products (such as molten salt heat exchangers and pumps, and nuclear-grade graphite), sustained supply of spares and replacement components, and nuclear fuel, which is addressed in detail in the separate fuel cycle strategic element.

KEY ISSUE: LACK OF FABRICATION CAPABILITY FOR MODULE FABRICATION

Most advanced reactor designs are leveraging modular construction, which will reduce the amount of construction at a reactor site and rely more on factory fabrication. However, the supply chain is not ready to meet the increasing need for larger modularized sections of facilities/plants driven by advanced reactor construction.

ACTION:

Expand module fabrication capability:

Priority 1

Document current domestic/regional capabilities and the projected need for module fabrication facilities. Identify specific production and capability gaps.

Action Owner: NEI, CNA, EPRI

Need Date: 2023

Address strategically important modular capabilities and capacity demand gaps via joint investments of the fabricators, owners, and developers to establish necessary capabilities.

Action Owner: Advanced reactor vendors, suppliers and owner/operators

Need Date: 2028

KEY ISSUE: SHORTAGE OF NUCLEAR-GRADE COMPONENTS

The supply chain for nuclear-grade (Appendix B-Compliant QA Program and N-Stamp qualified manufacturers) components, although generally available for the current operating fleet, needs to be expanded to meet advanced reactor needs.

To secure manufacturer/supply source for needed nuclear-grade components, a plan should be identified and executed. The plan should include feedback from interested stakeholders and should be endorsed by the regulators.

ACTION:

Establish a sufficient supply of nuclear grade components:

Priority 1

Document current domestic/regional capabilities and the projected need for nuclear grade components; identify gaps.

Action Owner: NEI, CNA, EPRI

Need Date: 2023

TECHNOLOGY READINESS
SUPPLY CHAIN

Priority 1

Launch domestic/regional "Nuclear Grade Supplier Development Program(s)" and expand Canada's Organization of Canadian Nuclear Industries (OCNI) Ready4SMR program. Use these programs to help non-nuclear suppliers prepare to provide nuclear-grade components.

Action Owner: NEI, CNA, EPRI, INPO, suppliers

Need Date: 2024

Establish a methodology for using international standards (ISO-9001) to meet nuclear quality assurance requirements.

Action Owner: NEI, and others identified by the Advanced Reactor Roadmap Steering Group.

Need Date: 2025

Expand on established processes to procure low-risk-significant or low-safety-significant components from non-nuclear suppliers, including establish and/or contribute to task groups in nuclear codes and standards to enable procurement of low-risk-significant or low-safety-significant components with reduced auditing burden.

Action Owner: EPRI, CNA, NEI, and others identified by the Advanced Reactor Roadmap Steering Group.

Need Date: 2023-2028

KEY ISSUE: SMALL FORGING FACILITIES INADEQUATE TO HANDLE POTENTIAL DEMAND

Although the United States and Canada have capabilities to support smaller forgings, piping, and other components, these capabilities will be strained as construction and deployment of advanced reactors proceed. Additionally, for many of the nuclear components, these suppliers will need to acquire and maintain their certifications to fabricate nuclear-grade components.

ACTION:

Increase the capacity of small forging facilities:

Priority 1

Document current domestic/regional production capabilities and the projected need for small forging facilities. Identify specific production and capability gaps.

Action Owner: NEI, EPRI

Need Date: 2023

Connect candidate forgers with developers through workshops and industry events to establish shared demand and economies to establish and/or re-establish.

Action Owner: EPRI, NEI

Need Date: 2023-2030

TECHNOLOGY READINESS
SUPPLY CHAIN

Priority 1

Bring together gaps, industry demand, and candidate manufacturers and manufacturing hubs with applicable government funding opportunities and initiatives, such as what is available under the Inflation Reduction Act.

Action Owner: NEI, CNA, EPRI, suppliers, and others identified by the Advanced Rector Roadmap Steering Group

Need Date: 2023-2030

Form new or join existing consortiums to establish necessary forging capabilities and proof-of-concept research with shared resources.

Action Owner: Advanced reactor vendors, suppliers and owner/operators

Need Date: 2030

KEY ISSUE: SPECIFIC MATERIALS SUPPLY CHAIN GAPS

Specific components needed for advanced reactors, especially for the nuclear island, might be affected by supply chain issues. Materials identified include nuclear graphite, helium, sodium, molten salts, and beryllium. To secure sources for needed nuclear-grade materials, input from nuclear-grade manufacturing vendors and national laboratories should be collected to establish the basis for implementing expansion or starting up new capabilities, and a plan to establish at least one manufacturer/supplier of the nuclear-grade materials needed should be developed and executed.

ACTION:

Establish competent material supply chain with production capacity:

Priority 2

Document current domestic/regional production capabilities and the projected need for specific materials. Identify specific production and capability gaps.

Action Owner: NEI, CNA, EPRI

Need Date: 2023-2024

Connect candidate manufacturers with developers via workshops and industry events to establish shared demand and economies to establish and/or re-establish production lines.

Action Owner: EPRI, NEI, CNA

Need Date: 2024-2025

TECHNOLOGY READINESS
SUPPLY CHAIN

KEY ISSUE: COMMERCIALIZATION OF ADVANCED MANUFACTURING CAPABILITIES

Advanced manufacturing technologies are being considered during design, but they have not reached commercial maturity yet. In that regard, the United States is well positioned in developing advanced manufacturing for nuclear: powder metallurgy–hot isostatic pressing, directed energy deposition additive, electron beam welding, diode laser cladding, and special materials development capable of handling the corrosive and high-temperature conditions of advanced reactor designs.

All of the aforementioned are currently under development. However, these technologies need to be commercialized on an industrial scale to support the deployment of a fleet of advanced reactors.

ACTION:

Commercialize advanced manufacturing capabilities:

Priority 2

Document current domestic/regional capabilities and projected demand. Identify gaps and develop plans to close said gaps for strategic advanced manufacturing technologies that address other manufacturing gaps.

Action Owner: EPRI, NEI

Need Date: 2023

Provide proof-of-concept research and prototype demonstrations for strategic and high MRL / TRL

techniques. **Action Owner:** EPRI

Need Date: 2023–2028

Qualify strategic techniques and materials in codes and standards and regulatory bodies based on deployment timeline and

demand. **Action Owner:** EPRI, Advanced Reactor developers, suppliers

Need Date: 2024–2030

Connect designers, developers, OEMs, and advanced manufacturers through workshops and industry events to tie demand with capabilities.

Action Owner: EPRI, NEI

Need Date: 2023–2030

TECHNOLOGY READINESS

NUCLEAR BEYOND ELECTRICITY

The Nuclear Beyond Electricity (NBE) strategic element includes activities needed to achieve decarbonization goals and capture new business markets for advanced reactors to participate in energy markets beyond providing baseload power to the electric grid. These markets include producing hydrogen, providing direct industrial electricity (for example, data centers), and providing heat for industries or district energy networks, among others.

With the effects of climate change becoming more apparent and increasing engagement in decarbonization policy across the world, the potential role of NBE in North America is increasing in importance. Advanced reactors, with some designs providing a smaller required geographic footprint or higher-temperature heat, present an opportunity for nuclear power plants to provide their reliable, carbon-free energy to other markets. Success in this strategic element will enable newly developed advanced reactors to serve a broad range of market areas by the 2030s.

KEY ISSUE: NBE-RELATED TECHNOLOGY MATURITY AND IMPLEMENTATION

Some NBE technologies are not yet ready for full-scale deployment and need further research and development for implementation even if not paired with an advanced reactor. Others will require development for integration with advanced reactors, including development of a marketplace to make the NBE service economically feasible.

Additionally, advanced reactor technologies must be developed to provide the service and/or form of energy that is useful for NBE customers.

