EPRI

2023 White Paper

2024 Global Forum for Nuclear Innovation: Creating the Future We Envision

TABLE OF CONTENTS

BRINGING THE FUTURE INTO FOCUS

When we think of the future, it is often imagined as out of focus and in the abstract. As we envision the seemingly far-off, aspirational future for our world and those who come after us, it is important to "begin with the end in mind," as author Steven Covey encourages in 7 Habits of Highly Effective People. We must look to the future, put a pin in the map where we want to be, and plot the course for getting there. So it is, too, with nuclear energy as part of a future that champions clean, sustainable, and equitable energy systems that can meet society's needs. The International Energy Agency (IEA) report, "Net Zero by 2050: A Roadmap for the Global Energy Sector" [1], calls for an "all hands on deck" approach in which all clean energy sources will be required to work in concert on the global path to decarbonization. Over the past 50 years, the use of nuclear power has reduced CO2 emissions by more than 60 gigatonnes—nearly two years' worth of global energy-related emissions [2]. The International Atomic Energy Agency (IAEA) estimates that reaching net-zero carbon emissions will require a doubling of nuclear capacity [3].

This paper addresses four Grand Challenges facing a nuclear industry poised to assume an expanded role in providing abundant, affordable, reliable, and clean energy. The Grand Challenges—No Talent, No Sector; Operating a Lean Machine; Safe Doesn't Have to Be Slow; and Beyond Electricity—were identified at the Global Forum for Nuclear Innovation (GFNI) in 2022. This event was co-organized by EPRI, Électricité de France (EDF), International Atomic Energy Agency (IAEA), OECD Nuclear Energy Agency (NEA), and National Nuclear Lab (NNL). This paper provides an introduction to these Grand Challenges, ongoing industry initiatives, and potential innovative ideas.

WHAT COULD NUCLEAR'S FUTURE LOOK LIKE?

The future of nuclear energy could be one in which nuclear power plants are designed, licensed, and constructed rapidly and effectively to meet global needs [4]. Nuclear power plants of various sizes and designs could offer energy access to underserved and underpowered populations. Communities that have historically had limited access to electricity could have utility services including clean water, sewer, district heating, and district cooling through nuclear energy. The new fleet of nuclear power plants could be easily deployed worldwide through globally accepted standards and regulations.

As emerging technologies are developed to support the next generation of nuclear power plants, those technologies are also enhancing the life cycles of the world's original nuclear power plants. These plants, most of which were constructed from the 1960s through the 1980s, will play an important role as they continue to operate and support the clean energy transition, in some cases up to 100 years past their construction. Nuclear energy accounts for 10% of all electricity generated in the world, with nuclear generating as much as 70% of the electricity for some individual countries, like France [5]. The current global

fleet of nuclear plants represents the second largest source of low-carbon power, generating just 12g CO_2/kWh, which is similar to wind and lower than all types of solar power [6]. Both existing and new nuclear power plants could be necessary to sustainably meet demand.

Technology and automation are enabling optimization of site operations, engineering, and maintenance staff, allowing for management through a smaller, technically diverse group of workers. Such innovations aim to drive down the overall cost of nuclear energy and are contributing to its expanded adoption [7]. Model-based systems engineering (MBSE) is an example of a new technology that could be applied at the outset of the design as new plants are built. MBSE is a formalized methodology that focuses on creating digital systems and engineering models as the means to exchange information [8]. MBSE could enable new nuclear power plant integration with digital twins used to inform everything from construction to operations to component replacement.

There are other ways in which the industry is evolving to help meet future energy needs of the world—and beyond. A project is currently under way to develop small nuclear reactors that can be used to provide power to the first continuously human-inhabited station on the Moon [9].

This exciting future, and much more, is possible if we plan for it now and prepare to meet its challenges head on. Creative thinking, collaboration, cultural adoption, and accountability—all on a global scale—are imperative as the nuclear industry translates innovative concepts into sustainable solutions for the future.

HOW DO WE GET THERE?

The nuclear industry is driving positive change and is collectively committed to innovation and collaboration. The GFNI arose as an industrywide clarion call in 2018 to address the challenge of accelerating the deployment of innovation in nuclear power. To date, two GFNI events have equipped a growing network of nuclear innovators to think bigger and be bolder as they influence change in their organizations and in the industry. A third event will take place June 24–27, 2024, in Miami Beach, Florida, focused on turning ambition into action.