ACTION:

Priority 2

Develop and demonstrate NBE applications: Identify and document application-specific technical requirements; develop conceptual system designs for NBE applications; and identify the need for, develop, and test NBE-related technology.

Action Owner: Owners/Operators, EPRI

Need Date: 2026

KEY ISSUE: CHALLENGES TO DEPLOYMENT DUE TO BUSINESS MODELS

The business model for the nuclear industry has historically been centered on producing electricity and delivering it to the power grid. NBE will have multiple business models that will change this approach by deploying advanced reactors for alternative missions and alternative customers.

The economic viability of these new business models is an essential prerequisite to drive the public and private investment needed for widescale deployment.

ACTION:

Priority 2

Develop novel business models for NBE: Develop a range of business model templates that will document the different owner, operator, and customer relationships to support development of the NBE business models.

Action Owner: EPRI, NEI, CNA, customers, Advanced Reactor developers

Need Date: 2025

TECHNOLOGY READINESS

NUCLEAR BEYOND ELECTRICITY

KEY CHALLENGE : REGULATORY CHALLENGES FOR NBE APPLICATIONS

Several regulatory barriers and risks are specific to the NBE strategic element. In some instances, these issues may be addressed as part of the process for demonstrating separation of the nuclear island from the end user facility.

Further discussion on regulatory issues (beyond NBE technical issues) is included in the Regulatory Efficiency strategic element.

ACTION:

Priority 2

Establish decoupling framework for NBE users: Develop the methodology to demonstrate separation of nuclear facilities

Action Owner: EPRI, NEI, CNA, advanced reactor developers, owners

Need Date: 2025

TECHNOLOGY READINESS
CODES & STANDARDS

Consensus codes and standards provide acceptance criteria, methodologies, processes, and other data based on the accumulated experience of the industries they serve and documented by subject matter experts. The design of advanced reactors and a new generation of nuclear reactor construction challenge the context and numerous assumptions that the current consensus codes and standards are based on. The purpose of this document is to identify the most critical gaps related to codes and standards as well as actions and milestones required to successfully deploy more than 100 advanced reactors in North America in the 2030s.

KEY ISSUE: ALIGNMENT AND IMPROVEMENT OF CODES AND STANDARDS

The changes to the basic methodology and assumptions inherent in nearly all advanced reactor designs, construction methods, and operating parameters will need to be understood, challenged, and embraced. Advanced reactors will not come to fruition without industry, government, and public stakeholders stepping out of the legacy "this is how it's always been done" mindset.

ACTION:

Priority 1

Identify gaps in and timelines for advanced reactor codes and standards:

- Consolidate and update prior advanced reactor codes and standards gap analyses
- Define development timelines for commercial relevance
- Prioritize gaps and associated actions
- Secure resources to address gaps in and timelines for advanced reactor codes and standards development

Action Owner: Standard developing organizations (SDOs), NEI, CNA, EPRI and Advanced Reactor vendors

Need Date: Gaps identified by 2024

KEY ISSUE: RISK-INFORMED AND PERFORMANCE-BASED DESIGN APPROACH

Historically, plants were designed using deterministic methods on a component level with system classification and other design conditions as input. Although constructing components will remain largely a deterministic approach, there is a growing belief that a risk-informed, performance-based approach to select licensing basis events, safety classification of SSCs (SSC such as NEI 18-04 in the U.S.), and maintenance strategies (monitoring, nondestructive evaluation, and so on) would lead to a more optimized plant design for construction and operation.

However, a probabilistic and system-based approach is more complex than current risk-informed methods, and many codes and standards are not directly compatible.

ACTION:

Priority 2

Demonstrate risk-informed and performance-based approach: Develop and execute a pilot project that applies risk-informed, performance-based methods in development of a new advanced reactor standard jointly with U.S. and Canadian SDOs (potential crosscut with International Harmonization action).

Action Owner: ANS, ASME, and CSA with NEI, CNA and Advanced Reactor vendors

Need Date: 2025

PROJECT EXECUTION

PROJECT MANAGEMENT

The scope of the project management strategic element is to develop guidance for project management processes, methods, and tools for new advanced reactor power plant projects. This includes contract, scope, schedule, cost, quality, human resources, communication, and risk management. The desired outcome is to provide resources for organizations and project managers to execute advanced reactor projects on time and on budget with safety, sufficient quality, and regulatory compliance.

KEY ISSUE: INSUFFICIENT PROCESSES, METHODS, AND TOOLS TO MANAGE LARGE PROJECTS

The key challenge is that management of large, complex projects involves significant funding, a large workforce, regulatory and governmental oversight, and public engagement. The anticipated volume of advanced reactor projects also makes delivering new projects a challenge due to competing resources. The action to address this challenge is to research the project management processes, methods, and tools available for management of large complex projects.

ACTION:

Priority 1

Develop effective management of large projects: Research the project management processes, methods, and tools available for management of large, complex projects. Determine which ones require further development, and work with the appropriate parties (the industry, software developers, and so on) to make these a reality. Develop a guideline on implementing these processes, methods, and tools for advanced reactor projects.

Action Owner: NEI, INPO and EPRI with owner/operators

Need Date: 2025 for guidance

KEY ISSUE:NEW ADVANCED REACTOR TECHNOLOGIES

The key challenge is that advanced reactors projects have a significant number of new technologies, which come with unique risks—particularly for the first project implementation. The action should determine how to manage these projects, including risk identification and strategies to resolve those risks.

ACTION:

Priority 2

Develop effective project management guidance for projects with significant new technology: Develop guidance on how to manage these projects, including risk identification and strategies to resolve those risks.

Action Owner: NEI and EPRI with owner/operators

Need Date: 2025

PROJECT EXECUTION

PROJECT MANAGEMENT

KEY ISSUE: OWNER/OPERATOR CAPABILITY FOR MULTIFACETED ADVANCED REACTORS PROJECTS

The key challenge is that many potential owners might have a knowledge gap with multifaceted advanced reactor projects, which will pose a challenge to the management of the project. The action to address this challenge is to form owner/operator user groups to develop and identify the critical lessons learned from past projects and how to apply them appropriately to future advanced reactor project management teams. These user groups need to distribute this information across the industry and make a clear guideline that others can follow for project management planning.

ACTION:

Priority 2

Bolster potential owner/operators project capabilities related to the task of deploying Advanced Reactors: Provide training on how to build capabilities in an owner/operator, including key elements in developing an organization capable of safely and reliably commissioning a nuclear plant.

Action Owner: NEI, EPRI and INPO

Need Date: 2025

KEY ISSUE: SELECTING APPROPRIATE CONTRACTING STRATEGY

The key challenge is that ownership groups will be diverse, and owners need to be familiar with various contracting strategies to be able to choose the best one for their project. The action to address this challenge is to develop guidance on options for contracting strategies for advanced reactor projects that owners, developers, advanced reactor suppliers, and vendors can apply.

ACTION:

Priority 2

Deploy project appropriate contracting strategies: Develop guidance on options for contracting strategies for advanced reactor projects that owners, developers, advanced reactor suppliers, and vendors can apply. Research organizations with expertise in contract strategies for nuclear development and construction should investigate contracting strategies that ensure equitable risk sharing and accountability among stakeholders.

Action Owner: NEI, EPRI with owner/operators, Advanced Reactor vendors and construction companies

Need Date: 2025

PROJECT EXECUTION

ENGINEERING & PROCUREMENT

The scope of the engineering and procurement strategic element is to develop guidance for engineering processes, methods, and tools to support the design, licensing, construction, and commissioning for advanced reactor power plant projects. The desired outcome of the engineering and procurement strategic element is to provide engineering and procurement resources for organizations to execute advanced reactor projects on time and on budget with sufficient quality and regulatory compliance.

KEY ISSUE: OVER APPLICATION OF NUCLEAR OPERATING STANDARDS AND PROCESSES

The industry's commitment to high levels of safety and reliability is a foundational element of the culture and must be maintained. However, it also must be recognized that over time, some activities have been pursued where the incremental gain from additional processes has not been necessary or cost-effective. Previous industry efforts to reduce unnecessary burden and eliminate low value work, while maintaining or improving safety and reliability, were effective in improving the efficiency of the operating fleet. This same pursuit of efficiency in processes has not necessarily been applied to new nuclear construction projects. It must be recognized that there is a need for engineering to be flexible, adaptive, and timely to support emergent issues that come with advanced reactor designs and large-scale construction.

Nuclear design efforts must apply or adopt similar approaches to pursue increased value and improve efficiency while maintaining focus on safety and reliability. The actions to address this challenge are to develop procedures and processes that clearly define when nuclear versus non-nuclear/commercial design methods can be used and adopting risk informed or graded approaches to design activities. A firewall must be erected to separate the commercial aspects to ensure a right-sized approach. Adopting a mindset of "optimal effort to achieve maximum effect" will aid in delivering nuclear designs that achieve the levels of safety and reliability expected in a nuclear plant in an economical way.

ACTION:

Priority 1

Establish a mindset of "optimal effort for maximum effect": Establish an industry initiative to develop processes that right-size approaches to design activities. Guidance from previous industry-level efforts should be reviewed for application in design activities. Similar action is in construction and commissioning.

Action Owner: to be identified by the Advanced Reactor Roadmap Steering Group with support from NEI

Need Date: 2024

KEY ISSUE: DESIGN COMPLETION BEFORE CONSTRUCTION

Procuring equipment and starting to build the plant before design, analyses, and regulatory reviews are complete entail considerable risk of rework with delays and higher costs. Unfortunately, the economics of a long development time along with regulatory and/or development delays will result in the design phase not being completed when the procurement and construction phases should start.

ACTION:

Priority 2

Institute principles on sufficient design completion before construction: Develop a guide to discuss tradeoffs of more or less design completion and how to ensure that there is sufficient design completion prior to construction.

Action Owner: NEI, EPRI and INPO

Need Date: 2024

PROJECT EXECUTION

CONSTRUCTION COMMISSIONING

The scope of the construction and commissioning strategic element is to develop guidance for organizing construction contract companies, personnel, and tools to support the building, logistics, construction equipment, and commissioning of advanced reactor power plant projects. The desired outcome would be construction and commissioning, which can be much more efficient and timelier than recent nuclear construction projects.

KEY ISSUE: NUCLEAR CONSTRUCTION CULTURE

Nuclear construction projects have several unique aspects and requirements when compared with other large scale construction efforts. This reality presents a key challenge of meeting the additional nuclear specific construction requirements and expectations while also delivering the project within reasonable tolerances of schedule and budget. While previous efforts to eliminate unnecessary burdens will be informative, more will be needed to right-size approaches for advanced reactors.

ACTION:

Priority 1

Establish a mindset of "optimal effort for maximum effect" for the construction of advanced reactors: Establish an industry initiative to develop right-sized approaches for nuclear construction activities. In particular, processes should be established that eliminate unnecessary or burdensome work that adds little or no value to the project. Similar actions are present in engineering and procurement.

Action Owner: to be identified by the Advanced Reactor Roadmap Steering Group.

Need Date: 2025

KEY ISSUE: ADVANCED CONSTRUCTION TECHNOLOGIES AND STANDARDIZATION

The key challenge is that many new designs are looking to use new, unproven construction technologies. The action to address this is to review and provide assessments of upcoming new technologies. Such assessments should provide an overview of users so that industry stakeholders can reach an agreed-on and clear pathway to commissioning.

Trade organizations must be engaged early to ensure that these groups are aware of and train apprentices and journeypersons on using the collection of innovative tools, machinery, modifications, and so on, during the construction phase of a project.

ACTION:

Priority 2

Develop, enable, and utilize new construction technologies: Assess the capability of new construction technologies to achieve schedule and workforce reductions. Engage advanced reactor developers and construction modularization experts to close technology and codification gaps. If needed, perform construction demonstrations and tests to accelerate their deployment.

Action Owner: EPRI, Advanced Reactor vendors, designers, and constructors

Need Date: Starting 2023 and continuing

PROJECT EXECUTION

CONSTRUCTION COMMISSIONING

KEY ISSUE: NUCLEAR CONSTRUCTION EXPERIENCE

The key challenge is that most nuclear owner/operators do not have recent construction oversight experience in new nuclear plant construction. Because of this barrier, owner/operators might lack the skills to take on a large new nuclear construction project.

The action to address this key challenge is to compile construction guidelines that contain information on adequate division of responsibilities, construction feasibility, and critical lessons learned from previous construction projects in and out of the nuclear industry. The best practices should be shared with project managers to avoid any future difficulties.

ACTION:

Priority 2

Use existing construction experience and share new construction experience: Establish a construction task force from Engineering, Procurement and Construction (EPC) experts to put together construction plan guidance. The guidance should include strategies for project optimization, considering various construction technologies planned for the next generation of nuclear power plants.

Action Owner: EPRI, NEI and INPO

Need Date: Starting 2024 and continuing

PROJECT EXECUTION

INITIAL OPERATIONS & MAINTENANCE

The scope of the Initial Operations and Maintenance strategic element is to identify and determine areas of focus where lessons learned are applied and new technologies and processes are employed to operate the plant safely and reliably. We must leverage our experience to operate and maintain the plant better while being efficient and cost-effective. The strategic element must therefore encompass processes and technologies that ensure that plants are maintained reliably while keeping costs as reasonably low as possible for the design life of the plant. To achieve this strategic objective, the emphasis must be placed on reducing the overall scope of the maintenance program and optimizing maintenance. Setting up the processes and technologies beginning at the design phase is essential in achieving this goal. The desired outcome is a well-thought-out O&M program that enables an advanced reactor to be financially competitive while uncompromisingly ensuring the safety of the plant.

KEY ISSUE: ADVANCED REACTOR O&M FUNCTIONS COST PARITY

Much of a nuclear plant is not different from other thermal plants. After accepting some increase in costs for the nuclear specific aspects, cost parity with those other thermal plants for the non-nuclear SSCs can be achieved. The key challenge is that nuclear has special requirements which are ingrained into the culture of the nuclear industry and the thought of reductions in O&M requirements will fundamentally change the concept of what it means to operate a nuclear power plant.

ACTION:

Reduce operating and maintenance costs to a level similar to other thermal plants:

Priority 1

Perform a gap analysis of all operations functions for the existing fleet and compare to other thermal plants to determine what design and/or regulation changes are needed to drive toward cost parity. A long-term plan to address these gaps will be developed.

Action Owner: EPRI

Need Date: 2026

Advanced reactor vendors should issue designs with safety features that result in fewer safety-related and other regulated SSCs.

Action Owner: Advanced Reactor Vendors

Need Date: Upon significant design completion

Determine how to leverage advanced reactor safety features to minimize engineering programs and nuclear-specific support organizations that exist in the current fleet while still maintaining the high level of nuclear safety with regard to the protection of the public.

Action Owner: EPRI and INPO

Need Date: 2026

PROJECT EXECUTION

WORKFORCE DEVELOPMENT

The workforce development strategic element will address the development of a new advanced nuclear workforce for design, construction, and operation and the needed skillsets and training. The overall goal of this element is to ensure an adequate level of skilled labor in support of both construction and operation of the advanced reactor fleet. A secondary goal is to accomplish this without undue impact on existing plants.