At the 2022 GFNI event in London, the following Grand Challenges were identified in areas requiring the industry's commitment to investing in and implementing innovative approaches. One significant focus of GFNI 2024 will be reviewing progress made in addressing the Grand Challenges.

Grand Challenge: No Talent, No Sector

For the nuclear energy sector to meet its full potential, there is demand for a skilled workforce that is flexible and adaptable with the capabilities and expertise required for construction and operation of nuclear power plants. For example, the U.S. Department of Energy's *Pathways to Commercial Liftoff* [10] report estimates that building and maintaining the necessary expansion of nuclear in the United States alone will require developing a workforce of approximately 375,000 people. The U.S. industry directly employs around 100,000 people today; more than three times as many will be needed before 2050.

According to the U.S. Bureau of Labor Statistics, the labor force participation rate is trending downward and is projected to continue to do so, declining from 61.7% in 2021 to 60.1% in 2031, due to retirements and declining population rate [11]. Nuclear workers are highly skilled and receive years of specialized training. The loss of these workers means a loss to both the workforce and the knowledge base of the nuclear energy sector. For nuclear power plants to continue to thrive, a strategy is needed for bringing in new workers prepared to operate the future fleet.

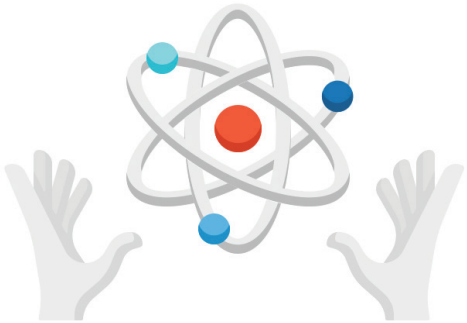
The EPRI-Nuclear Energy Institute (NEI) Advanced Reactor Roadmap Phase 1: North America identifies workforce development as an enabler for large-scale deployment of advanced nuclear power plants [12]. The specific issues for workforce development are identified as building a pipeline of qualified skilled trades, attracting and retaining the advanced nuclear workforce, maintaining adequate workforce for existing nuclear fleet, and the training model.

The Institute of Nuclear Power Operations (INPO) is focusing on deploying the concept of teaching and learning as described in *Guidelines for Advancing Teaching and Learning in the Nuclear Power Industry* (INPO 23-001) [13]. It provides guidance to strengthen continuous learning and move beyond conventional training methods that are based on the science of learning and practical teaching as well as learning methods applied in other organizations.

To continue identifying how to best define and develop the future workforce, one idea is to investigate a learner-centric workforce development model that uses holistic, learner-centered data and guidance to support training design and delivery methods that stem from an understanding of the learner. Another idea is to identify best practices and emerging technologies in learning science. The proposed ideas have the potential to innovate outmoded formal learning processes by creating a roadmap and learner-centric model that more fully engages and develops the future workforce.

Grand Challenge: Operating a Lean Machine

Nuclear power plant operation has historically required execution of thousands of repetitive, process-based tasks every year. Although these tasks are necessary to maintain safe and efficient operation, completing this work requires a significant investment of person-hours from a limited labor force. Between the volume of tasks and the necessary investment of time from nuclear workers, there is the opportunity for nuclear power plants to continue to increase operational efficiency. Lean operation strategies include modernizing plant equipment and processes [14] as well as embracing digital transformation [15] that can optimize performance and improve the way the business is performed at a nuclear power plant.



OPERATING A LEAN MACHINE

EPRI's Plant Modernization Program [16] has been working to establish a technical and programmatic foundation for existing nuclear power plants to adopt new technologies and process improvements to reduce operations and maintenance (O&M) costs while improving reliability and safety. For example, a business case analysis of digital safety-related instrumentation and control (I&C) system modernization performed with the Idaho National Labs Light Water Reactor Sustainability program found that substantial savings in O&M (net present value of $50M–$80M USD over the remaining life with license extension) can be realized through improved labor efficiencies and reducing costs associated with analog components [17]. Building upon these efforts, EPRI introduced a project to develop a technical foundation supporting the digital transformation (DX) of both the existing and future nuclear fleets. By leveraging existing DX research from across EPRI's sectors and collaborating with other organizations, EPRI is initiating new research in DX as a part of the DX Research Initiative [18]. DX of the nuclear industry will require improving and automating work processes, leveraging existing technologies to increase worker productivity, and allowing utilities to accomplish more with less labor, all while maintaining high levels of safety, availability, and affordability for customers. To facilitate DX implementation, cross-functional, multidomain skills teams working within an established framework using agile/Scrum project execution may be required to rapidly deploy and deliver DX functionality.