KEY ISSUE: BUILDING PIPELINE OF QUALIFIED SKILLED TRADES

Lack of supply of skilled trade labor in North America has been well documented in the national press and trade journals for years. It is a well-known problem facing the expansion of power plant construction in the 2030s. Given demographic trends and the preference for four-year degrees by high school seniors, the shortage is not likely to correct itself unless there is meaningful full-time and long-term work prospects for those seeking to enter the workforce.

Many of the skills necessary for building, operating, supporting, and maintaining advanced nuclear technology are known and have been well integrated by the construction industry.

The most in-demand skills in the construction phase are specialized trades, such as pipe fitters, welders, boilermakers, concrete and rebar workers, electrical installers, and wiring technicians. However, there are others that will be required based on the new plant designs. A greater emphasis on digital and software will demand new skills that might not be generally present in the current power plant or general construction workforce. These skills and qualifications must be well understood and addressed in order to build a healthy workforce.

ACTION:

Priority 1

Develop specific programs to create skilled labor workforce:

- Create a clear picture of the workforce demand and supply for advanced reactors
- Develop a strategy to coordinate the development of worker programs with local and state/provincial workforce developers (National Association of Workforce Boards, NGA Center for Best Practices, and so on) and consider collaboration on strategies between Canada and the United States.
- Coordinate with local/regional trade and vocational schools to create greater supply of needed skilled and craft workers
- Implement the U.S. Nuclear Uniform Curriculum Program or similar programs in local or regional community colleges and trade schools
- Coordinate with NEDHO and other veterans' organizations to ensure that qualifications are integrated into undergraduate and graduate programs (that is, work with Troops to Energy, Veterans in Energy, and Veterans Affairs) to ensure pipeline from military

Action Owner: NEI, CNA, EPRI and INPO with support from others identified by the Advanced Reactor Roadmap Steering Group

Need Date: 2024

PROJECT EXECUTION

WORKFORCE DEVELOPMENT

KEY ISSUE: ATTRACTING AND RETAINING THE ADVANCED NUCLEAR WORKFORCE

To build a workforce, it is necessary first to attract people to the industry. Strong competition for workers is expected in the future. Therefore, advanced nuclear must make an appealing case. Work in construction in general and advanced nuclear specifically will need to be made in an efficient way, with aspects of long-term stability built into the message. Creating a retention and career map for incoming and interested workers will show the longevity and value of an education tailored to building, operating, and maintaining advanced nuclear technology.

To recruit and retain workers, the industry must become more attractive and flexible. More than communicating the idea, the work environment must adapt to the workers of the future. Some aspects of the traditional nuclear work environment would impede the prospect of attracting workers.

ACTION:

Priority 1

Develop and execute a program for attracting and retaining workforce: Meet the demands of the future advanced reactor and existing reactors workforce:

- Develop message that resonates
- Create advertising/messaging to appeal to potential workers
- Work with K-12 education to make craft work attractive

Action Owner: NEI, CNA, and EPRI with support from others identified by the Advanced Reactor Roadmap Steering Group.

Need Date: 2024

KEY ISSUE: MAINTAINING ADEQUATE WORKFORCE FOR EXISTING NUCLEAR FLEET

Maintaining the operational performance of the existing fleet is important to ensuring confidence in the growth of the advanced reactor fleet. It is very likely that an expansion of the advanced nuclear fleet will draw resources from the existing fleet. For current skilled workers, the advanced reactor fleet could be the more attractive opportunity, and it will be impossible to prevent an outflow of talent from the existing fleet. However, it is possible to minimize the impact by focusing on retention and efficiency to ensure safe operation at lower staffing levels.

ACTION:

Priority 2

Develop adequate workforce to meet future nuclear industry demands for existing and new reactors:

- Ensure that sufficient numbers of skilled employees are in the pipelines to meet the needs of both the operating fleet and advanced reactors
- Encourage the modernization of facilities and workplace best practices
- Create advertising/messaging to appeal to workers

Action Owner: NEI and EPRI with support from others identified by the Advanced Reactor Roadmap Steering Group.

Need Date: Four years ahead of deployment of first advanced reactors

PROJECT EXECUTION

WORKFORCE DEVELOPMENT

KEY ISSUE: TRAINING MODEL

Several training models can conceivably add value for construction and O&M workers. Because training in construction skills is mostly covered by trade schools, attention should be directed to teaching the specialized skills needed by the advanced nuclear workforce.

In the current nuclear model, this nuclear-specific training is covered by accredited training programs maintained by the licensee for each reactor. With differing owner/operator models, and potentially more standard designs with less safety related plant equipment, the old model should be reconsidered.

ACTION:

Priority 2

Develop the training model that suits the advanced advanced reactor workforce:

- Define requirements
- Define regulatory model
- Clarify ownership of training delivery and accreditation

Action Owner: NEI, CNA, EPRI and INPO with support from others identified by the Advanced Reactor Roadmap Steering Group.

Need Date: 2025

IMPLEMENTATION

- INDUSTRY ENGAGEMENT, COORDINATION, AND LEADERSHIP
- SUCCESS CRITERIA

IMPLEMENTATION

The Advanced Reactor Roadmap defines a path forward for ensuring successful delivery of valuable advanced reactors in the time frame needed by the market. The successful widescale deployment of advanced reactors can be key for the United States and Canada to achieve their energy, climate, environmental, economic, and national security goals. A coordinated effort of enablers and industry actions will drive the value of advanced reactors to fulfill critical market needs. Implementation will depend on industry engagement, coordination, leadership, and strong support from stakeholders.

INDUSTRY ENGAGEMENT, COORDINATION, AND LEADERSHIP

Achieving the large-scale deployment of advanced reactors to meet the market need will present new opportunities for innovation and impact.

The industry can rise to and capture this opportunity; however, the status quo is unlikely to achieve the needed outcomes. Success will rely on the collaborative and coordinated participation and contributions from many industry and external stakeholders (including non-government and governmental organizations), in particular, the industry participants providing leadership and helping to drive the industry forward.

Industry leadership must drive the path forward, promote collaboration and coordination with external stakeholders, seek and drive solutions to hurdles and barriers, ensure that industry actions are being completed, and ultimately ensure that nuclear energy can support the United States and Canada in meeting their various goals. Industry leadership needs to articulate a vision that attracts capital and investment, as well as inspires the industry to bring new technology to the market and achieve the needed deployments, overcoming potential challenges along the way.

The industry must create momentum toward these critical goals. Based on the complexity, different stakeholders, decision making, timing, and overall responsibility to ensure action and success, dynamic leadership is needed to achieve that outcome. Also, there will be numerous lessons learned and new information that arise from the industry efforts. Success will rely on leadership to ensure effective program management to regularly assess progress, identify and knock down barriers, consider the need for or benefits of refining and evolving the roadmap, and continually maintain a focus on the overall objective to drive the value of advanced reactors in order to deliver the scale, types, and timeliness of technology needed in the market.

ADVANCED REACTOR ROADMAP STEERING GROUP

An industry steering group made up of a small number of industry leaders will be formed to ensure that the opportunities presented in the roadmap are actualized and the roadmap actions are completed. Actions that now do not have specific owners will be assigned owners by the Advanced Reactor Roadmap Steering Group. Regular meetings throughout the year will be established to hold the actions' owners accountable. All actions will have NEI and/or EPRI champions who may not have the action but will also be responsible to see the actions completed.

IMPLEMENTATION

SUCCESS CRITERIA

Industry success in delivering and deploying advanced reactors is measured by achieving the needed widescale deployments beginning in the mid-2030s, not necessarily by achieving the fastest deployments.

Attributes of the industry vision for the mid-2030s illustrate what success looks like, provide guidance for the industry, and maintain a view on the long-term goals. These attributes include:

- There is strong public acceptance of advanced reactors, recognizing and embracing their role in decarbonizing the energy landscape and welcoming facilities located near communities.
- Customers confidently seek advanced reactor options to address their energy needs.
- A variety of standard designs have been approved by the regulators to meet a range of market and customer needs, ready for owner use.
- The timeline for a customer from deciding to deploy advanced reactors until the facility is in operation is less than three years.
- Each developer can deploy tens of reactors per year, and an owner/customer is able to turn on a new advanced reactor facility every 12 months or less.
- Industry vendors, suppliers, and contractors reliably and predictably deliver technology and facilities on schedule and on budget.
- The cost of advanced reactors is competitive in the market, with steadily decreasing costs through operating experience and technology improvements.
- Government energy and climate policies treat nuclear energy equitably with other low-carbon energy sources.
- Advanced reactors achieve safe and reliable operation; no significant events and industry goals for reliability are met.
- The industry has "changed the game" and culture for deployment of advanced reactors—innovative technology and simplicity with low-risk profiles appropriately regulated are enabling the full benefits of advanced reactors for society.

The approach to deliver value to the market will undoubtedly evolve and strengthen as new information is learned, designs mature, applications become better understood, and the overall demand is refined.

Stakeholders are relying on nuclear technology, along with other carbon-free sources, to deliver a reliable, affordable clean energy portfolio. This collaborative roadmap is intended to be a valuable tool to help the nuclear industry address the need.

PRIORITY 1 ACTIONS

STRATEGIC ELEMENT	ACTION
LICENSING	**Develop recommendations for enhancements to NRC licensing processes:** Recommendations will be established that would enable more timely and efficient reviews and approvals of advanced reactors
LICENSING	**Provide industry input into the NRC rulemaking on security:** Ensure that the new rule and guidance appropriately reflect advanced reactor technology safety and security features
LICENSING	**Provide industry feedback and recommendations on Part 53:** Establish and communicate detailed feedback and recommendations for enhancing the NRC's Part 53 rulemaking to enable rules and guidance that are technology-neutral, performance-based and risk-informed and efficiently reflect the safety and security features of advanced reactors
LICENSING	**Provide industry input into the NRC rulemaking for Parts 50 and 52:** Ensure that the new rule and guidance appropriately reflect advanced reactor technology safety and security features
LICENSING	**Provide joint recommendations to NRC and CNSC on regulatory alignment:** Review and develop recommendations for enhancing alignment of regulatory processes and requirements to facilitate the efficient approval and licensing of advanced reactors in both countries.
ENVIRONMENTAL & SITING	**Enable NEPA exclusions:** Develop input to the NRC that enables the implementation of proposed categorical exclusions under NEPA and 10 CFR Part 51 for advanced reactor licensing and/or operation
ENVIRONMENTAL & SITING	**Enable environmental assessments in place of EIS:** Develop input to the NRC that enables the future use of environmental assessments in lieu of more detailed environmental impact statements for the licensing of certain advanced reactors
ENVIRONMENTAL & SITING	**Streamline the Canadian Impact Assessment Act and CNSC Environmental Assessment for Advanced Reactors:** • Short-term: Ensure no delays at the regulator end to the legislated or regulated assessment timelines • Medium term: Revise implementing regulations to streamline the process and shorten timelines especially as applied to Nth of a kind and fleet deployments, to only require assessment of site-specific aspects and not re-assessing aspects already addressed at other sites • Revise federal Acts and Provincial legislation to recognize the climate-change imperative and environmental benefits of nuclear power, and revise legislative requirements appropriately to enable faster and more predictable deployment of non-GHG emitting energy sources
ENVIRONMENTAL & SITING	**Support the successful implementation of GEIS:** Participate in the NRC rulemaking process and provide technical and legal input to ensure the agency's final Advanced Reactor GEIS, associated rule, and implementing guidance meet its objective to "streamline the time and effort needed to complete environmental reviews under NEPA for most advanced nuclear reactors."

PRIORITY 1 ACTIONS

STRATEGIC ELEMENT	ACTION
PLANT/SSC DESIGN	**Capture material data and close data gaps necessary for deployment of Advanced Reactors:** Identify the materials needed for AR designers in both the near- and mid-term and ensure materials testing is performed for on-time qualification. The materials roadmap developed by EPRI should be updated, vendors' needs should be collected and prioritized, and the needed tests should be performed with a timeline that meets AR designers' needs. In addition, Canada should ensure sufficient laboratory facilities are available for Canadian testing and data development requirement.
SUPPLY CHAIN	**Expand Module Fabrication Capability:** • Document current domestic/regional capabilities and the projected need for module fabrication facilities. Identify specific production and capability gaps. • Address strategically important modular capabilities and capacity demand gaps via joint investments of both the fabricators, owners, and developers to establish necessary capabilities
SUPPLY CHAIN	**Establish a sufficient supply of nuclear grade components:** 1. Document current domestic/regional capabilities and the projected need for nuclear grade components. Identify gaps 2. Launch domestic/regional "Nuclear Grade Supplier Development Program(s)" and expand Canada's Organization of Canadian Nuclear Industries (OCNI) Ready4SMR program. Use these programs to help non-nuclear suppliers prepare for providing nuclear grade components 3. Establish and/or contribute to task groups in nuclear codes & standards to enable procurement of low risk-significant or low safety-significant components with reduced auditing burden 4. Expand upon establish processes to procure low risk-significant or low safety-significant components from non-nuclear suppliers
SUPPLY CHAIN	**Increase the capacity of small forging capacity:** 1. Document current domestic/regional production capabilities and the projected need for small forging facilities. Identify specific production and capability gaps 2. Connect candidate forgers with developers via workshops and industry events to establish shared demand and economies to establish and/or re-establish 3. Bring together gaps, industry demand, and candidate manufacturers (and manufacturing hubs) with applicable government funding opportunities and initiatives such as what is available under the Inflation Reduction Act 4. Form new or join existing consortiums to establish necessary forging capabilities and proof of concept research with shared resources
CODES & STANDARDS	**Identify AR Codes & Standards gaps and timelines:** 1. Consolidate and update prior AR C&S gap analyses 2. Define C&S development timelines for commercial relevance 3. Prioritize C&S gaps and associated actions 4. Secure resources to address AR Codes & Standards development gaps and timelines
FUEL CYCLE	**Government Support for Domestic Commercial Fuel Enrichment:** Employ government funding and/or offtake agreements to catalyze rapid private sector investment and build-out of domestic LEU and HALEU production capacity. Advocate for government funding and/or offtake agreements to catalyze rapid private sector investment and build-out of LEU and HALEU production capacity.