Advanced equipment development and installation and adoption of technology to enhance, or even transform, existing processes are actively being pursued [19]. The Operating a Lean Machine Grand Challenge could focus on maintaining efficient operations while continuing to explore new opportunities to advance DX through collaborative research and development.

Modernizing and deploying digital technologies at nuclear power plants could also optimize the workforce and shrink the current labor force gap by reducing or eliminating workload and attracting the next generation workforce, as outlined in the No Talent, No Sector Grand Challenge.

Grand Challenge: Safe Doesn't Have to Be Slow

The nuclear industry's commitment to "safety first" has made nuclear power plants one of the world's most reliable sources of energy. However, safety and speed have been perceived as inversely proportional when it comes to nuclear plant licensing, construction, and operation. Historically, nuclear plants have required significant capital investment for construction while simultaneously facing uncertain political climates and regulatory barriers. Long, unpredictable construction timelines have challenged the completion of new nuclear power plants, due in part to material and human capital resource challenges and the implementation of costly, unplanned design changes [20]. The nuclear industry has the opportunity to find innovative ways to efficiently and proactively navigate regulatory processes to ensure that the existing fleet can continue to operate, and that a future fleet of nuclear power plants can come online.

Research and development projects under way across the energy sector to address this challenge are empowering people to make decisions to drive change and put nuclear at the cutting edge, while maintaining nuclear industry safety culture and protecting the environment [21]. Regulatory organizations are currently implementing strategic initiatives that focus on simplifying, streamlining, and aligning regulatory practices and procedures while still creating a culture in which safety, security, and environmental protection are viewed through an innovative lens [22].

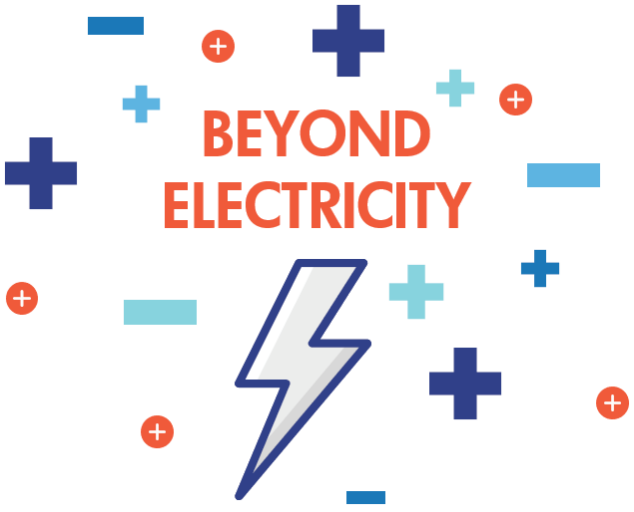
For example, the Gateway for Accelerated Innovation in Nuclear (GAIN) initiative recently awarded funding to Argonne National Laboratory (ANL) and Idaho National Lab to research new coatings for nuclear fuel to enhance fuel reliability and safety. ANL will also research deploying new technologies into molten salt microreactor systems that could make the microreactors even smaller and easier to build and transport while still maintaining rigorous safety standards [23].

IAEA's Nuclear Harmonization and Standardization Initiative (NHSI) was developed in 2022 to increase "regulatory collaboration to avoid duplication of regulatory efforts, increase efficiency and facilitate reaching common regulatory positions without compromising nuclear safety and national sovereignty," according to Anna Bradford, director of nuclear installation safety at the IAEA and chair of the regulatory track of the NHSI [24].

An example of a concept that fits within the Safe Doesn't Have to Be Slow Grand Challenge is using artificial intelligence (AI) to assist with understanding emerging trends in current regulatory review and approval processes. EPRI has initiated a project to investigate AI-assisted tools to determine whether portions of regulatory submittals for the existing fleet could be automated, thus reducing the time nuclear workers spend developing the submittals.

Grand Challenge: Beyond Electricity

The 20th century saw the discovery of nuclear energy and its utilization for marine propulsion and electricity production. Since this discovery, nuclear energy continues to stand uniquely positioned as the most energy dense of the clean energy sources, produced around the world in a wide range of climate conditions and dispatched to meet market demands. The 21st century is envisioned to expand nuclear energy usage to a plethora of markets including the continued support of the grid, along with low-carbon fuel production, process and manufacturing, district energy, data centers, water and wastewater processing, and even extraterrestrial applications beyond electricity [25].