PRIORITY 1 ACTIONS

STRATEGIC ELEMENT	ACTION
PROJECT MANAGEMENT	**Develop effective management of large complete projects:** Research the project management processes, methods, and tools available for management of large complex projects. Determine what processes, methods, and tools require further development and work with the appropriate parties (industry, software developers, etc.) to make these a reality. Develop a guideline how to implement these processes, methods, and tools for AR projects.
ENGINEERING & PROCUREMENT	**Establish a mindset of "optimal effort for maximum effect":** Establish an industry initiative to develop processes that right-size approaches to design activities. Guidance from previous industry-level efforts should be reviewed for application in design activities. Similar action is in construction and commissioning.
CONSTRUCTION & COMMISSIONING	**Establish a mindset of "optimal effort for maximum effect" for the construction of advanced reactors:** Establish an industry initiative to develop right-sized approaches for nuclear construction activities. In particular, processes should be established that eliminate unnecessary or burdensome work that adds little or no value to the project. Similar actions are present in engineering and procurement.
INITIAL OPERATIONS & MAINTENANCE	**Reduce operating and maintenance costs to a level similar to other thermal plants:** • Perform a gap analysis of all operations functions for the existing fleet and compared to other thermal plants to determine what design and/or regulation changes are needed to drive towards cost parity. A long term plan to address these gaps will be developed. • AR designs shall limit the number of safety related and other regulated SSCs. • Determine how to leverage advanced reactor safety features to minimize engineering programs and nuclear-specific support organizations that exist in the current fleet while still maintaining the high level of nuclear safety with regards to the protection of the public.
WORKFORCE DEVELOPMENT	**Develop and execute a program for attracting and retaining workforce:** • Develop message that resonates • Create advertising/messaging to appeal to potential workers • Work with K-12 education to make craft work attractive
WORKFORCE DEVELOPMENT	**Develop specific programs to create skilled labor workforce:** • Creating a clear picture of the workforce demand and supply for advanced reactors • Develop a strategy to coordinate the development of worker programs with local and state workforce developers (National Association of Workforce Boards, NGA Center for Best Practices, and so on) and consider collaboration on strategies between Canada and the United States. • Coordinate with local/regional trade and vocational schools to create greater supply of needed skilled and craft workers. • Implement the U.S. Nuclear Uniform Curriculum Program, or similar programs, in local or regional community colleges and trade schools • Coordinate with NEDHO to ensure qualifications are integrated into undergraduate and graduate programs. e.g. Work with Troops to Energy, Veterans in Energy, and Veteran's Affairs to ensure pipeline from military.

PRIORITY 2 ACTIONS

STRATEGIC ELEMENT	ACTIONS
LICENSING	**Develop emergency planning methodologies:** Methodologies will be needed for implementing the new NRC rule and guidance (pending approval) that can be used to establish the emergency planning zone distance. For Canada, technical justifications will be needed for appropriately sized emergency planning zones meeting Canadian requirements and expectations. Canada and United States to collaborate on common methodology development and review.
LICENSING	**Develop industry recommendations for NRC guidance on operator staffing:** Recommendations will be established to implement operator requirements appropriate for advanced reactor technologies.
ENVIRONMENTAL & SITING	**Develop technical input to siting criteria:** Industry will provide technical input to support the NRC's preparation of guidance on technology-inclusive, risk-informed, and performance-based criteria for the policy on siting away from population centers that will increase the number of allowable sites for advanced reactors in comparison to current guidance while still controlling societal risks.
ENVIRONMENTAL & SITING	**Develop guidance for site selection and evaluation:** The guidance will focus on simplifying and streamlining the site selection and site suitability evaluation processes for advanced reactors, including reactors that may be sited on former coal-fired power plant sites.
ENVIRONMENTAL & SITING	**Utilize best waste heat cooling technologies in order to ease permitting process:** Develop guidance on available cooling water technologies and cooling water system design options to assist applicants using water-cooled advanced reactor technologies in avoiding or mitigating challenges related to cooling water availability and permitting.
OVERSIGHT	**Develop guidance on modernizing regulatory oversight:** The guidance will modernize the oversight of advanced reactors during the construction and operation phases. The focus will be to reduce unnecessary burden and gain efficiencies while retaining elements necessary to achieve outcomes related to safety and reliability.
OVERSIGHT	**Engage external stakeholders:** For each advanced reactor deployment project, implement an Indigenous community and public engagement plan consistent with industry's commitment to environmental justice principles, community engagement best practices, and a just transition to a decarbonized energy economy.

PRIORITY 2 ACTIONS

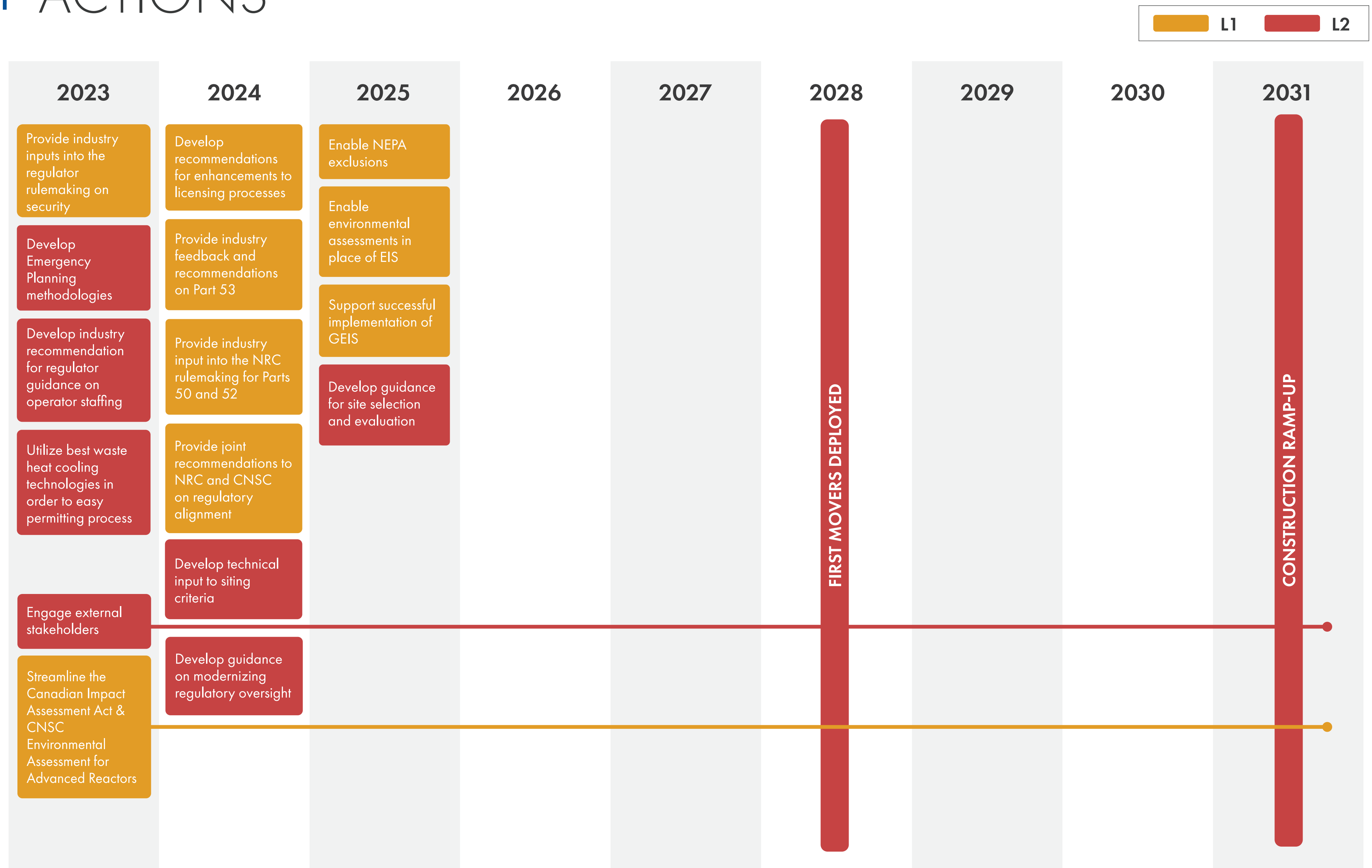
STRATEGIC ELEMENT	ACTIONS
FUEL CYCLE	**Qualify AR Fuel:** The qualification conditions for advanced fuels should be defined, a test plan for each advanced fuel should be developed, and a gap analysis to determine needs and develop new equipment should be performed. Additionally, the use of existing testing facilities should be coordinated and the need for new testing capacity determined.
FUEL CYCLE	**Develop spent fuel handling and storage strategy:** A technology neutral acceptance criteria for long term storage repository will be established, spent fuel handling technologies for advanced fuels will be evaluated, and a cost benefit analysis of fuel storage options will performed. The Canadian Nuclear Waste Management Organization (NWMO) and the U.S. DOE will continue to collaborate on option development.
PLANT/SSC DESIGN	**Develop and Qualify Analytical Tools for AR Design:** Survey AR vendors to identify analytical tools needed for optimal design. Crate an action plan to develop and/or qualify tools as needed.
PLANT/SSC DESIGN	**Develop Guide on Leveraging Legacy Reactor Experience:** Identify best-case uses of legacy AR demonstration experience and data, while providing guardrails based on their shortcomings.
SUPPLY CHAIN	**Establish competent material supply chain with production capacity.** 1. Document current domestic/regional production capabilities and the projected need for specific materials. Identify specific production and capability gaps 2. Connect candidate manufacturers with developers via workshops and industry events to establish shared demand and economies to establish and/or re-establish production lines
SUPPLY CHAIN	**Commercialize Advanced Manufacturing Capabilities:** 1. Document current domestic/regional capabilities and projected demand. Identify gaps and develop plans to close said gaps for strategic advanced manufacturing technologies that address other manufacturing gaps 2. Provide proof of concept research and prototype demonstrations for strategic and high MRL / TRL techniques 3. Qualify strategic techniques and materials in codes & standards and regulatory bodies based on deployment timeline and demand 4. Connect designers, developers, OEMs, and advanced manufacturers via workshops and industry events to tie demand with capabilities
NUCLEAR BEYOND ELECTRICITY	**Develop and demonstrate NBE applications:** Identify and document application specific technical requirements. Develop conceptual system designs for NBE applications. Identify the need for, develop and test NBE related technology.
NUCLEAR BEYOND ELECTRICITY	**Develop novel business models for Nuclear Beyond Electricity:** Develop a range of business model templates that will document the different owner, operator and customer relationships to support NBE. Development of the NBE Business Models.

PRIORITY 2 ACTIONS

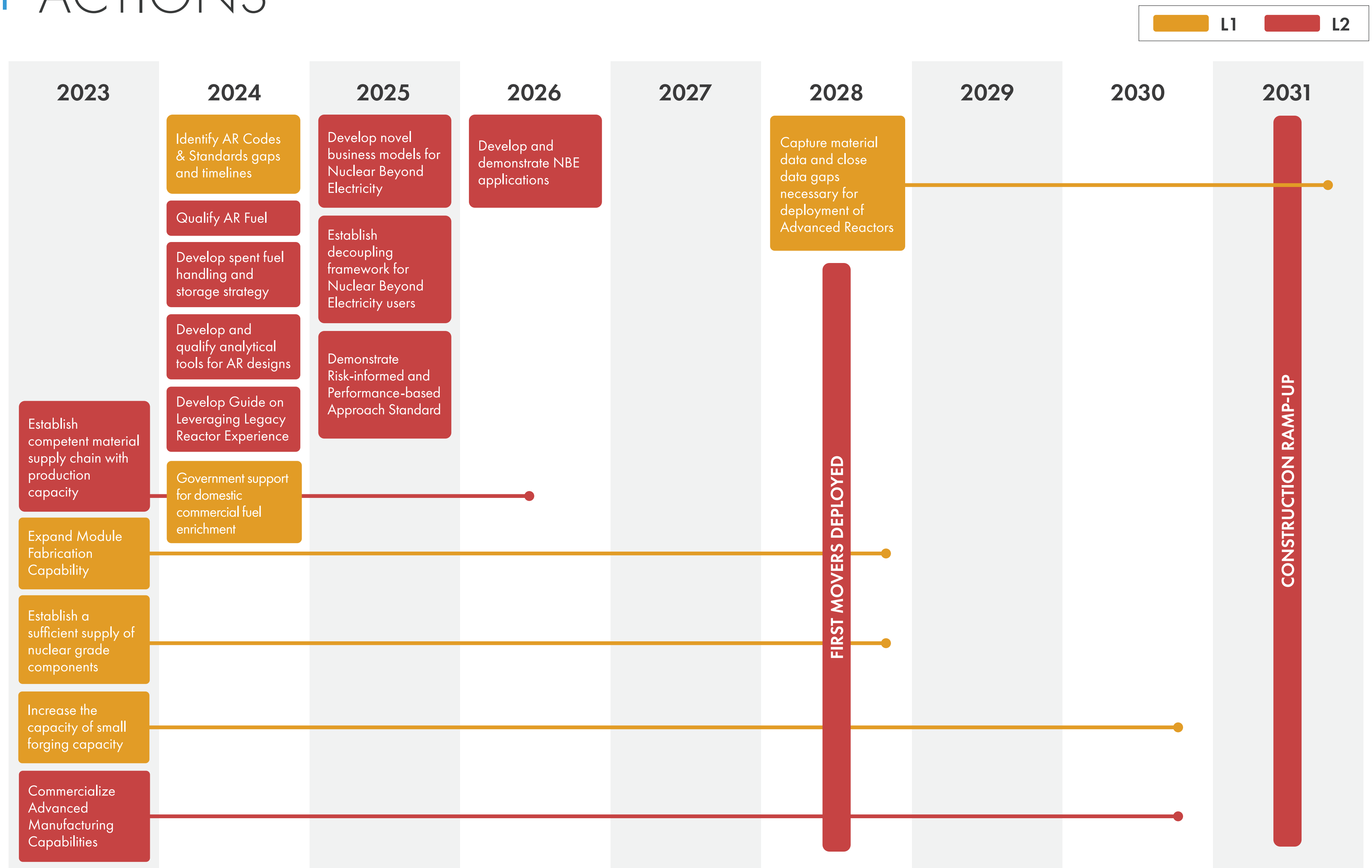
STRATEGIC ELEMENT	ACTIONS
NUCLEAR BEYOND ELECTRICITY	**Establish decoupling framework for Nuclear Beyond Electricity users:** Develop the Methodology to Demonstration Separation of Nuclear Facilities.
CODES & STANDARDS	**Demonstrate Risk-Informed and Performance-Based Approach:** Develop and execute a pilot project that applies RIPB methods in development of a new AR standard jointly with the United States and Canada-based SDOs (potential cross-cut with International Harmonization action).
PROJECT MANAGEMENT	**Develop effective project management guidance for projects with significant new technology:** Develop guidance on how to manage these projects, including risk identification and strategies to resolve those risks.
PROJECT MANAGEMENT	**Bolster potential owner-operators project capabilities to the task of deploying ARs:** Provide training on how to build capabilities in an owner-operator.
PROJECT MANAGEMENT	**Develop project appropriate contracting strategies:** Develop guidance on options for contracting strategies for AR projects that owners, developers, AR suppliers, and vendors can apply. Research organizations with expertise in contract strategies for nuclear development and construction should investigate contracting strategies that ensure equitable risk sharing and accountability among stakeholders.
ENGINEERING & PROCUREMENT	**Institute principles on sufficient design completion before construction:** Development of a guide to discuss the trade-offs between design completion and construction starting. This will optimize the approach to how much design is needed to start construction.
CONSTRUCTION & COMMISSIONING	**Develop, Enable and Utilize new construction technologies:** Assess the capability of new construction technologies for achieving schedule and workforce reductions. Engage AR developers and construction modularization experts to close technology and codification gaps. If needed perform construction demonstrations and tests to accelerate their deployment.
CONSTRUCTION & COMMISSIONING	**Utilize existing construction experience and share new construction experience:** Establish construction task force from EPCs experts to put together a generic project execution plan. The plan shall include strategies for project optimization considering various construction technologies planned to be used in the next generation nuclear power plants.
WORKFORCE DEVELOPMENT	**Maintain adequate workforce for existing nuclear fleet** • Ensure sufficient numbers of skilled employees are in the pipelines to meet the needs of both the operating fleet and advanced reactors. • Encourage the modernization of facilities and workplace best practices • Create advertising/messaging to appeal to workers
WORKFORCE DEVELOPMENT	**Develop the training model that suits advanced reactor workforce:** • Define requirements • Define regulatory model • Clarify ownership of training delivery and accreditation