Novel uses for existing reactors being explored today include district energy [26], hydrogen production [27], desalination [28], and powering data centers [29]. The Beyond Electricity Grand Challenge could address how to select a nuclear energy technology to meet the unique demands of these emerging applications and how to identify the optimal use of all energy provided from the nuclear reaction, including the residual heat generated by nuclear power which is traditionally thought of as waste heat. The Beyond Electricity Grand Challenge seeks to reimagine the deployment of nuclear energy.

CONCLUSION

The nuclear industry is transforming, with the potential for an expanded role in the portfolio of clean energy sources enabling worldwide net-zero emissions goals. In response, the industry must work together to break down barriers and embrace disruptive change and innovation. The Grand Challenges summarized here represent a cross section of key issues facing the industry. The plans developed to address these should be approached individually and in total as an effective blueprint for the innovative, agile change necessary for enabling the nuclear industry's future.

Progress toward addressing the Grand Challenges to date will be assessed at GFNI 2024 as the event's evolving focus shifts to "Ambition into Action." To learn more about GFNI, visit www.globalnuclearinnovation.com.

REFERENCES

1. International Energy Agency (IEA), "Net Zero by 2050: A Roadmap for the Global Energy Sector," October 2021, www.iea.org/reports/net-zero-by-2050.
2. International Energy Agency (IEA), "Nuclear Power in a Clean Energy System," May 2019, www.iea.org/reports/nuclear-power-in-a-clean-energy-system.
3. R. Mariano Grossi, "Nuclear energy can be the turning point in the race to decarbonize," World Economic Forum, May 22, 2022, www.weforum.org/agenda/2022/05/nuclear-energy-decarbonization.
4. A. Finan, "3 Ways to Make Nuclear Power Plants Faster and More Affordable to Build." Department of Energy, Office of Nuclear Energy, July 8, 2021, www.energy.gov/ne/articles/3-ways-make-nuclear-power-plants-faster-and-more-affordable-build.
5. World Nuclear Association, *Nuclear Power in the World Today*, London, UK, August 2023, https://world-nuclear.org/information-library/current-and-future-generation/nuclear-power-in-the-world-today.aspx.
6. World Nuclear Association, *Nuclear Energy and Sustainable Development*, London, UK, October 2022, https://world-nuclear.org/information-library/energy-and-the-environment/nuclear-energy-and-sustainable-development.aspx.
7. C. Warren, "Data-Driven Decisions Benefit the Nuclear Power Industry," *EPRI Journal*, March 10, 2022, https://eprijournal.com/data-driven-decisions-benefit-the-nuclear-power-industry.
8. European Space Agency (ESA), *Model-Based Systems Engineering*, June 28, 2022, www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Model-based_system_engineering.
9. J. Dinner, "Rolls Royce gets funding to develop miniature nuclear reactor for moon base," Space.com, March 19, 2023, www.space.com/rolls-royce-funding-microreactor-moon-base.
10. U.S. Department of Energy, *Pathways to Commercial Liftoff: Advanced Nuclear*, Washington, D.C., March 2023, https://liftoff.energy.gov.
11. U.S. Department of Labor, Bureau of Labor Statistics, "Projections overview and highlights, 2021–31," Washington, D.C., November 2022, www.bls.gov/opub/mlr/2022/article/projections-overview-and-highlights-2021-31.htm.
12. *Advanced Reactor Roadmap—Phase 1: North America*. EPRI, Palo Alto, CA: 3002027504 and NEI, Washington, D.C., May 2023, www.epri.com/about/media-resources/press-release/73SPk7KsrJeMom5sQ5sFLJ.
13. Institute of Nuclear Power Operations, *INPO 23-001: Guidelines for Advancing Teaching and Learning in the Nuclear Power Industry*, Atlanta: Institute of Nuclear Power Operations, 2023. INPO Member Website.
14. *Nuclear Plant Modernization Toolbox*, EPRI, Palo Alto, CA, https://nuclearplantmod.epri.com.
15. Nuclear Engineering International, "Making nuclear lean," *NEI Magazine*, January 10, 2020, www.neimagazine.com/features/featuremaking-nuclear-lean-7591587.
16. Plant Modernization Program, EPRI, Palo Alto, CA, https://www.epri.com/research/programs/111344.