REGULATORY EFFICIENCY

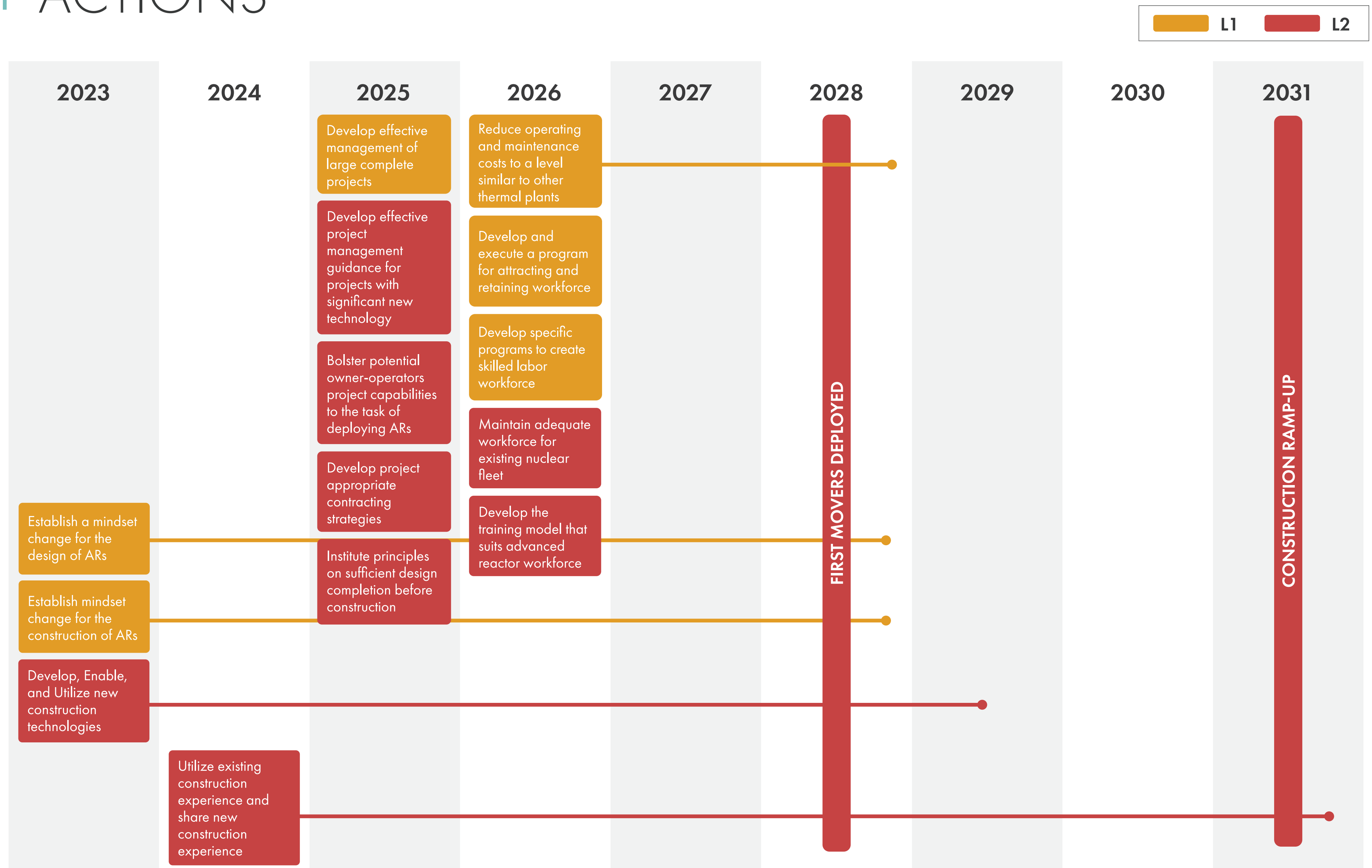
ACTIONS



TECHNOLOGY READINESS
ACTIONS

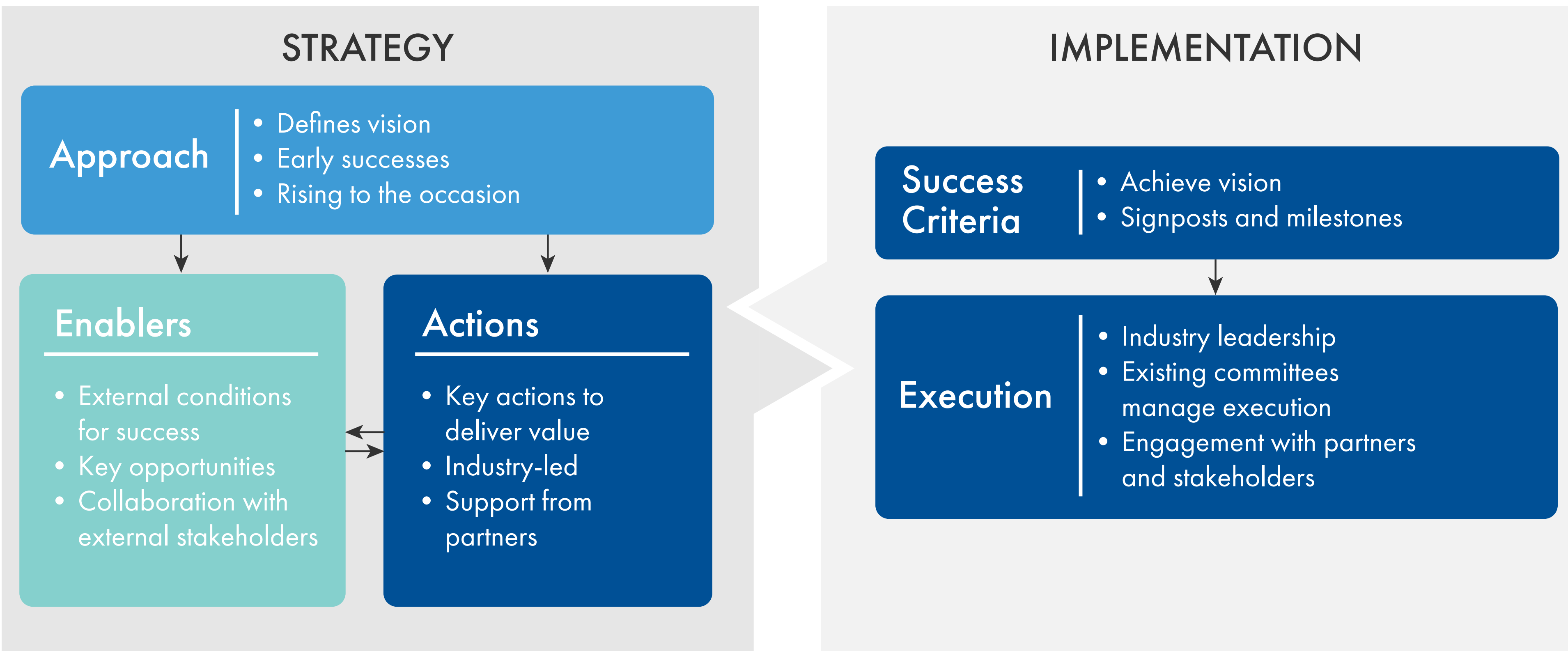


PROJECT EXECUTION
ACTIONS



ROADMAP

ROADMAP



About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

3002027504 May 2023

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA • 800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com