17. U.S. Department of Energy, Office of Nuclear Energy, "Light Water Reactor Sustainability Program: Business Case Analysis for Digital Safety-Related Instrumentation and Control System Modernizations," August 2020, https://lwrs.inl.gov/SafetyRelated%20Pilot%20Upgrade/Business_Case_Analysis_Digital_Safety-Related.pdf.
18. *Digital Transformation Research Initiative (DXRI)*. EPRI, Palo Alto, CA: 2023. 3002027598. www.epri.com/research/products/3002027598.
19. A. Amann, "Mobile apps can improve nuclear plant inspection," *Power Engineering*, April 26, 2022, www.power-eng.com/nuclear/mobile-apps-improving-nuclear-plant-inspection/#gref.
20. P. Carajilescov, J. Moreira, "Construction Time of PWRs," 2011 International Nuclear Atlantic Conference—INAC 2011, Belo Horizonte, MG, Brazil, October 24–28, 2011, https://inis.iaea.org/collection/NCLCollectionStore/_Public/42/105/42105221.pdf.
21. Nuclear Energy Agency (NEA), "Over 40 years of collaborative nuclear safety research: lessons learnt and new opportunities," Paris, France, January 27, 2023, www.oecd-nea.org/jcms/pl_77639/over-40-years-of-collaborative-nuclear-safety-research-lessons-learnt-and-new-opportunities.
22. D. Smeatham, "Enabling Nuclear Innovation: A regulator's view," Innovation News Network, November 25, 2022, www.innovationnewsnetwork.com/enabling-nuclear-innovation-a-regulators-view/27705.
23. Argonne National Laboratory (ANL), "Argonne engineers to drive innovation with three GAIN funding awards," Lemont, IL, July 13, 2023, www.anl.gov/article/argonne-engineers-to-drive-innovation-with-three-gain-funding-awards.
24. J. Liou, "IAEA Initiative Sets Ambitious Goals to Support the Safe and Secure Deployment of SMRs." *IAEA*, July 4, 2022, www.iaea.org/newscenter/news/iaea-initiative-sets-ambitious-goals-to-support-the-safe-and-secure-deployment-of-smrs.
25. C. Warren, "New revenue streams are needed for nuclear power to continue to drive decarbonization.", *EPRI Journal*, Nuclear Beyond Electricity, November 22, 2021, https://eprijournal.com/nuclear-beyond-electricity.
26. *Current and Past Use of District Energy Using Nuclear Power: A Review of Nuclear District Energy Facilities*. EPRI, Palo Alto, CA: 2022. 3002023462. www.epri.com/research/products/000000003002023462.
27. Department of Energy, Office of Nuclear Energy, "3 Nuclear Power Plants Gearing Up for Clean Hydrogen Production," November 9, 2022, www.energy.gov/ne/articles/3-nuclear-power-plants-gearing-clean-hydrogen-production.
28. C. Baraniuk, "Could nuclear desalination plants beat water scarcity?", BBC News, June 21, 2022, www.bbc.com/news/business-61483491.
29. D. Swinhoe, "Talen Energy finishes construction on first data center at Pennsylvania nuclear station," *Data Center Dynamics*, January 17, 2023, www.datacenterdynamics.com/en/news/talen-energy-finishes-construction-on-first-data-center-at-pennsylvania-nuclear-station.

Links to references were verified at the time of publication.

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

EPRI PREPARED THIS REPORT.

THE TECHNICAL CONTENTS OF THIS PRODUCT WERE NOT PREPARED IN ACCORDANCE WITH THE EPRI QUALITY PROGRAM MANUAL THAT FULFILLS THE REQUIREMENTS OF 10 CFR 50, APPENDIX B.THIS PRODUCT IS NOT SUBJECT TO THE REQUIREMENTS OF 10CFR PART 21.

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.

EPRI CONTACT

WYNTER MCGRUDER, *Technical Leader III*
704.595.2205, wmcgruder@epri.com

For more information, contact:

EPRI Customer Assistance Center
800.313.3774 • askepri@epri.com

3002027820 October 2023

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

© 2023 Electric Power Research Institute (EPRI), Inc. All rights reserved. Electric Power Research Institute, EPRI, and TOGETHER...SHAPING THE FUTURE OF ENERGY are registered marks of the Electric Power Research Institute, Inc. in the U.S. and worldwide.